Eucalyptus Species Management, History, Status and Trends in Ethiopia

Edited by

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Proceeding of the conference on *Eucalyptus* Species
Management, History, Status, and Trends in Ethiopia
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The memory of this Conference is dedicated to Margarita Burón Barrio who passed away in Ethiopia the 12th June 2007 on a car accident.

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Welcome speech

Maria Cruz Ciria
Head Development Cooperation
Spanish Embassy, Ethiopia

Distinguished guests
Ladies and gentlemen

I am honoured to stand here today to welcome you all, on behalf of the Spanish Ambassador, and myself, to the First Conference on *Eucalyptus* management, history, status and trends in Ethiopia.

Over the coming three days, we will be discussing important issues that affect the lives, and livelihoods of millions of people in Ethiopia. A brief look at of the *Eucalyptus* Conference program shows that most presenters and panels will focus on the experience gained in rewarding local people and industries for providing sustainable products and environmental services, with a particular focus on climate change mitigation in this country and elsewhere.

In Ethiopia, as well as in many other countries in both the developed and the developing world, including Spain, local farmers have managed their forests for centuries as part of their overall livelihoods strategy. As farming areas expanded, the pressure on forests increased and, consequently, the problems linked to deforestation: erosion, lost of genetic resources, decrease of soil fertility and water retention capability, etc.

Eucalyptus, the most planted tree in the world, has been grown in Ethiopia for over a century. Expanded widely, today this tree dominates rural and urban landscapes. For smallholder growers, *Eucalyptus* suits their limited resources and yields more money than other tree crops. On top of this, the increasing demand for fuel wood and construction material has created a dependable market for *Eucalyptus* products. This certainly contributes to the steady expansion of *Eucalyptus* in the country.

In the last few years a general debate in the country pro and against *Eucalyptus* plantations has been heated. The need of scientific well-based arguments to support the land users and policy makers in selecting the right species for the adequate sites and purposes constitutes an important issue. In the same way, the management of plantations is essential so that the drawbacks are minimized and the benefits are optimized until alternatives are readily available should be the goal.

In this sense, the choice of the tree species having the best potential for conversion of soil nutrients and water into biomass together with the election of the planting sites constitutes an important decision-making process.

In this framework the Spanish experience in reforestation of degraded lands, increase of the productivity of plantations with silvicultural techniques and genetic improvement can be a support for the Ethiopian Forestry Sector.

On the other hand, the promotion of networks between different agencies involved in the Forestry Sector is essential both to exchange information and to establish common strategies and plans of action in relatively large areas.

Ethiopia is one of the priority countries of the Spanish International Development Cooperation Agency AECID, and a technical office has been opened in Addis Ababa in 2007 to strengthen the cooperation between the two countries. Food security, Health and Gender are the AECID priority sectors in Ethiopia. The Spanish contribution during 2009 has reached 60 M Euros.

I want to thank the Ethiopian Institute of Agriculture Research EIAR, the "Universidad Politécnica de Madrid" UPM, and the Spanish National Cellulose Enterprise ENCE for organizing this event, that will contribute to the strengthening of the Ethiopian – Spanish relationship on the sector, and particularly to Dr Wubalem Tadesse, who has led the organization of the event.

I sincerely hope that you leave this room inspired, and that this meeting will pave the way for new ways of cooperation between scientists, managers, policy makers, and landholders to improve the knowledge to grow an adequate supply of the renewable resource, which appears to offer an efficient and cost effective solution to Ethiopia's woody biomass crisis.

Thank you very much!

Opening Speech

Solomon Asefa
Director General of EIAR

Prof. Luis Gil, Polytechnic University of Madrid
Maria Cruz Ciria, Head Development Cooperation, Spain Embassy in Ethiopia
Invited Guests
Conference Participants
Ladies and Gentlemen

It is my great pleasure, to welcome you all to this Conference entitled "Conference on *Eucalyptus* species management, history, status and trends in Ethiopia" organized by the Ethiopian Institute of Agricultural Research, Polytechnic University of Madrid and ENCE of Spain.

There are tangible facts that Ethiopian forest resources are extremely deforested and degraded at an alarming rate. The major causative factors of deforestation are demand for agricultural land expansion, demand for different forest products, infrastructures development etc. stimulated by the rapidly growing population and economy of the country. The continuous loss of forest resources has resulted land degradation, which is stimulated by soil erosion, loss of soil fertility, sedimentation problems in lakes and rivers, and loss of biodiversity.

The new economic policy framework of Ethiopia recognises a reversal of the current environmental degradation, critical to the overall economic development of the country by way of reducing deforestation, land degradation and increasing agricultural productivity keeping the balance between replacement and exploitation of the natural resources. To date, there are a number of good gestures shown by both Federal and Regional Governments on massive reforestation programs all over the country; this strongly requires knowledge based intervention on proper species/provenance selection and site matching, management and appropriate utilization.

Presently, the government's long standing believe in the fulfilment of the international commitments to combat desertification, climate change, and the clean development mechanism (CDM) of the Millennium Development Goal (MDG) together with its agricultural led industrialization program is working hard line of reducing forest resources destruction to ensure a sustainable economic development highly amicable with the social and environmental requirements.

Introduction of *Eucalyptus* species to Ethiopia and utilization for versatile purposes has passed more than a century. Currently, its high adaptability, wide distribution even on degraded lands and socio-economic contribution as a short rotation and high yielding cash crop is significant. It became the primary species to many farmers and wood lot growers of Ethiopia and a controversial and dilemma species as well. From the perspective of declining indigenous timber species and raise of forest products demand, well-managed *Eucalyptus* species could be one alternative species to Ethiopia.

In this regard, I believe that this timely organized conference will help to share experiences and create understanding among the participants on the *Eucalyptus* tree species management, history, status, and trends in Ethiopia**.** This conference will assist you preparing a feasible strategy and integrated projects to save the endangered ones, promote potential species and utilize them sustainably. The lessons learnt will help enhance the appropriate management and utilization of the species. The success of this objective, however, requires from all of us the spirit of working together to utilize the opportunities available and overcome the challenges we are facing today and to live the coming generation better and ourselves tomorrow.

The conference will entertain paper presentations and group discussions, focusing on the different thematic areas of *Eucalyptus* species in Ethiopia and experiences from Spain and other countries. I hope, the Conference will undertake the overall opportunities, challenges and finally device strategies of development and utilization as way forward to balance maximizing the economic benefits including value additions and minimizes ecological impacts if at all exists due to home-grown *Eucalyptus* species. This may lead to policy intervention and implantation issues on how, when and where to develop, manage and rationally utilization *Eucalyptus* species in Ethiopia.

We want to encourage the bilateral initiative started between Spain and Ethiopia. This shall be strengthened and diversified in our future endeavours.

Having said these, I would like to assure that the Ethiopian Institute of Agricultural Research will stand by the side of you all who are involved in research, development, conservation, resources management for your irresistible endeavour shall become true to the best of the communities you are serving and the nation in general.

With this brief remark, I wish you all very successfully deliberations and I now declare that the Conference is officially opened.

Thank you!

Introduction

The intense forest destruction and degradation in Ethiopia and its devastating economic, ecological, and socio-cultural consequences were repeatedly reported. Consequently, this resulted in gigantic consequences such as critical shortage of fuel and construction wood, soil erosion, destruction of habitat loss for wild life, loss of biodiversity, pollution of water and electric power dam siltation, climate change (low rainfall and high temperature), decline of crop production etc. In the past 100 years, deforestation has been most drastic. In the beginning of 1900, it was estimated that about 35 % of Ethiopia's land mass, which is about 110 million ha was covered with high forests. By the early, 1950s, it declined to 16%. In the early 1980s, high forest cover was 3.6 % and 2.7% at present.

The natural forests of the country, particularly the *Juniperus procera*, *Olea europaea* and *Podocarpus falcatus* stands around the capital city were depleted due to deforestation that led to scarcity of fuel wood and construction material. Emperor Menelik II (1868-1907) recognized this and decided upon to start afforestation and reforestation activities in the country.

Eucalyptus one of the diverse genus of flowering plants in the world belongs to the Family *Myrtaceae* (subfamily *Myrtoideae*) and comprises about 800 species. Eucalyptus has high socio-economic and ecological benefits to the worlds. The term *Eucalyptus* derived from the two Greek words, “eu” meaning “well,” and “kaluptos” meaning covered. *Eucalyptus* means in brief true cover, well-covered, botanical reference to trees, flowers, and fruits.

Eucalyptus was first introduced to Ethiopia during the regime of Emperor Menelik II (1868-1907) in 1895. His major aim was to solve the critical shortage of fuel wood and construction material in Addis Ababa and other towns in the country. He recognized the fact that town development and natural forest preservation in the absence of any other alternative measure could be contradicting to each other. He made various incentive mechanisms, including tax relief and the distribution of *Eucalyptus* seeds and seedlings free of charge, to encourage every landowner to plant more trees on his land for various uses.

Fast growing exotic tree species including the 15 *Eucalyptus* species Acacia and pines were introduced from Australia, Portugal, Italy, Greece, etc in a form of seed to Ethiopia during 1895 by the request of Emperor Menelik II and with advice of Mondon-Vidaillhet, a French railway engineer and philologist. The introduction of *Eucalyptus* species in Ethiopia was a great success, has expanded over large parts of the country, and became an integral part of most Ethiopian farming system, dominates the landscapes of the country today and became one of the most important tree species.

Eucalyptus since its introduction have been widespread in the country and used as alternative source of raw material to supply the ever-increasing demand for different forest products including construction, industrial, fuel wood and composite products. Since 1985 to present time out of the 800 *Eucalyptus* species of the world, about 60 have been introduced and planted most species as trial research in the different regions of Ethiopia**.**

At present, due to its high adaptability, tolerance of severe periodic moisture stress, low soil fertility, tolerance of fire, insect and browsing animal damages, and wide distribution even on degraded lands and socio-economic contribution as a short rotation and high yielding cash crop, it became the primary species to many farmers and wood lot growers of Ethiopia. It is also a controversial and dilemma species as well. From the perspective of declining indigenous timber species and raise of forest products demand, well-managed *Eucalyptus* species could be one of the top alternative species to Ethiopia.

Currently, indigenous timber species such as *Juniperus procera*, *Hagenia abyssinica*, *Cordia afrcana*, *Podocarpus falcatus, Olea europaea,* and *Pouteria adolfi-friederici* once covering about 85% of the demand are now endangered and the first four were gazetted not to be harvested from both Regional and Federal Forests of the country. There are no such single genus having potential indigenous species in terms of adaptability, growth and yield and, area coverage and distribution and multiple uses.

In Ethiopia, *Eucalyptus* plantations are 58% (about 500, 000 ha) of the total plantation cover followed by *Cupressus* (29%), *Juniperus procera* (4%) and pines (2%). *E. camaldulensis*, *E. globulus*, *E. grandis* and *E. saligna* are widely planted in Ethiopia. These species are among the most promising species in Hararge in their adaptability and overall performance. In Addis Ababa out of the 6000 ha forestland 80-85% is *Eucalyptus* species. Eucalypts planting on degraded lands at proper density and management improves the wood product scarcity for household consumption as well as for market and keep the balance of the environment.

Currently, *Eucalyptus* growers of Ethiopia preferred *Eucalyptus* more than any other tree species due to their fast-growth, high yield per unit area and year, coppicing ability, easy silvicultural management, unpalatable by animals, good demand for its wood with reasonable prices, and their adaptations to a wide range of ecological conditions. The debates among experts continue on its alleged ecological disadvantages due to the stated socio-economic advantages. Eucalypts growers claim that there is no equally productive and adaptive species to replace or substitute *Eucalyptus.* Thus, from farmers' perspective benefits from growing eucalypts far outweigh its environmental costs.

Among the criticisms associated with *Eucalyptus* species plantation is the impediment of the establishment of other plants in their understory by out-competing for moisture and nutrients, as well as by direct inhibition through phytotoxic exudates from leaves and litter.

In contrast to this view, many plantations of *Eucalyptus* species have been found to host high herbaceous species richness and foster natural regeneration of woody species such as *Juniperus procera*, *Podocarpus falcatus*, etc as can be seen at Entoto and elsewhere in Ethiopia. *Eucalyptus* plantation can have a catalytic effect on regeneration of native species and used as a management tool for restoration of degraded forestlands.

What alternative tree species do we have then to Ethiopia now? Such type of question was asked 100 years ago by Emperor Menelik II and his local and foreigner advisors. The answer that time was and now too could be to plant appropriate *Eucalyptus* species on appropriate sites, properly manage and utilize. Shall we continue importing lumber against hard currency while there could be potential species in the country? We have the grateful *Eucalyptus, pines*, *Cupressus* if we manage them well and utilize rationally based on timber characteristics of each species and appropriate technologies.

The genus eucalyptuses of many species are fast growing even on very low nutrient sites, high yielding per unit area and year, short rotation, desiccation-tolerant, drought-tolerant, unpalatability of its leaves, and its adaptability to a wide range of site condition, coppicing, produce large quantities of wood in a given area, versatile uses and high economic benefits, when grown well-managed *Eucalyptus* are known as one of the world's three major fast-growing tree species that has been widespread in tropical and subtropical regions.

The principal benefit of *Eucalyptus* trees is their wood (timber, fuel, charcoal, pulp, paper…) due to the fast growth, short rotation, and high yielding per unit area and year. It is considered the world’s top quality pulping species due to its high fiber yields, source of notable essential oils, distillates, tannins, nectar, pollen, lowering water table, horticulture, shade, plant dyes, honey flora, and ornamentation due to the colourful flower of many species. *Eucalyptus* are basis for several industries (sawmills, pulp and paper, charcoal, poles and posts, and others). Eucalypts have versatile uses, which have made them economically important trees, and have become a cash crop in poor areas including Ethiopia.

The conference helped to share experiences and create understanding among the different disciplines participants on the *Eucalyptus* species history, management, utilization, and trends in Ethiopia. The conference was entertaining 31 papers where 20 as power point presentations and the rest as poster presentations. Group discussions, focusing on the different thematic areas of *Eucalyptus* species in Ethiopia and experiences from Spain and other countries were obtained. The major discussion points entertained were (i) trends of *Eucalyptus* expansion in the world and in Ethiopia; (ii) what are the drivers for expansion and international experiences; (iii) *Eucalyptus* research in Ethiopia; (iv) how to add value on *Eucalyptus* forestry and its products?; (v) eucalypts environmental/ecological controversy: is it misunderstanding or reality?; and (vi) what are the options/alternatives other than *Eucalyptus*?

This conference was also assisted to undertake the overall opportunities, challenges, and finally device strategies of development and utilization as way forward to balance maximizing the economic benefits including value additions and minimizes ecological impacts due to homegrown *Eucalyptus* species. This may lead to policy intervention and implantation issues on how, when and where to develop, manage and rationally utilization the grateful *Eucalyptus* species in Ethiopia.

This proceeding covers papers the major thematic areas namely (i) history of *Eucalyptus,* present situation and utilization, (ii) community needs and point of view: social and environmental debate, (iii) nursery and plantation techniques, (iv) plantation management: silviculture and harvesting and (v) *Eucalyptus* related forest policies in Ethiopia. The different papers of the Conference are addressing to a various extent *Eucalyptus* species socio-economic and ecological significance and adverse effects due to lack of proper management schemes.

Chapter I

History of *Eucalyptus,* Present Situation and Utilization

Review of cultivation, History and Uses of Eucalypts in Spain

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Abstract

Eucalyptus is the most planted hardwood genus around the world. After their discovery around end of XVIII and early XIX century, they were rapidly spread as result of their wide adaptability to diverse type of soils and climates but also the fast growth and varied uses of their wood. The first introduction record in Spain was in 1863 by Rosendo Salvado, a missionary monk who sent seeds from Australia to his family in Pontevedra. Ten years late, establishment of plantations were associated to the demand of fuel wood and supports by the mine companies in the North and South of Spain. After 1908, policies for the development of forestation were promoted by the government and eucalypts plantations were adopted to compensate the deficit of wood observed during these moments. Simultaneously, technical references about eucalypts culture and management become available by forest organisation as result of their interest, specifically on *E. globulus* and *E. camaldulensis*. Then, the destinations of the wood were mainly for firewood, charcoal, and building material, critically scarce after the Spanish Civil War (1936-1939). The distillation practice of the essential oils was also increasing with time turning into a brilliant business by years 1950´s. However, no sector of forest world has expanded rapidly as the industrial use of eucalypts for paper. The great global demand of short fiber pulp promoted massive expansion of eucalypts plantation, and Spain was not the exception. Cellulose mills were established in the early 1960`s and plantations were increased and consolidated under a solid economical market. For example, shortly after the industry establishment in Huelva figures went from 60,000 to 140,000 hectares of plantation. Many scientific experimental trials and introduction of species were undertaken at the same times that plantations expanded and breeding program started. At the present and after a steady demand, eucalypts are the most important species in the forest economy of Spain. The rate of species planted has been changed. Meanwhile the area covered with *E. globulus* is steady, areas of *E. camaldulensis* have been abandoned, but new others with *E. nitens* have been established. It is not just the present role in the forest sector; it is also the potential for the increasing interest to meet the supply of biomass for energy production in Mediterranean countries of Europe. The knowledge of new species is under study in many sites. Surely, some of these may come up as new players in the pool of species for energy culture. Now, more than 6,700 hectares of intensive energy culture has been established in Spain. Meanwhile, eucalypts will keep be used as source of fuel, building material in rural communities, industries and will open new opportunities in the second transformation of the cellulose.

Keywords: forestry, energy culture, biomass

Introduction

Eucalypts plantations in Spain represent 3.74% of the national forest state, producing a 27.33% of the country's industrial wood (Nicolás 2005). It is estimated that an area of about 500,000 ha of eucalypts (Toval 1999) and more than one hundred species of the genus planted among plantations and *arboretums* (de la Lama 1976; Sánchez et al. 2009). Only *Eucalyptus globulus*, *Eucalyptus camaldulensis* and *Eucalyptus nitens* occupy an area that may be of interest from the point of view of silviculture (Ruiz et al. 2008). The main area of cultivation is located in Galicia (61% of the total), Atlantic Coast (16%), western Andalucía region (17%) and Extremadura region (6%), highlighting the provinces of La Coruña with 31%, Lugo with 17% and Huelva with 15% of the total surface (Aspapel 1988).

The first eucalypts plantations in Spain had the target of production for mine supports (de Madariaga 1924, Ruiz 2006) and energy use (Pajarón 1911; Martín 1946), but today undoubtedly, the pulp paper is the most important use (Villena 2003). Furthermore, in the last decade, mainly in the North of the Iberian Peninsula, there has been a clear trend towards diversification of its uses in the manufacture of boards (fibber, Medium-density fiberboard and plywood) and lumber (parquet, planks, etc) (Baso 2003).

The first plantations and beginning of eucalypt culture

The cultivation of eucalypts in Spain began between 1860 and 1866 (Sanchez et al. 2009), nearly a century after that Banks and Solander collected the first sample of this genus during the first voyage of the Captain Cook's across the Pacific Ocean (1768-1771). The first seeds planted of which there is reference correspond to the species *E. globulus*. The missionary monk Fray Rosendo Salvado sent to his family in Tui (Pontevedra) seeds from Australia of this species in 1863 (Rigueiro 1993). The flowering of this species is cited in 1865 in La Granja de Barcelona (Font

Quer 1975) and knowledge in the Madrid´s Royal Botanic Garden at the same time. This species was discovered on the Island of Tasmania by French explorers in 1792 and was one of the first species of the genus to be formally described (Labillardie 1799). The rapid expansion across the globe to the nineteenth century makes it the first species to be known outside Australia and industrially planted (Jacobs 1981; Doughty 2000).

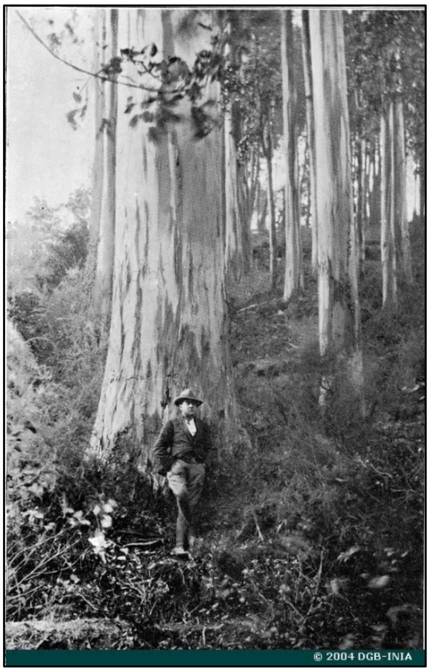

Fig.1. 1925 Paderne (La Coruña). *E. globulus* 40 years old (Montero et al. 2007).

Originally, it was planted as a botanical curiosity and ornamentally. Some of those first trees planted still growth across the country (Ruiz 2006). Reforestations for different purposes, emphasizing those related to mining for the construction of supports and railway sleepers, were realized in short time. By 1878, all the railroad stations of Rio Tinto Mines (Huelva) had eucalypts plantations surrounding (Anonymous 1878). Between 1912 and 1927, the Mining and Metallurgical Peñarroya Company (Cordoba) made *E. camaldulensis* plantations for the same purpose (Martín 1946). Eucalypts plantations were also associated with mining operations in Northern Spain, next to the coalmines of Oviedo and Cantabria (Goes 1977). The same author cites that in the 70's production of eucalypts wood for mining use was approximately 40% of national production (approximately 340,000 cubic metres per year).

In parallel with the first plantings, the genus was becoming popular as benefactor tree to eliminate malaria by deal away mosquitoes. Eucalypts forest were associated with the current practice of inhaling the fumes of the decoction of its leaves for cough and bronchitis remedies, what it is the name that is commonly known in Catalan: *arbre de la salut* (health tree) (Toval 1999).

From the beginning, eucalypts raised the interest of forest owners and they were who undertook the first commercial plantations. In Galicia, there is reference to different plantations made by D. Vicente Pardo de la Lama in 1870 with the firm intention of finding industrial applications (Touza, Sanz 2002). In Southwestern Iberian Peninsula, the first plantations on private initiative correspond to D. José Duclós in 1918 in the Huelva province (Martín, 1946). Several references to private initiative in the commercial plantations of entity can be found in the first half of XX century. Madariaga (1924) describes some of these private initiatives of the first reforestation with eucalypts in Southwestern Iberia. The author justifies the high demand of wood for various purposes, emphasizing the use of domestic energy. By then, the population had already noticed the high heat capacity of eucalypts wood and its high density.

The first historical references on the applications and properties of *E. globulus* (commonly known as *white eucalypt* in Spain) wood are logically linked to the place of origin. Thus, before the arrival of British settlers to Australia there was a search for alternatives to wood commonly used in Europe. The proximity of the native forest of *E. globulus* the coast facilitated the use and knowledge of their wood (Potts et al. 2004). The first report issued in Tasmania in the XIX century described *white eucalypt* wood as dense, hard, and very durable. Its high density coupled with resistance to sea-worm's *teredo* quickly became a very popular wood for marine construction, including construction of vessels (Lawson 1949). These properties were also advised by the Spanish forest to timber production destined to the construction and carpentry bank.

History of eucalypts plantations in Spain

The forestry administration of the Spanish government made the first experimental eucalypts plantings from 1908, thus striving to meet the high expectations that society was giving the faster-growing species (Groome 1990). These plantations were motivated by a new legal scheme (Montiel 1999), as the 1908 Law of Conservation and Forestry Reforestation and the 1926 Royal Decree Law on the General Reforestation Plan, whose efforts were directed to increase forest area and forest land of the country.

At national scale, in 1938 the government adopted a "General Plan of Reforestation in Spain" to be put into operation since 1940. The Patrimonio Forestal del Estado (PFE) was established in 1934, beginning its activities after 1939 (de la Lama 1976). This was a great boost for afforestation with fast growing species on land managed by the Spanish government. De la Lama (1951) describes the objective of work undertaken by the PFE:

> *"...the general approach taken in the reforestations has been to maximize, within the possibilities of technical facilities and operational capacity, all the soil characteristics and climate of each area or plot of the mountain, to produce and develop appropriate species of greater industrial growth and value, in the light of national needs... "*

In the first decade of the PFE, 28,003 ha were reforested in the Southwest provinces, of which 31.4% were *E. globulus* and *E. camaldulensis*. These plantings began their regular production in the 50's producing timber, firewood, and oil essences (de la Lama 1976). The author mentions the need to act quickly in the light of national needs. Indeed, in the decade of the 40's, targeted by the national forest policy was to achieve an increase of the production of wood for domestic consumption in order to move towards self-sufficiency.

The Spanish Commission Report to the United Nation of 1954 on forestry policy reflects the deficit of the Spanish wood trade balance. This deficit contrasts with the surplus products such as resin, cork and esparto (*Stipa tenacissima*) (Montiel 1999).

The deficits of industrial wood were accentuated in the case of industry railway sleepers (Sánchez 1998) and mine supports (Villegas 1953). This author discusses the need for increase the eucalypts wood production and other fast growth species in the North of Spain, in order to reduce the cost of coal production. Undoubtedly, in those years the wood was an essential raw material for industrial expansion.

Through many *arboretums,* the PFE settled with different species of which were aimed at identifying the species most suitable in each particular site. In the 60's this work is extend at most of the Spanish regions (de la Lama 1976). Some of these collections are still preserved today such as the Gaucin *Arboretum* (Malaga), the Villar *Arboretum* (Bonares, Huelva), The Lourizán *Arboretum* (Pontevedra),… representing botanical collections of scientific, ethnographic and anthropological (Sanchez et al. 2009).

In 1971, it was established the National Institute for the Conservation of Nature (ICONA) assumes the functions of the state forest polity. According to the national statistics, the eucalypts plantations on the initiative of the state had a rate of about 7,000 ha per year until the transfer of functions to regional autonomous forest in the 1980s.

Between 1940 and 1982 the government recorded a total of 273,537 ha planted with eucalypts by its own initiative. This area represents 9.3% of reforestation area undertaken by the state. Contrary to what has reached to the public, this shows that the plantations in that period were mainly made with native species (Gil 2008).

Fig.2. 1941 El Abalario (Huelva). Village in Coto Ibarra for the forest workers (Montero et al. 2007).

Conservation groups have always denounced this state's reforestation efforts. Their accusations are based on the theory that reforestation with exotic species were made by replacing native species such as holm oak and cork oak. But these accusations are unfounded because in most cases the government polity acted on spoiled soils without forest, following the initial target set by the national forest policy. This is demonstrated by several approaches to the problem (Gil 2008, Espinosa 2000).

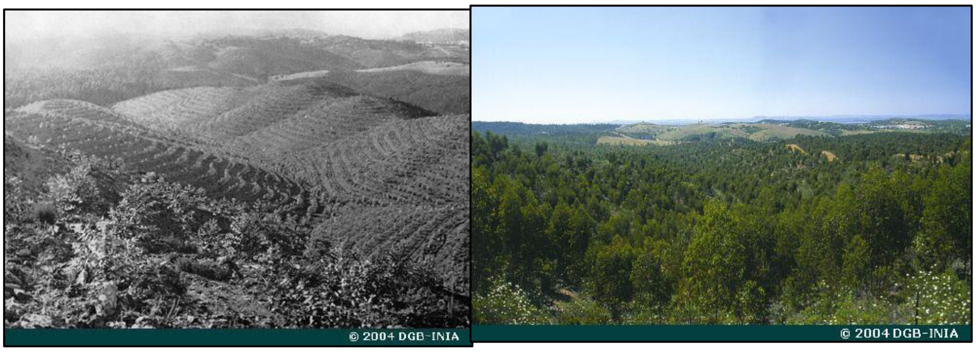

Fig.3. 1970 (left) 2001 (right) Santa Bárbara de Casas (Huelva). *E.globulus* plantation in Las Tinajas forest. (Montero et al. 2007)

During the 40 years of the PFE this acted reforesting the land owned by the state, acquiring land and establishing partnerships with regional governments and individuals. This work led to Spanish State to act on land formerly occupied by settler farmers resulting in different social conflict. Some authors have explained the main reasons for these social conflicts (for more detail see Authors: Fourneau 1983; Groome 1990; Márquez 1977). This conflict occurs because there was a disagreement between the national interests following by the works of the PFE and the distance between them and the daily needs of the population. However, the National Reforestation Plan had a clear social objective, by which got financial support and stability for three decades (Gil 2008).

Plantations by government's initiative with exotic species in general, and eucalypts in particular, drop dramatically since the transfer from political competition to the forest regional autonomous communities. In the lasts two decades most of the eucalypts forest with low productivity on public lands has been reforested with native species. This situation has meant a clear reduction in eucalypts forest area on public lands especially in the Andalucia region (CMA 2008).

Evolution of planted areas and productions

According to statistics from the Spanish Ministry of Agriculture, forest area of eucalypts in 1959 reached 118,822 ha, of which 54% were in the Southwestern provinces. First National Forest Inventory (1965-1974) in Spain recorded 225,234 ha of eucalypts plantations, which more than half were made in the Southwestern regions, mainly in the province of Huelva (41, 3%). The 51.3% of this land belonged to private owner. That show how the private forest initiative was very important for the eucalypts culture implantation. Data from the II National Forest Inventory (1986-1996) showed an area of 379,852 ha with eucalypts as dominant species of which 67.2% were private property.

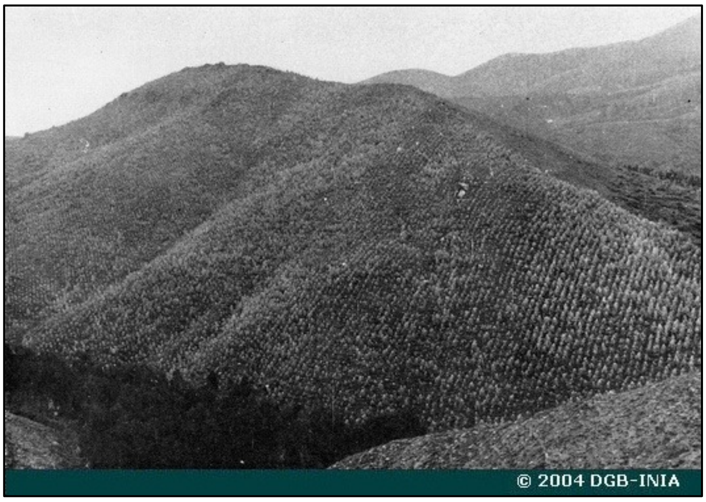

Fig.4. 1965 Mazcuerras (Cantabria). 1 year old *E. globulus* forest (Montero et al. 2007)

The partial data of the III National Forest Inventory report an enlargement of the area occupied by eucalypts plantations of 138,500 ha only in the region of Galicia, northwest of Spain (Bermudez, Touza 2000). This expansion has come at the expense of new forestry plantations on previously deforested areas. No doubt, this increase area is due also to the expansion of *E. nitens*. The first plantations with this species started in 1988 (Pérez 2009). By 1999, state of *E. nitens* rise up 20,000 ha, concentrated most of the plantations in the Lugo province. This figure has increased recently. In latest years the area has grown up to 40,000 ha in Galicia and Asturias provinces, due to its rapid and sustained growth and greater frost resistance in comparison of *E. globulus*, a species which has been gradually replaced at higher elevations (Lorenzo, Álvarez 2000).

The first national statistics recorded a production of 380,023 cubic meters in 1959 (Flores 1962). Annual production is estimated at the end of the 60's in about 900,000 cubic meters per year between *E. globulus* and *E. camaldulensis* (Ruiz 2006; Goes 1977). In the year 2001 exceeded 4 million cubic meters harvested (4,160,000) (INE 2005). Certainly, the current production must have exceeded 5 million cubic meters per year.

Use of eucalypts oil essences

Eucalypts oil is known to Western man since 1788. In that year John White, the chief surgeon of a British expedition composed of the called First Fleet, distilled a quarter gallon of what he called *"Sydney peppermint"* (Low 1990). The Australian Aborigines already knew and used eucalypts medical properties by leaves infusions as a traditional medicine for treating body pains, sinus congestion, fever, and colds (Barr et al. 1988).

The production of eucalypts essential oil obtained by distillation began in Spain during the First World War (Torner 1957). In the Southwestern of the country this achievement was due to the existence of a traditional industry in aromatic oils as poleo (*Mentha pulegium*), rosemary (*Rosmarinus officinalis*), thyme (*Thymus sp*.), fennel (*Foenicilus vulgare*), lavender (*Lavandula pedunculata*), etc. (Márquez 1977). The eucalypts oil industry has gradually grown with the increase area planted with eucalypts, and especially during the Second World War. The considerable increase in output during this period is justified by the high demand for fighter's countries to meet their needs.

The procedures used for the extraction of essential oils were very simple and rudimentary. On this basis could be considered more a craft than a real industry. Generally the boilers were located in the near of the forest of eucalypts and not too far of the villages. It was usual to install one or two boilers, but there were quotes from farms with up to six boilers in operation (Márquez 1977). The facilities used to work continuously, and that while a boiler is operating, the other can carry the load and preparations for its implementation.

Thus, the distillation of eucalypts leaves was carried out in the countryside. The boilers were built of cylindrical iron sheet with approximate 2 m in diameter and 3 m in height, thus achieving the ability to distiller a ton of leaves per boiler (Martín 1946). In Huelva 85 boilers were operated at time, while most of them located in the South of the province (Márquez 1977).

The leaves and branches were harvested by two systems: orderly pruning and in the integrate tree harvesting. For the latter, at the same time that wood logging, in South-western Spain was obtained an average of 13 tons of leaves and branches per hectare (Torner 1957). The distillation process was as follows: in the boiler were deposited 300 litres of water approximately, following a false floor on which were arranged the leaves and branches to be distilled and in order to separate it from direct contact with water and avoid hydrolysis. The heating was produced with direct fire to boil the water. As fuel, it was used the material itself once distilled and air-dried. The generated steam carried the oil to a coil, collecting the mixture in a container for its separation.

Several applications of cineole from the *E. globulus* oil essence were obtained. It was used in pharmacy, perfumery, as paints thinner, separating minerals by flotation, as germicide, and as stabilizing properties of fuels in jet engines.

Torner (1957) sites that the Spanish annual production of eucalypts oil reaches 150 tons with clear upward trends. The Spanish eucalypts oil industry probably peaked in the 50's with an annual production around 300 tons distilled (Penfold, Willis 1961). By 1970 Spain produced 250 tons per year, concentrated in the province of Huelva, being the second largest producer after Australia (Ruiz 2006). The Iberian Peninsula production dropped dramatically in the 80s with the inclusion of China in the international market (FAO 1995). At present, the production of eucalypts oil in Spain has only a traditional craft interest.

Fig.5. 1928 Sierra Cabello (Huelva). *E. globulus* oil boiler. (Montero et al. 2007)

Use of firewood and charcoal

There are several reports in the literature to justify the introduction of eucalypts cultivation in different countries to supply firewood and charcoal (FAO 1981). The fuel use has undoubtedly been the main achievement in almost all countries where the culture of eucalypts has been introduced (Goes 1977). In the same way, the charcoal from eucalypts produces a good product and from the earliest times the man has observed significant advantages compared to the firewood air dried.

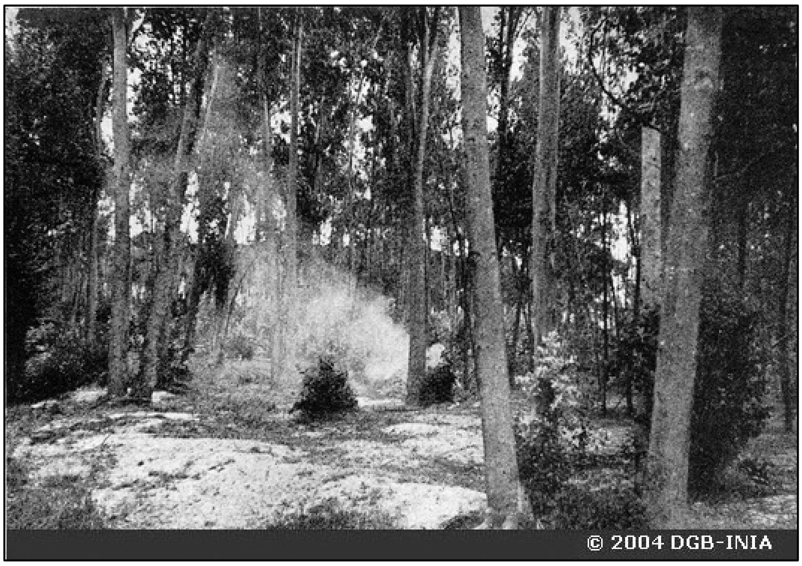

Fig.6. 1928 Sierra Cabello (Huelva). *E. globulus* charcoal production underground. (Montero et al. 2007)

The first technical references to eucalypts plantations in Spain referred the energy use. Pajarón (1911) mentioned the interest in eucalypt wood energy in comparison to others firewood based on its high calorific value and quality coal compared to *Pinus pinaster*. Madariaga (1924) showed the results of some performed tests with *E. globulus* and *E. camaldulensis* wood making the following comments: The air-dried wood loses only 7.5% water at 100 °C, burns easily, leaving very small amount of ash that are infusible red, having the advantage of not adhering to the grids and therefore not clogged. By this time there were various energy characterizations that set in 4,353 calories per kilogram the calorific value of the *E. globulus* wood.

The production of firewood and charcoal from eucalypts plantations in the province of Huelva according to Martín Bolaños (1946) was not so good as the holm oak (*Quercus ilex*) charcoal because it was more expensive to prepare for its high water content. *E. camaldulensis* had higher yield and quality for energy use at these times.

The statistics of production and use of eucalypts wood indicate its relative importance, which never growth up to 15% of the timber harvested in Southern Spain. Eucalypt wood for firewood in this region ranged on average around 10% in the decade 1946-1956, very close to the wood of *Pinus pinaster* (Márquez 1977).

By 1962, the eucalypts had little demand in the firewood domestic market. The high yield losses in weight during the process of charcoal justify their low domestic energy use (Flores, 1962). Applying traditional techniques used for other firewood, charcoal yield of the main species of eucalypts is 15-20%. These yields are lower than cork oak (*Q. suber*) and holm oak (*Q. ilex*) but Goes (1977) mentioned that eucalypts charcoal is considered as high quality, especially *E. camalddulensis*.

Pulp and paper production

Among the historical uses of eucalypts, wood highlights the industrial raw material for the manufacture of cellulose pulp. In particular, *E. globulus* is the best species because of its excellent physical and chemical properties. The comparison with other species of the genus based on properties such as basic density, fiber morphology, chemical composition, cooking raw performance, specific consumption of wood and solid contribution to the black liquor, shows that *E. globulus* superior as raw material for paper pulp mill industry (Villena 2003). The species is also considered worldwide as one of the most important for the manufacture of paper pulp (Potts et al. 2004).

In 1906, the Portuguese company Caima was the first to use *E. globulus* wood to produce bi-sulfite pulp (Watson, 1969). In 1957, another Portuguese company introduced the kraft or sulfate process plant in Cacia mill (Alves 2001).

Fig.7. 2010. ENCE Huelva pulp mill.

In 1950, the Spanish company Sniace began manufacturing eucalypt dissolving pulp in Torrelavega (Cantabria). Two years later FEFASA started the pulp production in Miranda del Ebro (Burgos) and in 1957, the Spanish National Institute of Industry (INI) created the National Cellulose Companies (ENCE) of Pontevedra, Huelva, and Motril, of which the production of Huelva was designed from eucalypts wood with an initial capacity of 36,000 pulp tonnes per year. From an annual production capacity below 60,000 tons of pulp during the decade of the 50's, the production has been increasing gradually until a nominal capacity of close to 2 million tons of eucalypts pulp cellulose (Aspapel 2008). This production is carried out in eight production mills. The ENCE company mill in Navia (Asturias) has the highest capacity, with 500,000 air-dry pulp tons per year (Ence 2009a).

Production of solid wood products

Since the beginning of the eucalypts wood applications, more than 200 years ago, experts generally agree with its mechanical properties of the timber, and therefore a high potential for several applications. In Spain, we can find historical references to the use of solid eucalypts wood for the manufacture of parquet flooring, barrels, containers, and hard fibreboard (Martín 1946, Goes 1977; Baso 1999). Despite this, an industry of processing and woodwork around the eucalypts timber has never developed before.

The difficulties of drying and processing resulting from its high density have limited industrial use. For years, the drying of eucalypts wood has been a technological challenge because of the peculiarities of the wood and its tendency to deformation and collapse. Its use by the processing industry has been limited by the need of a fine and slow drying due to the tendency of wood to suffer cracks, collapse, deformation (Touza, Pedras 2002). In fact, during the first half of the last century it was denied any other application than the mine supports, firewood, and charcoal (Martín 1955).

However, the propagation of the species *E. globulus* in the last decade has peaked in recent years interest in the mechanical processing industry to use solid wood of *white eucalypts*. There are already many references in Spain of plywood mills and sawmills that manufacture eucalypt wood products which are mainly parquet, tools, furniture and construction. This orientation agrees with the objective of forestry policy to promote diversification of the use of eucalypts to meet forestry-wood chain to ensure the proper development of the sector (Baso 1999).

The fibreboard mills consume in Spain about 1 million cubic meters per year. Three main industries are located in the Galicia region that manufacture MDF and Hardboard made entirely from white eucalypts wood. The main applications of this type are shuttering panels, packaging, furniture manufacturing, automobile industry, toy industry, faces of flush doors and flooring (Touza, Sanz 2002).

During the seventies began the industrial exploitation of white eucalypts wood in Spain in the manufacture of plywood and decorative veneer. It was caused primarily by the need to replace the tropical timber supply, which began to show problems. The veneer and sawmills showed a consumption of 300,000 cubic meters per year in average.

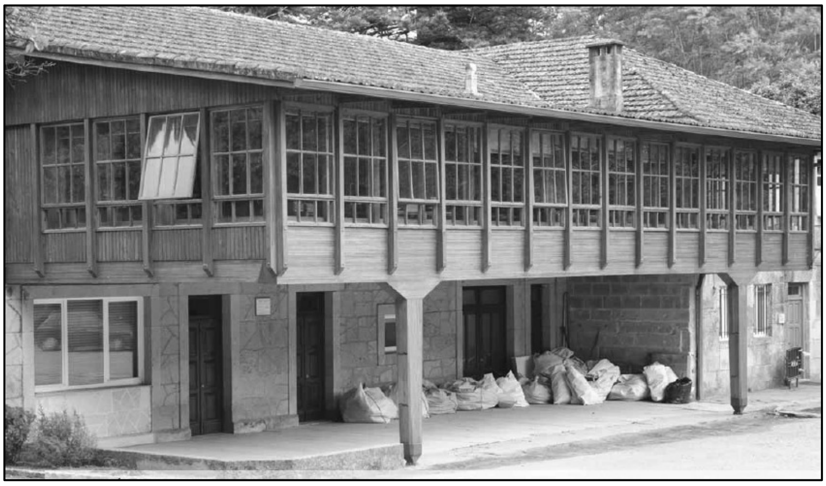

Fig.8. 1982 Lourizan (Pontevedra). Gallery from glued laminated wood of *E. globulus*. (Touza, González 2007)

Another classic application is the manufacture of handles tool. The white eucalypts wood is an excellent raw material for this use, due to its high density and mechanical resistance to bending.

In recent years there has been a reversal of progressively increasing the number of companies that have incorporated the eucalypts as raw material in industrial processes. According Touza and Sanz (2002) in the Northern regions of Spain there are over 80 companies that have experience in processing this wood.

Renewable energy production

Eucalypt wood for steam and energetic productions have been associated frequently with others main industries applications in Spain. The electricity production from industrial residual biomass and the energy production form lignin are real examples of complete utilization (energy-timber) adopted by the Spanish pulp industry for years Thus, the company ENCE produces more than 1 million Mwh of electricity from residual biomass and lignin in its three mills in Spain. This energy optimization is also applied by other industries in the transformation of eucalypts timber. These applications show the potential of the eucalypts as a renewable energy source that is used by man since its discovery. Indeed, all the ecological and technological characteristics of the eucalypt genus (adaptation, vigour, frugality, high basic density, and re-growth ability) highlight the eucalypt plantations as a renewable energy source solution.

Short rotation eucalypts plantations for biomass production and recovery of residual biomass from conventional timber harvesting are arousing great interest.

These initiatives respond to the development of a new legal framework for energy production from renewable raw materials, given the need to develop clean energy production at the same time to reduce dependence on foreign energy and atmospheric emissions of CO_2 and other greenhouse effect, in accordance with the objectives set in the Kyoto Protocol.

In recent years, the company ENCE is developing a project aimed at increasing its energy production capacity from biomass. Currently it manages about 6,700 ha of eucalypt short rotation woody crops mainly in Southwester Spain (Soria 2009). Navia ENCE mill is the largest producer of renewable energy in Spain with a current rated capacity of 77 Mw, of which 37 Mw are exclusively from biomass and 40 Mw are from lignin (ENCE 2009b).

Fig.9. 2 year old *E. globulus* short rotation crop for biomass production. 2009 (Huelva).

The possibility of developing a biomass use in the eucalypts plantations opens new economic expectations for the profitability of the forest, increasing and diversifying the production while it may reduce logistical difficulties.

References

Alves JF. 2001. Indústria da Pasta do Papel em Portugal. Edição Portucel SGPS, AS. Lisboa.

Anonymous. 1878. Crónica Montes. Nº25. Vol. II. pp. 59-63.

Aspapel. 1988. Inventario Forestal del Eucalipto. Eila Proyectos. Madrid, 226 p.

Aspapel. 2008. Memoria de Sostenibilidad. Asociación Española de Fabricantes de Pasta, Papel y Cartón. Madrid, 82 p.

Barr A, J Chapman, N Smith, M Beveridge. 1988. Traditional Bush Medicines, An Aboriginal Pharmacopoeia, Greenhouse Publications, pp. 116-117.

Baso C. 1999. Usos alternativos de la Madera de eucalipto. Perspectivas de utilización en carpintería y mobiliario. En "Boletín de Información Técnica AITIM" nº 198. pp. 19-22.

Bermúdez J, M Touza. 2000. Las cifras del Tercer Inventario Forestal Nacional en Galicia y su incidencia en la industris de transformación de la madera. Revista CIS-Madera nº4. pp 6-24.

CMA. 2008. Borrador de la adecuación del Plan Forestal Andaluz para el periodo 2008-2015. Dirección General de Planificación e Información Ambiental. Consejería de Medioambiente de la Junta de Andalucía, 632 p.

Doughty RW. 2000. The Eucalypts. A natural and commercial history of the gum tree. Forest Science, 2000, vol. 46, nº 4, p. 585.

ENCE. 2009a. Annual Report, 171 pp.

ENCE. 2009b. Generación de empleo y riqueza, 31 pp.

Espinosa E. 2000. El eucalipto bajo el Patrimonio Forestal del Estado 1941-1971. I Certamen de Estudios Forestales. Universidad de Huelva. CIDEU, 19 pp.

FAO. 1981. El eucalipto en la repoblación forestal. FAO-Montes. Roma. Serie Forestal nº11. 677 p.

FAO. 1995. Flavours and fragances of plant origin. Series title: Non-Wood Forest Products - 1. 111 pp.

Flores C. 1962. El eucalipto en Andalucía. Ministerio de Agricultura. Dirección general de coordinación crédito y capacitación agraria. Madrid, 24 pp.

Fourneau F. 1983. La provincial de Huelva y los problemas de desarrollo regional. Excma. Diputación Provincial de Huelva. Instituto de Estudios Onubenses Padre Marchena.

Font Quer P. 1975. Diccionario de botánica. Editorial Labour, 1.244 p.

Gil L. 2008. Pinares y Rodenales. La diversidad que no se ve. Real Academia de la Ingeniería. Madrid, 202 p.

Goes E. 1977. Os eucaliptos (Ecología, Cultura, Produçõe e Rentabilidade) Portucel-E.P. Centro de Produção Florestal, 366 p.

Groome . 1990. Historia de la politica forestall en el Estado Español. Agencia de Medio Ambiente de la Comunidad de Madrid.

INE. 2005. Anuario Estadístico de España. Instituto Nacional de Estadística. Madrid, 801 pp.

Jacobs MR. 1981. Eucalypts for planting. FAO, Rome, Forestry Series No. 11, 677 p.

Labillardière JJHd. 1799. Relation du voyage a la recherché de la Pèrouse. Jensen. Paris.

de la Lama G. 1951. Diez años de trabajos forestales. Montes nº 39, pp.195-201.

de la Lama G. 1976. Atlas del Eucalipto. Tomo I, Información y Ecología. INIA, ICONA. Sevilla.

Lawson W. 1949. Blue gum flippers and whale ships of Tasmania. Georgian House. Melbourne.

Lorenzo JJ, JG Álvarez. 2000. Primeros resultados de crecimiento y producción de las masas de *Eucalyptus nitens* en la provincia de Lugo. Congreso de Ordenación y Gestión Sostenible de Montes. Santiago de Compostela (España), 4-9 de octubre de 1999.

Low T. 1990. Bush Medicine, A Parmacopeia of Natural Remedies, Angus and Robertson, 85 p.

de Madariaga JA. 1924. Eucaliptos y Acacias en la Península Ibérica. Revista Montes. Nº 1092, pp. 68-80.

Márquez D. 1977. La Geo-Economía Forestal de Huelva y el dilema de sus Eucaliptales. Ed. Del Instituto de Desarrollo Regional. Publicaciones de la Universidad de Sevilla. nº11, 269 p.

Martín M. 1946. Impresiones comentadas sobre los eucaliptos de Sierra Cabello. Madrid. Instituto Forestal de Investigaciones Forestales, 89 p.

Martín M. 1955. Eucaliptos de mayor interés para España. Madrid. Instituto Forestal de Investigaciones Forestales, 95 p.

Montero G, R Vallejo, R Ruiz-Peinado. 2007.Fototeca Forestal Española Dgb-Inia. Ministerio de Medio Ambiente y Ministerio de Educación y Ciencia. http://www.inia.es/fototeca

Montiel C. 1999. Evolución histórica de la política forestal en la Comunidad Valenciana. Revista Forestal Española. nº22, pp 28-34.

Nicolás F. 2005. Iberian *Eucalyptus* pulpwood markets. In Proceedings of the International Pulpwood Resource and Trade Conference. Montevideo, April-2005. CD-Rom.

Pajarón D. 1911. Especies de ensayo. El eucalipto. Revista Montes. Nº 822, pp. 257-265.

Penfold AR, JL Willis. 1961. The Eucalypts. Leonard Hill (Books) Ltd., London.

Pérez C. 2009. Herramientas de gestión para plantaciones de Eucalyptus *nitens* (deane and maiden) Maiden con el objetivo de fijación de carbono. Trabajo de investigación tutelado. Universidad de Santiago de Compostela, Julio de 2009. Lugo.

Potts BM. 2004. Genetic improvement of eucalypts. In: Encyclopedia of forest sciences. Elsevier, Oxford, UK, pp. 1480-1490.

Rigueiro A. 1993. El eucalipto: Un árbol controvertido. Montes nº31, p. 43.

Ruíz F, G López, G Toval, R Alejano. 2008. Selvicultura de *Eucalyptus globulus* Labill. *In:* Rafael Serrada, Gregorio Montero and José A. Reque (eds.) "Compendio de Selvicultura Aplicada en España" INIA. Fundación Conde del Valle de Salazar. pp. 117-154.

Ruiz J. 2006. Flora Mayor. Organismo Autónomo Parques Nacionales. Dirección General para la Biodiversidad. Madrid, 1.757 p.

Sánchez E, JM Caraballo, F Ruiz. 2009. Los arboretos de eucaliptos históricos de Huelva. Bouteloua 6, pp. 115-133.

Sánchez J. 1998. La Politica Forestal en la provincial de Jaén. Una interpretación de la actuación pública durante la etapa de la administración centralizada (1940-1984). Instituto de Cultura de la Excma. Diputación Provincial de Jaén.

Soria F. 2009. La selvicultura de especies productoras de biomasa. VI Jornadas Forestales "El Monte Productor". Huelva, november 2009

Torner J. 1957. El Eucaliptol en el Sur de España. Revista Montes nº75, pp. 191-199.

Touza M, F Pedras. 2002. Una propuesta industrial de secado de madera de eucalipto blanco (*Eucalyptus globulus*) de Galicia. Revista CIS-Madera 2002 (8). pp. 6-22.

Touza M, F Sanz. 2002. Nuevas aplicaciones de la Madera de eucalipto. Revista CIS-Madera 2002 (9). pp 6-22.

Touza M, O González. 2007. *Eucalyptus* woos applications. CIS Madera. 42 pp.

Toval G. 1999. In "Ciencias y Técnicas Forestales. 150 años de aportaciones de los Ingenieros de Montes". Madrigal A (Coord.). Fundación Conde del Valle de Salazar. ETSI Montes Madrid, pp. 313-339.

Villegas R. 1953. Repoblaciones de eucalipto y pino insigne en el Norte de España. Escuela Especial de Ingenieros de Montes. Madrid, 235 pp.

Villena J. 2003. Calidad de la madera de *Eucalyptus globulus ssp. globulus* como materia prima para la industria pastero-papelera. En: Actas del I Simposio Iberoamericano de *Eucalyptus globulus*. Montevideo. CD-ROM.

Watson AJ, WE Cohen. 1969. Pulping of Eucalypts – An historical surrey. Appita. Vol 22, nº4.

Major Characteristics and Potential Uses of *Eucalyptus* Timber Species Grown in Ethiopia

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Abstract

Fast growing exotic trees, particularly *Eucalyptus* and pine species were introduced to Ethiopia since 1895, to be used as alternative source of raw material to supply the increasing demand for different forest products. The results of the study indicated that most mechanical properties improved about 60% when the boards (lumber) from these *Eucalyptus* species were seasoned below 30% moisture content (MC). High increase occurred for compression strength (71%) and low increment (11%) for modulus of elasticity. The results revealed that these *Eucalyptus* species were significantly different ($P< 0.01$) in their characteristics and have good timber quality. *E. microcorys* has the highest density (860 Kg/m^3) while *E. deglupta* the least (410 Kg/m^3). The mechanical properties ranges are bending strength (modulus of rupture): 69-147 N/mm^2, modulus of elasticity: 8332-17715 N/mm^2) and compression parallel to the grain: 33-76 N/mm^2. *E. paniculata* showed the highest modulus of rupture value *(*147 N/mm^2) and *E. deglupta* the least (69 N/mm^2). *E. microcorys,* in terms of modulus of elasticity and compression strength indicated, respectively the highest values *(*17715 N/mm^2 and 76 N/mm^2) and *E. deglupta* the least values (8332 N/mm^2 and 33 N/mm^2). The lumber when dried (seasoned) in air and kiln showed seasoning defects (warp, bending, surface and end checks, and end splits) to different extent. In general, the lumber of most study species were found heavy and hard to work with hand tools and machines and in terms of wood durability compared with such species *Cupressus lusitanica*, *Pinus patula*, *Pinus radiata*, *Podocarpus falcatus, Hagenia abyssinica*, *Cordia africana* and *Pouteria adolfi-frederici*, etc were found more resistant against subterranean termite and fungal attack. Most of these eucalyptuses are well suited for structural work, light and heavy construction and furniture work. Widely used for fencing, electricity transmission, telegraph poles and posts, fuel wood and charcoal. They have good potential as veneer, plywood, chipboard, pulpwood, hardboard, short fiber pulp for papermaking, etc. So far, only *E. globulus* has been used for both particleboard and hardboard productions in Ethiopia while other potential and alternative species could be available. Well-managed *Eucalyptus* from the perspective of declining indigenous timber species and raise of forest products demand is multipurpose and grateful species to Ethiopia. Owing to the different wood characteristics, *Eucalyptus* species with the right provenance could also be used as a partial or complete substitute of the endangered indigenous and other important tree species of Ethiopia for specific purposes provided that *Eucalyptus* species have been well established, managed, matured enough, properly seasoned, handled, processed and rationally utilized.

Keywords: density, *Eucalyptus* wood, lumber, moisture content, timber mechanical and working properties, preservation, seasoning, uses

Introduction

How are Forest Products demand, scarcity, and availability of alternative timber species in Ethiopia**?** The demand on forest products in Ethiopia has been increasing with the rise of the present huge construction all over the country, industries, continuous destruction, and degradation of forests, scarcity of forest products, improper utilization, and population growth through time. The 2010 projected demand and consumption of timbers and forest products in the country has been 84,618,000 m^3 while the supply has been 11,534,000 m^3.The gaps between demand and supply exceeds 730%.The demand for industrial forest products has been rising worldwide and will continue to rise, and plantations provide an increasing proportion of these products (Lopuppe *et al*., 2008).

Indigenous timber species such as *Juniperus procera*, *Hagenia abyssinica*, *Cordia afrcana*, *Podocarpus falcatus, Olea europaea,* and *Pouteria adolfi-friederici* once covering about 85% of the demand are now endangered and the first four were gazetted not to be harvested from both Regional and Federal Forests of the country (FDRE, 2007). There are no such single genus alternative and potential indigenous species in terms of adaptability, growth, yield and product quality, area coverage and distribution. What alternative species do we have then to Ethiopia now? Such type of question was asked 100 years ago by Emperor Menelik II and his local and foreigner advisors. The answer that time was and now too could be to plant appropriate *Eucalyptus* species/provenances on appropriate sites, properly manage including initial spacing and final stocking, and rationally utilize products. Shall we continue importing lumber against hard currency while there could be potential species in the country? We have the grateful *Eucalyptus,* pines, *Cupressus* if we manage them well and utilize rationally based on timber characteristics of each species and appropriate technologies.

Eucalyptus originated between 35 and 50 million years ago (Anonymous, 2010ac). *Eucalyptus* species are among the tallest (100 m, *Eucalyptus regnans*) flowering plants/trees (angiosperms) of the world while other six species namely *E. obliqua*, *E. delegetnsis*, *E. diversicolor*, *E. nitens*, *E. globulus* and *E. viminalis* exceeds 80 m in height with long, cylinder and clean trunk bole (Lamprecht, 1989; Anonymous, 2010ac). *Eucalyptus* species were introduced to many parts of the world mainly from Australia. China introduced *Eucalyptus* in 1989 four years late after Ethiopia and now having a total area of exceeding 170 million ha eucalypts plantations, ranking the second in the world (Liu and Li, 2010). South America (Brazil and other countries) is expected to produce 55% of the world's *Eucalyptus* round wood by this year, 2010 (Anonymous, 2010ac).

The principal benefit of *Eucalyptus* trees is their wood (timber, fuel, charcoal, pulp, paper…) due to the fast growth, short rotation, and high yielding per unit area and year. It is considered the world's top quality pulping species due to its high fiber yields, notable essential oils, lowering water table, horticulture, shade, plant dyes, honey flora, and ornamentation due to the colourful flower of many species (Anonymous, 2010a). *Eucalyptus* are basis for several industries (sawmills, pulp and paper, charcoal, poles and posts, and others). Eucalypts have versatile uses, which have made them economically important trees, and have become a cash crop in poor areas (CSIRO, 2002; Anonymous, 2010a) including Ethiopia. On average on good sites have 2.5 m root length with annual growth is about 1.5-2 m height and 1.5-2 cm diameter, mean increment in terms of volume is about 15-30 m^3/ha/year (exceptionally 100 m^3/ha/year when using the right colones on good sites with intensive management) (Lamprech, 1989; Anonymous, 2010c).

Fast growing exotic tree species include: *E. camaldulensis, E. globulus, E. tereticornis, E. amygdalina, E. largiflorens, E. cladocalyx, E. cornuta, E. diversicolor, E. incrassata, E. leucoxylon, E. melliodora, E. patens, E. resinifera, E. rudis* and *E. Salubris*. Acacia and pines were introduced from Australia, Portugal, Italy, grace, etc in a form of seed to Ethiopia during 1895 by the request of Emperor Menelik II and with advice/support of Mondon-Vidaillhet, a French railway engineer and philologist (Vernéde, 1955; Britenbach, 1963; Adudna Zerihun, 1981; Amare Getahun et al., 1990; Desata Hamito and Feyisa Abate, 1994; Anonymous, 2010a).

What is the potential of *Eucalyptus* species in Ethiopia? *Eucalyptus* since then have been widespread in the country and used as alternative source of raw material to supply the ever-increasing demand for different forest products including construction, industrial, fuel wood and composite products. Since 1985 to present time out of the 800 *Eucalyptus,* species of the world (Louppe et al., 2008) about 60 have been introduced and planted most species as trial research in the different regions of Ethiopia. *Eucalyptus* species have remaining a defining features and green belts, forest products source and as a consequence basis of permanent survival of the capital city Addis Ababa, regional cities and towns.

In Ethiopia *Eucalyptus* plantations are 58% (> 148, 000 ha) of the total plantation cover 255, 214 - 955, 705 ha (Demel Teketay, 2000; Anonymous, 2004) followed by *Cupressus* (29%), *Juniperus procera* (4%) and pines (2%) (Demel Teketay 2000; WBISPP 2000; Anonymous, 2004; Sisay Nune et al., 2008). *E. camaldulensis*, *E. globulus*, *E. grandis* and *E. saligna* are widely planted in Ethiopa. According to Adudna Zerihun (1981), these species are among the most promising species in Hararge in their adaptability and overall performance.

What is to be done to utilize properly *Eucalyptus* wood in Ethiopia? Majority of the 17 *Eucalyptus* study species except the stated four are still available at the Forestry Research Center (FRC) tree species trial stations and/or seed stands and in the formers ARDU (Arsi Rural Development Unit)/CADU(Chilalo Agricultural Development Unit) stations in Arsi/ Asella, Hamulo, Degega, Wondo Genet

College of Forestry and Natural Resources arboretum, etc. However, industrial and other commercial benefits, proper development, management, and rational utilization activities are not yet fully realized (Getachew Desalegn *et al*. 2009). Plantations of exotic timbers including *Eucalyptus* species make up about 30% of Ethiopia's plantation stock and provide about 10% of the fuel, furniture and construction timber to the country (Alemu Gezhagne et al., 2004; Abebe Haile et al., 2009).

Wood quality requirements for sawn dried (seasoned) and dressed products can be grouped into five main categories: mechanical properties (bending, stiffness, tensile, compression strength, hardness), dimensional stability (low distortion, shrinkage, and collapse), biological performance (consistent colour, durability), and manufacturing performance (good gluability, machining), and log processing performance (low splits, low distortion) (Armstrong, 2003).

Appropriate utilization of the wood of different tree species essentially demands adequate understanding/ determining of the different wood characteristics especially physical (moisture content, density, seasoning and related characteristics), mechanical and working properties, durability, effectiveness of applied wood preservatives, uses, and utilization methods. Information and/or technologies generation on processing, handling, and efficient utilization has been of paramount importance.

So far, the major timber characteristics, uses and utilization methods of over 50 different majority potentially useful and lesser-known indigenous and homegrown exotic tree species including *Eucalyptus* have been studied in the country (Getachew Desalegn et al, 2009). Home- grown *Eucalyptus* species namely *E. camaldulensis*, *E. globulus, E. grandis* and *E. saligna* differently have been commonly used as source of fuel wood, local construction, transmission poles and fencing posts. These and other *Eucalyptus* species, usually considered as less valuable species for furniture and structural purposes. Since then, only *E. globulus* has been used for both particleboard and hardboard productions in Ethiopia while other potential and alternative species available in the country.

Through intervention is needed on management, timber characteristics, suitability for different purposes and utilization aspects of these species. The basic timber characteristics and utilization technologies and/or information, potential and alternate uses of these species as lumber and composite products are not well known adequately to the processors and end users of the country. Therefore, the objectives of the study were to: (i) generate information on the physical, seasoning and mechanical characteristics of each timber species and rational utilization technologies, (ii) evaluate natural durability of timbers, select efficient preservative application techniques, treatability with-and- effectiveness of preservatives against subterranean termites and fungal attack, and (iii) highlight woodworking properties and potential uses.

Material and Methods

Test material selection, description and sample preparation

This study includes 15 *Eucalyptus* species, namely *Eucalyptus globulus subsp. bicostata, E. camaldulensis, E. deanei*, *E. deglupta*, *E. delegatensis*, *E. dunnii*, *E. fastigata*, *E. globulus subsp globulus* (Here after *E. globulus*) (Fig.1), *E. grandis, E. globulus subsp maideni.*, *E. microcorys*, *E. nitens, E. obliqua*, *E. paniculta*, *E. regnans, E. saligna,* and *E. viminalis*.

a. E. *globulus at* Entoto b. E. *globulus* at Addis Alem

Figure 1. The symbolic E. *globulus* trees planted by Menelik II

In this paper, nomenclature of tree/timber species names follows that of Bloza and Klot (1963), Bryce (1967), Hillis and Brown (1978), Webb *et al.,* (1984), Lamprecht (1989) and Anonymous (2010aandb). *Eucalyptus* belongs to the Family *Myrtaceae* (subfamily *Myrtoideae*) and comprises about 800 species (Lopuppe, et al., 2008). The term *Eucalyptus* derived from the two greek words, "eu" meaning "well" and "kaluptos" meaning covered. Eucalptus means in brief true cover,well-covered, botanical reference to trees, flowers and fruits (FAO, 1988).

In Ethiopia now practically naturalized and cultivated as plantations, wood lot and around homesteads as cash crop in altitudes from 15000 to 2500 m. About 15 -20 years can be considered as the rotation age of *Eucalyptus* for saw log harvesting and lumber utilization (WUARC, 1995). Thus, ten matured trees with good morphological quality, straight and cylindrical stem free from visible defects were selected from different sites (Aman, Aris, Addis Ababa, Gimbi, Hamulo, etc) and felled, cross cut into a series of 5 m long logs up to a top merchantable diameter of 20 cm. Mean and ranges of height and diameter of timbers has been 44 m (32-55 m) and 52 cm (35-76 cm), respectively. Most of these species were harvested at the age of more than 10 years. Logs were marked with tree and bolt identification codes and were immediately transported to Forest Products Labouratory to avoid moisture loss and development of biodegrading agents of wood. The sample logs were bucked at the saw mill into 2.5 m logs and converted to lumber (3 cm thick and 2.5 m long and width equal to log diameter) using through-and-through (sawn to the pith) sawing method at the saw-mill. The test samples were selected from each tree at about 1 m interval along the tree/ log height and prepared into standard sample sizes corresponding to each wood property test.

Standard testing methods and procedures were followed. Sample dimensions, number of specimens and wood characteristics were determined based on the ISO and British standards (ISO 3129, 1975; ISO 3130, 1975; ISO 3131, 1975; ISO 3133, 1975; ISO 3787, 1976; ISO 3348, 1975; ISO 3350, 1975; Lavers, 1983). The number of samples for density and mechanical properties per tree species and treatments were ≥ 30. The samples for testing mechanical properties (2 x 2 cm blocks) were used to test and determine moisture content (MC) and density of each timber species by measuring their initial and current weights and dimensions during oven seasoning. Tests were conducted at green and air seasoned conditions

This study mainly includes *Eucalyptus* lumber moisture content, density, seasoning and mechanical characteristics (bending strength and compression strength parallel to the grain), working properties, natural durability and effectiveness of applied wood preservatives.

Seasoning tests

The sawn boards (lumber) while green (> 30% MC) were grouped by dimension. Similar boards in thickness (3 cm) of each species were transported to the air seasoning-yard and compartment kiln-seasoning chamber–and were stacked using stickers, top loading, under shed and kiln, etc, following the same principles (Simpson, 1991; FPL, 1999; Deing et al, 2000).

The main principles of lumber stacking applied were (i) stacking similar species; (ii) similar thickness of lumber/board; (iii) similar dimension stickers to separate boards; (iv) similar spacing between boards; (v) high MC (sapwood) boards on top and sides; (vi) low MC (heartwood) boards in the middle; (vii) under shed in case of air seasoning and in closed chamber/kiln for artificial seasoning; and (viii) top loading to reduce seasoning defects. The lumber drying (here after seasoning) test for each species involved determination of MC, rate of seasoning, shrinkage characteristics, seasoning defects and measures (remedies) to be taken to minimize seasoning defects.

Ten defect- free sample boards per tree species and type of test, 100 cm in length, 3 cm thickness and width equal to log-diameter were prepared and used. Initial MC of each timber species was determined from the two small sections (1.2 cm length and 3 cm thickness) cross-cut into 20 cm inwards from each sample board ends. Green weights (hereafter, initial weight) and dimensions of all air seasoning samples were measured immediately after planning/machining and crosscutting using sensitive electrical balance and calliper, respectively. Weighing of initial MC samples at four hours interval was carried out as soon as samples were withdrawn from the oven drier to minimize moisture absorption and desorption (Desch, 1986; FPL, 1999; Deing et al., 2000). This was continued in the oven-seasoning chamber to a constant dimension at a temperature of 105 °C until the difference between two successive weights of each specimen was between 0.1-0.2 g and the final weight was taken as the oven seasoned weight (ISO 3130, 1975; FPL, 1999). In this test, air and kiln seasoning methods and a combination of them were used for the determination of seasoning characteristics.

Air seasoning

The air seasoning samples were weighed and re-placed into the stacks and re-weighed at one-week interval. The process was continued until the average final MC of the stack reached about 12%, which is the equilibrium MC for in- and out-door purposes and standard for comparison between and within timber species.

Kiln seasoning

Kiln seasoning samples were weighed and dimensions measured in a similar way to air seasoning but in this case measurements were taken and the direction of the fan was changed at 12 hour intervals, to allow uniform air circulation and seasoning, control the seasoning process and maintain quality of the wood seasoned.

Moisture content and rate of seasoning determination

Moisture content has been determined for both air and kiln seasoning stacks of each timber species. The oven- dry weight method of MC determination (the standard way) was applied (Haygreen and Bowyer, 1996; FPL, 1999; Deing et al., 2000).

$$MC\ (\%) = ((IW/OD)-1)\ x100 \qquad (1)$$

Where, IW= initial weight of wood with water (g), OD = oven dry weight (g).

Shrinkage characteristics determination

For the determination of shrinkage characteristics, 10 defect-free specimens per timber species at green state and standard dimensions (width, height and length) of 2 x 2 x 3 cm (ISO/DIS 4469, 1975) were used. Specimens were seasoned in the oven-seasoning chamber to a constant dimension at a temperature of 105 °C. Initial and current dimensions and weight of all the shrinkage samples were measured once per day. The measurements were taken like in the MC tests. Shrinkage rates of each specimen at tangential, radial and longitudinal directions, and volumetric were determined from green (≥ 30%) to 12% MC, and from green to 0% MC, respectively. Shrinkage values from green to oven dry were determined and classified based on Chudnoff (1980).

$$\text{Shrinkage characteristics (\%)} = (\text{Decrease in dimension (mm)}/\text{Original dimension (mm)})*100 \qquad (2).$$

Appearance of sawn timbers

The appearance (colour, figure, texture, etc) was considered from the seasoning boards and working property tests. The appearance has been determined using visual observation of the stated features on the planed (tangential, radial and longitudinal) surfaces of wood.

Density test

In this study, the shrinkage samples, procedures and measurements were used to determine the density (g/cm^3) and/or specific gravity values of each species using mathematical formulas (Density = Sample weight/Sample volume) at green and seasoned MC and sample volume conditions (ISO 3131, 1975; FPL, 1999; Denig et al., 2000).

Basic density= (Sample oven dry weight/Sample green volume) (3)

The density and mechanical characteristics values at seasoned condition have been converted to standard 12% MC for comparison purposes (Table 1) by applying the formulas and classified (Table 1) based on the adapted standard classification (Framer, 1987).

Density at 12% MC $(\rho 12) = Pw^* (1-0.01^*(1-K_O)^*(W-12))$ (4)

Where, Ko= coefficient of volumetric shrinkage for a range in 1% MC. For approximate calculations the value of $K_o = 0.85 \cdot 10^{-3} \cdot Pw$ when density is expressed in Kg/m^3 and $K_o = 0.85 \cdot Pw$ when density is expressed in g/cm^3.

Mechanical characteristics of *Eucalyptus* timbers

The materials for both green and air- seasoned physical and mechanical property tests were small defect-free specimens, free from visible defects. This study and results focused mainly on the major mechanical properties of the timbers which include (i) static bending- strength as a beam (modulus of rupture (N/mm^2), stiffness/elasticity as a beam- modulus of elasticity (N/mm^2), work to maximum load (mmN/mm^3) and total work (mmN/mm^3)), (ii) suitability as a post/pole-compression parallel to the grain (maximum crushing strength (N/mm^2)). The mechanical properties tests with their corresponding dimension of specimens were static bending (30 x 2 x 2 cm) and compression parallel to the grain (6 x 2 x 2 cm) (Lavers, 1983).

Physical and mechanical properties at green condition were carried out before the MC dropped below the fiber saturation point (FSP), about 30% MC (ISO 3129, 1975; Lavers, 1983; Desch, 1986). Dry tests were carried out after the samples were seasoned to < 20% MC and conditioned not to lose or gain moisture. Mechanical property experiments were conducted in a labouratory at a temperature of 20-25 ºC and relative humidity of 60-80%.

Mechanical properties $(Y_{12}) = Y_i\ (1+\alpha\ (W-12))$ for all mechanical properties except Modulus of elasticity (MOE) and MOE at 12% MC $(Y_{12}) = Y_i + \alpha\ (W-12)$, where Y_i and W represents each mechanical property and MC at test, respectively; α= correction factor for MC, which shows the change in 1% of the given property at a change in MC by 1%, α= 0.04 for compression strength parallel to the grain and static bending except MOE (α for MOE = 250) (ISO 3133, 1975; ISO 3787, 1976; ISO 3348, 1975; ISO 3350, 1975).

To determine the initial and current MC, all specimens were primarily subjected to measurements of initial weight and dimensions (width, thickness and length) using sensitive electrical balance and calliper, respectively and then promoted to mechanical tests. At the end of each mechanical property test, all pieces were transferred to the oven-seasoning machine at 105 °C, and weighed at four-hour intervals until the difference between two successive weights of each specimen was between 0-0.2 g and the final weight was taken as the oven dry weight (ISO 3130, 1975; FPL, 1999). This was done to determine the MC, density and mechanical properties of the species at test (green) and air seasoned from each single specimen.

Durability and effectiveness of preservatives against bio-deterioration attack

Treatability and preservative treatments were applied using the Rentokil Impregnation Machine *(1985 Sweden brand).* In this case, samples (hereafter, stakes) were treated with Copper Chromium Arsenate (CCA) and used motor oil preservatives using pressure impregnation and non-pressure methods, respectively.
For the laboratory treatability (absorption and retention) and field studies, ten stakes were prepared and used from each of the six timber species (Table 2) having dimensions (thickness, width and length) of 2 x 5 x 50 cm (NWPC, 1971) and four stakes for the permeability (penetration) tests with dimensions of 5 x 5 x 110 cm (Tack, 1979) in the tangential, radial and longitudinal directions, respectively.

Natural durability

Wooden stakes for testing natural durability were receiving prophylactic treatments such as handling during storage, transportation, seasoning (about 15% MC) and processing to avoid deterioration and discoloration before field installation. The natural durability of timbers was expressed from very durable to very perishable based on the modified and adapted grades (Bryce, 1962; Purslow, 1976; Melaku Abegaz and Addis Tsehay, 1987; Getachew Desalegnn et al., 2003; Wubalem Tadesse and Getachew Desalegn, 2007).

Non-pressure treatment

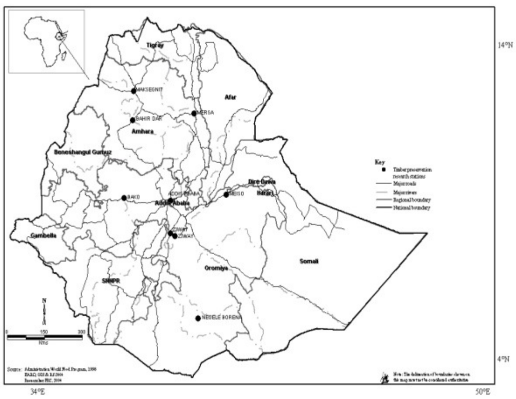
For the treatments with used motor oil, using hot-and-cold dipping tank method, open tank or thermal process (FAO, 1994) a mixture of Shell Rimula oils of high quality- heavy duty diesel oil 40 and Helix Ultra 40 engine oils were used. The stakes were submerged in a dipping tank containing 100 Kg of cold used motor oil. The solution was then gradually heated by burning wood under the dipping tank to about 90 °C to reduce viscosity of the oil and maintained for 4 hours.

Pressure treatment

Preservative treatments were applied on stakes after sawing and cross cutting wood to the standard final dimensions, and seasoning to < 20 % MC. Preservative treatments were applied on the species wooden stakes (FAO, 1994; Willeitner and Liese, 1992) using the Rentokil pressure Impregnation Machine, filled with a solution containing 24.5 Kg of CCA mixed with 820 litre of water in a 1:33 ratio of solute to solvent at 3% concentration, and were tested using one species at a time. Treated stakes were seasoned before graveyard installation at least for two weeks so that the solvent is evaporated and preservative is fixed into the wood (Willeitner and Liese, 1992).

Stakes graveyard installation and assessment against bio-deteriorating agents damage

Tests on natural durability of stakes and effectiveness of preservatives and application methods were conducted simultaneously in the field (Figure 2). The pits for the installation of stakes were 25 cm deep and had spacing of 25 cm between stakes and 50 cm between rows.



Graveyard Stations
1. Zeway (Rift Valley
2. Bako (West Ethiopia)
3. Mersa (Wello)
4. Maksegnit (Gonde
5. Bahir Dar
6. Meisso (Hararge)
7. Adami Tulu (Rift Valley)
8. Negele Borena
9. Yayu
10. Pawe
11. Addis Ababa

Figure 2. Graveyard Stations for testing timbers durability and effectiveness of preservatives in Ethiopia

During evaluation, visual inspection/ observation, strongly supported by sounding methods were applied to determine the resistance and/or deterioration rate of each test stake against subterranean termites and fungal attack. The parameters and symptoms of bio-deterioration attack were based on Nicholas (1985). The applied bio-deterioration grades were one to five (Gjovik and Gutzmer, 1986). Data collection was carried out at three, 6 and 12 months after installation of the stakes, and every year thereafter (Gjovik and Gutzmer, 1986; Highley, 1995; Getachew Desalegn et al., 2003; Getachew Desalegn et al., 2007).

Wood working property tests

The major wood working properties tests included using different sample dimensions, machines and hand tools were examination of the following properties/factors: (i) blunting (effect of sawing and machining), (ii) sawing (cross cutting and ripping), (iii) machining (surfacing, boring, turning, planing, shaping/moulding, sanding), (iv) gluing, (v) nailing, (vi) screwing and (vii) finishing. The numbers of samples per test were between 20 and 40. For testing working properties of most wood species, the surface planer speed 5600 rpm (rotation per minute), blade angle 30-35°, and for cutting with carbide-tipped circular saw, blades with a speed of 3200 rpm have been used.

Results and Discussion

Appearance

The appearance of *E. globulus* lumber is pale greyish to creamy; sapwood zone is narrow, greyish yellow and easily distinguishable from the reddish brown heartwood (fig 3b). *E. camaldulensis* has brilliant red wood (fig 3a), which can range from light pink through to almost black, depending on the age and weathering. The appearance of E. *grandis* sapwood extends up to 50 mm width and heartwood variable, ranging from pinkish-white to pink or rose-brown (fig 3c), depending on age and other characteristics. Grain is usually inter-locked or straight, and texture medium to coarse while *E. saligna* boards sapwood whitish and heartwood pink to red; reddish wood (fig 3d), very heavy, dense and strong; grain usually straight or slightly interlocked; texture rather coarse.

a. *E. camaldulensis* b. *E. globulus* c. *E. grandis*
d. *E. Saligna*
Figure 3. The four common *Eucalyptus* timber trees bole with clear lumber appearance

Seasoning, moisture content and shrinkage characteristics

Seasoning of the *Eucalyptus* wood below fiber saturation point (30% MC) results shrinkage on radial, tangential, and longitudinal surfaces as well as seasoning defects. Initial MC of the species in this test varies between 66-74% and the final MC was about 12%. As the seasoned density increases most mechanical properties increases.

The lumber from the 17 *Eucalyptus* species showed seasoning defects (warp, bending, surface and end checks, and end splits) to different extent when seasoned in air and kiln. Air seasoning took 38 to 90 days while kiln seasoning took 3.5 to 5 days. All air-seasoning rates of timbers were rapid. *E. camaldulensis* in kiln seasoning indicated cup, surface check, end check, end split; rate of seasoning - in air seasoning moderate rate and in kiln seasoning, took 3.5 days (very rapid); and shrinkage from green to 12% MC - tangential: 6.4%, radial: 5.3% and volumetric: 11.2%. The lumber from *E. globulus* was difficult in seasoning. It seasons relatively slowly in air (90 days) as well as in kiln (4 days). It was liable to twist, bow, crook, and end checks when dried in air. End and surface checks and twist have been observed during kiln seasoning. Proper stacking and loading in both methods and steaming in kiln are recommended. Shrinkage values for *E. globulus* from green to 12% MC were tangential: 6.84%; radial: 6.35% and volumetric: 6.59%.

E. grandis seasons both in air (38 days) and kiln (3.5 days) with all seasoning defects and it had been seasoned very rapidly and fairly in comparison with *E. globulus* and *E. saligna*. Proper stacking and loading before seasoning is needed. Shrinkage values for *E. grandis* from green to 12% MC: tangential: 6.84 %; radial: 3.83 % and volumetric: 10.26 %.

E. saligna seasons in air (60 days) and kiln (5 days) with end and surface checks. *E. saligna* is liable to twist, checks, split, bow and crook when seasoned in air. Immediate stacking and loading in both methods, and low temperature schedule in addition is recommended for kiln seasoning. Shrinkage values for *E. saligna* from green to 12% MC: tangential: 3.63%; radial: 2.62% and volumetric: 6.09% (Getachew Desalegn and Alemu Gezhagne, 2010).

Lumber of *Eucalyptus* species when seasoned in air and kiln showed seasoning defects (warp, bending, surface and end checks, and end splits) to different extent. Some of the remedies to offset these defects: (i) felling in the dormant season and air drying under shade reduces end splitting, (ii) proper stacking immediately after sawing, (iii) top loading of stacks in both methods, (iv) coating the ends with bitumen or using S-irons are also practised, (v) in the case of poles for power and telecommunication lines, treatment with a creosote fuel oil mix is advocated to prevent rot (Anonymous, 2010d) (vi) apply low temperature schedule and steaming in kiln seasoning.

Density

The green and air-dry density at 12% MC of homegrown *Eucalyptus* species ranged between 780-1070 Kg/cm^3 and 410-860 Kg/cm^3, respectively (Table 1 and Figure 4).

The air-dry density of *E. globulus* was about 28% and 13% higher than E. *grandis* and *E. saligna*, respectively. The air-dry density of *E. saligna* is 17% higher than *E. grandis* (Table 1 and figure 4).

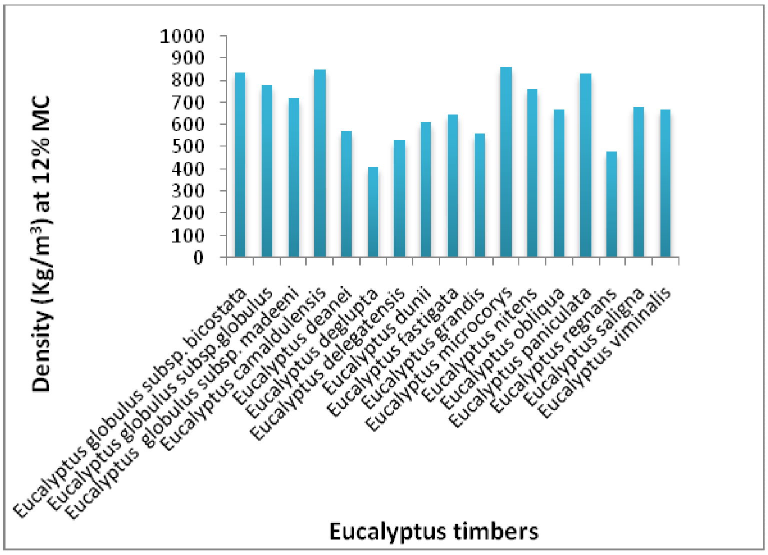


Figure 4. Density of Eucalptus species at 12% MC

Mechanical characteristics

The results of the study indicated that most mechanical properties increases to > 60% as the boards from these *Eucalyptus* species were seasoned below 30% MC. High increase occurred for compression strength (71%) and low increment (11%) for modulus of elasticity. The species of this study are fast growing with good performance (tall height, long and cylinder clear bole, large diameter and high volume increment potential) and timber quality (Table 1 and Fig 4 and 5).

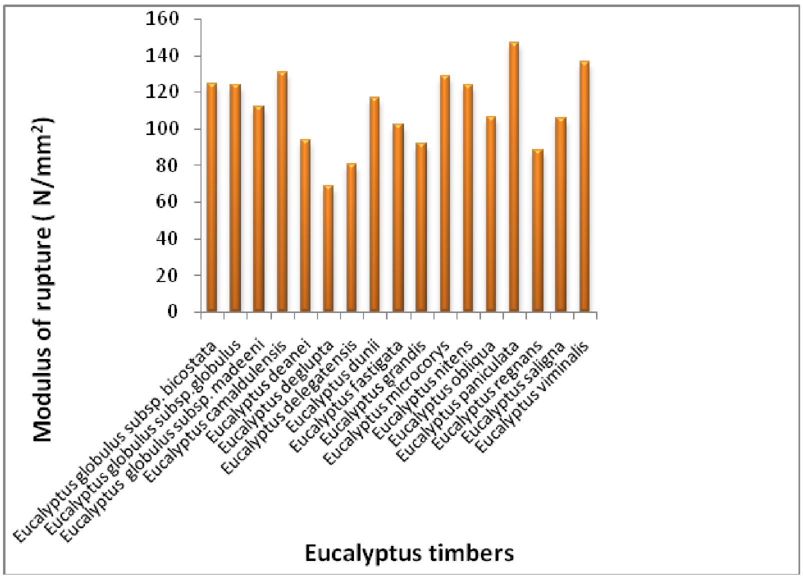


Figure 5. Modulus of rupture (N/mm^2) of *Eucalyptus* timbers species at 12% MC

The mechanical properties of the 17 *Eucalyptus* species ranges bending strength (modulus of rupture): 69-147 N/mm^2, modulus of elasticity: 8332-17715 N/mm^2, compression parallel to the grain: 33-76 N/mm^2 (Table 1).

Comparison of *Eucalyptus* timbers with other timbers

Some of the exotic species lumber and plywood especially pines are still imported against foreign currency to Ethiopia due to lack of data to know comparable and potential substitute species in the country. *Eucalyptus* species were compared at a standard 12% MC by their density and mechanical properties (Table 1) with the valuable indigenous species of Ethiopia such as *P. adolfi-frederici*, *J. procera, C. africana*, *H. abyssinica*, *P. falcatus,* etc. d with the world valuable timber species namely *Khaya ivorensis* (East Africa Mahogany), *Quercus robur* (Oak), *Tectona grandis* (Teak), *Fagus sylvatica* (Beech), *Pseudotsuga menziesii* (Douglas fir), *Pinus strobes* (Yellow pine), *Pinus sylvestris* (Scots pine), *Picea sitchensis* (Stika Spruce) and *Picea abies* (spruce European) (Table 1). Timbers were compared using values of density and mechanical properties at 12% MC with ± 10% accuracy.

The results revealed that these *Eucalyptus* species were significantly different ($P < 0.01$) in their characteristics and have good timber quality. *E. microcorys* has the highest density (860 Kg/m^3) while *E. deglupta* the least (410 Kg/m^3). The density and mechanical properties of the four common *Eucalyptus* timbers found in the country in descending order has been *E. camaldulensis, E. globulus*, E. *grandis* and *E. saligna* (Table 1 and Figure 2). The results revealed the highest modulus of rapture values *(*147 N/mm^2) and *E. deglupta* the least (33 N/mm^2). *E. microcorys,* in terms of modulus of elasticity and compression strength parallel to the grain indicated, respectively the highest values *(*17715 N/mm^2 and 76 N/mm^2) and *E. deglupta* the least values (8332 N/mm^2 and 33 N/mm^2). Most of these values of this study are low when compared with Bolza and Kloot (1963), Bryce (1967) and Louppe et al. (2008). This could be attributed due to low age and fast growth rate in this case.

The density and mechanical properties of *E. globulus* is found to be higher than that of *E. grandis* and *E. saligna*. The species *E. globulus* was comparable with *E. saligna, P. adolfi-frederici, Q. robur* and *T. grandis* by its compression strength. Density and mechanical properties of *E. saligna* were comparable with those of *P. adolfi-frederici*, *Q. robur* and *T. grandis*.

Table 1. Density and mechanical properties of *Eucalyptus* timbers, classification^ at 12% MC and comparison of Eucalyptus timbers with other timbers of the world by density and mechanical properties

No.	Timber species	Density (Kg/m^3)	Mechanical characteristics of timbers at 12% MC				
			Modulus of rupture (N/mm^2)	Modulus of elasticity (N/mm^2)	Work to Maximum load (mmN/mm^3)	Total work (mmN/mm^3)	Compression parallel to the grain (N/mm^2)
1	*Eucalyptus globulus subsp. bicostata*	840 (VH)	124 (H)	14050 (M)	0.0875	0.1704	54 (M)
2	*E. globulus globulus subsp. globulus*	780 (H)	124 (H)	11655 (L)	0.1600	0.3194	52 (M)
3	*E. globulus subsp. madeeni*	720 (H)	112 (M)	13442 (M)	0.0893	0.1343	61 (H)
4	*E. camaldulensis*	850 (VH)	131 (H)	14177 (M)	0.0735	0.1432	71 (H)
5	*E. deanei*	570 (M)	94 (M)	11553 (L)	0.2352	0.4214	47 (M)
6	*E. deglupta*	410 (L)	69 (L)	8332 (VL)	0.0679	0.1140	33 (M)
7	*E. delegatensis*	530 (M)	80 (L)	9811 (VL)	0.0805	0.1578	41 (M)
8	*E. dunii*	610 (M)	117 (M)	12817 (M)	0.1446	0.3254	52 (M)
9	*E. fastigata*	650 (M)	102 (M)	9872 (VL)	0.0606	0.1374	53 (M)
10	*E. grandis*	560 (M)	92 (M)	10308 (L)	0.1053	0.1830	45 (M)
11	*E. microcorys*	860 (VH)	129 (H)	17715 (M)	0.1019	0.2245	76 (H)
12	*E. nitens*	760 (H)	124 (H)	13636 (M)	0.0740	0.1881	58 (H)
13	*E. obliqua*	670 (H)	106 (M)	11511 (L)	0.0651	0.1202	58 (H)
14	*E. paniculata*	830 (VH)	147 (H)	15453 (H)	0.1151	0.2395	55 (H)
15	*E. regnans*	480 (M)	88 (M)	14254 (M)	0.0799	0.1511	51 (M)
16	*E. saligna*	680 (H)	106 (M)	11604 (L)	0.1359	0.2414	53 (M)
17	*E. viminalis*	670 (H)	136 (H)	15629 (H)	0.1783	0.4347	54 (M)
18	*Cordia africana*	410 (L)	64 (L)	6996 (VL)	0.0462	0.0949	29 (L)
19	*Cupressus lusitanica*	430 (L)	64 (L)	6145 (VL)	0.0668	0.0908	33 (L)
20	*Fagus sylvatica*	689 (H)	118 (M)	12600 (M)	0.1460	0.2390	56 (M)
21	*Hagenia abyssinica*	560 (M)	86 (M)	9563 (VL)	0.0952	0.2370	43 (M)
22	*Juniperus procera*	510 (M)	87 (M)	9081 (VL)		0.1083	38 (M)
23	*Khaya ivorensis**	497 (M)	78 (L)	9000 (VL)	0.0700	0.1280	46 (M)
24	*Picea abies**	417 (L)	72 (L)	10200 (L)	0.0860	0.1160	37 (M)
25	*Picea sitchensis**	384 (L)	67 (L)	8100 (VL)	0.0790	0.1250	36 (M)
26	*Pinus patula*	450 (L)	73 (L)	8428 (VL)	0.1508	0.1955	36 (M)
27	*Pinus radiata*	450 (L)	77 (L)	8983 (VL)	0.1596	0.2147	40 (M)
28	*Pinus strobes**	430 (L)	80 (L)	8300 (VL)	0.0890	0.0970	42 (M)
29	*Pinus sylvestris**	513 (M)	89 (M)	10000 (L)	0.1030	0.1340	47 (M)
30	*Podocarpus falcatus*	530 (M)	88 (M)	9526 (VL)	0.1189	0.1195	41 (M)
31	*Pouteria adolfi-frederici*	680 (H)	93 (M)	10029 (L)	0.1060	0.1419	46 (M)
32	*Pseudotsuga menziessii**	497 (M)	91 (M)	10500 (L)	0.0970	0.1720	48 (M)
33	*Quercus robur**	689 (H)	97 (M)	10100 (L)	0.0930	0.1670	52 (M)
34	*Tectona grandis**	609 (M)	100 (M)	10100 (L)	0.1000	0.1430	52 (M)

Note: *Under density and mechanical properties columns, the first number = property values, letter in brackets = classification of the property at 12% MC where, L= low, M= medium and H= heavy/high.*
^- Density and mechanical property values classification at 12% MC has been adapted from (Farmer, 1987). Density (kg/m^3) classification at 12% MC: exceptionally light < 300), light = 300-450; medium= 450-650; heavy = 650-800; very heavy = 800-1000; exceptionally heavy > 1000 kg/m^3.
**-known timber trees of the world used for comparison.*

Mechanical property values (N/mm^2) classification at 12% MC are very low, low, medium, high and very high, respectively and the corresponding classification per property are: Modulus of rupture: < 50, 50-85, 85-120, 120-175, and > 175. Modulus of elasticity: < 10000, 10000-12000, 12000-15000, 15000-20000 and > 20000. Compression parallel to the grain: < 20, 20-35, 35-55, 55-85, > 85 N/mm^2. For comparison purposes, the results of timbers (Table 1) have been adapted *Cordia africana* from Truneh Kide (1988), *H. abyssinica* from Getachew Desalegn (2006) and *J. procera* from Bryce (1967 and those marked with (*) from Lavers (1983) and Farmer (1987). The values of compression strength parallel to the grain for *E. globulus* were comparable with *P. adolfi-frederici*, *E. saligna*, *Q. robur* and *T. grandis*. It was higher than the rest of the species with the rest properties. *E. saligna* was comparable with *P. adolfi-frederici*, *Q. robur* and *T. grandis* by its density and mechanical properties. *E. grandis* in density was comparable with *H. abyssinica*, in modulus of rupture with *P. adolfi-frederici*, *P. menziessii,* in compression with *H. abyssinica*, *K. ivorensis, P. sylvestris, P. adolfi-frederici*, *P. menziessii* (Table 1). *E. deglupta* in density and modulus of rupture with a±10% accuracy was comparable with *C. africana*, *C. lusitanica*, E. *delegatensis, E. grandis*, *Picea abie*, *P. patula*, *P. radiata*, *P. strobes, H. abyssinica, J. procera, P. sitchensis, P. falcatus*. Most of these values of this study are low when compared with Bolza and Kloot (1963), Bryce (1967) and Louppe et al. (2008). This could be attributed due to low age and fast growth rate in this case.

Durability of *Eucalyptus* and effectiveness of wood preservatives

The results of durability studies revealed that *Eucalyptus* species were moderately resistant against bio-deteriorating agents (Table 2). *E. globulus* was moderately resistant to preservative treatments and moderately durable against bio-deteriorating agents. *E. grandis* was moderately resistant to preservative treatments and non-durable. *E. saligna* was resistant to preservative treatments and non-durable against subterranean termites and fungal attack (Getachew et al, 2003; Getachew *et al*, 2007).

Table 2. Natural durability of timbers and effectiveness of preservatives

Species	Permeability*	Natural Durability of timbers**		Effectiveness of CCA treatment**	
		Termite	Fungi	Termite	Fungi
Eucalyptus camaldulensis	ER	MD	MD	MD	MD
Eucalyptus deglupta	MR	ND	ND	MD	MD
Eucalyptus globulus	MR (7 mm)	2.6(6) MD	100(6) MD	0 (13), D	100 (13), D
Eucalyptus grandis	MR (8.5 mm)	0 (4) ND	0 (4) ND	92.5 (7), MD	85 (7), MD
Eucalyptus regnans	R	ND	ND	ND	ND
Eucalyptus saligna	R (5 mm)	2.5 (13) D	95 (13) D	47.5 (13), D	25 (13), D

**- Permeability grades: P = Permeable (> 18 mm penetration), MR = moderately resistant (6-18 mm penetration), R = Resistant (3-6 mm penetration) and ER = extremely resistant (< 3 mm penetration) (Bryce, 1967; Tack, 1969; Farmer, 1987).*
***Abbreviations = durability grades ND = Non-durable (1-5 years), MD = moderately durable (5-10 years), and D = Durable (10-15 years). The first number = timbers mean result (%) of resistance against subterranean termites and fungal attack, number in brackets = service life of timbers (years).*

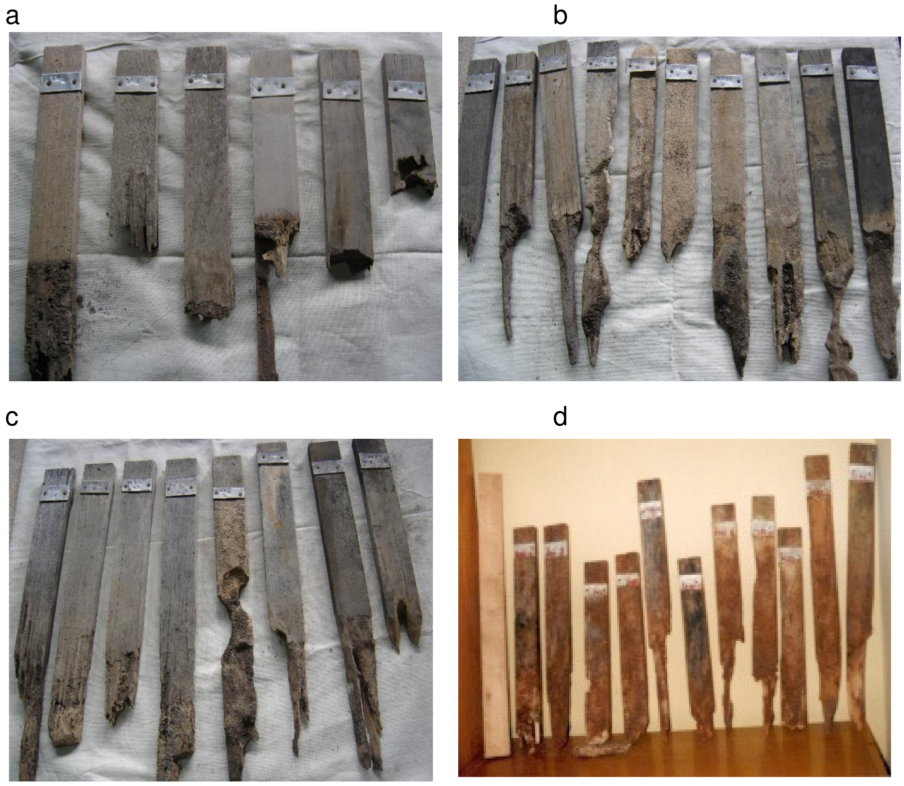


Figure 6. Trends of timber bio-deterioration at Meisso, Mersa, Gonder, Bako and Ziway station

Resistance of untreated stakes and effectiveness of preservatives against subterranean termites and fungi were varied. There was significant difference ($P< 0.01$) on the natural durability among the study species. Untreated *E. globulus* stakes degraded to 97.5% at year six by termite attack, while *E. grandis* degraded and fell down to the ground at the fourth year by both termite and fungal attacks. At Meisso station all the control stakes of *E. deglupta* underground parts were 100% deteriorated and fell down to the ground by termites during the first year field exposure and evaluation periods (perishable) while J. *procera* stakes were deteriorated by termites to 72.5% and intact by fungi. *E. saligna* at year 13 have been degraded to 97.5% and 5% by termite and fungi, respectively (Table 2).

The wood durability study indicated that lumber of *E. camaldulensis, E. globulus*, *E. grandis,* and *E. saligna* species compared to *C. lusitanica*, *P. patula*, *P. radiata*, *P. falcatus, H. abyssinica*, *C. africana,* and *P. adolfi-frederici* were found resistant to subterranean termite and fungal attack.

Durability results revealed that the long-term service life construction purposes for ground and soil contact applications from these *Eucalyptus* species requires adequate pressure impregnation treatment with the right environmentally safe preservatives such as Tanalith E and Celcure AC preservatives.

Working properties of *Eucalyptus* wood

Lumber of most *Eucalyptus* species as compared to the other species were found heavy and hard that needs adequate care to work with hand tools and machines. Most of the species have good appearance as household and office furniture, structural work and parquet.

Eucalyptus species were hard and difficult to work with machines and hand tools, but compared with the high-density indigenous hardwood species such as *Prunus africana*, Olea species and *Manilikara butugi,* were better. The lumber of *E. globulus* can be worked with machines and hand tools with medium resistance to the cutting blades. The lumber planed well with chip marks and slight torn grain on cutting. Moderately resistant with some saw burning and saw marks on the cut surface. While nailing, it is resistant; holds nails properly with slight splitting and its screw holding ability is quite good. It finishes well with finishing techniques and materials such as sander, lacquer, varnish, and satin.

E. grandis works easily and well, and finishes satisfactorily. It holds nails well, but tends to split when nailing near the ends of the pieces. Thus, pre-boring is needed for screwing. *E. saligna* is hard but works well with certain machining defects. It has moderate resistance to the cutting blades, resulting in saw marks and dulling of the cutting blades. Torn grain, chip marks and raised grain were observed during planing. *E. saligna* holds nails properly. It is easy to drive in screw and holds very well. It takes a high polish and finishes well.

E. camaldulensis seasoned wood is extraordinarily hard, very dense and difficult to work and somewhat brittle and is often cross-grained, making hand working difficult. It needs careful selection as it tends to be quite reactive to changes in humidity; can take a fine polish and carves well; popular timber for wood turners, particularly if old and well-seasoned.

Laminating technology (binding lumber) with each other and/or with other spp. will increase application opportunities (appropriate length and thickness for the purpose), mechanical properties, durability, beauty appearance, and in general maximum utilization of each species. Practiced uses of *Eucalyptus* lumber as tested at FPURP were: (i) household and office furniture from home-grown *Eucalyptus* species (*E. grandis* tables and chairs; *Eucalyptus* and other species appropriate utilization in terms of lamination; *E. saligna* bed, *E. saligna* and *Cordia alliodora* mixed chair and (ii) Parquet from *E. camaldulensis* and *E. globulus* species lumber.

If the knots on the *Eucalyptus* lumber are not decorative and rather making holes on boards, it is important to avoid these serious-dead knots carefully and fill the holes with other pieces of decorative wood using glues. Applying of finishing materials such as lacquers and varnish during the finishing process or using stains has been observed as a good possibility to make them less permeable to moisture and bio-deteriorating agents, the whitish boards more decorated and changed externally to the desired appearance of end-users.

Potential uses of *Eucalyptus* species timbers

Each *Eucalyptus* species based on the different properties tested (physical, mechanical, and working properties, seasoning characteristics and durability) and utilization methods (proper seasoning, proper machining and joining, applying the right protection measures) sated above has versatile present and potential uses/applications. These *Eucalyptus* differently are well suited for structural work, light and heavy duty construction/ building work, for furniture and cabinetwork due to the high fiddle back figure, light and heavy flooring, ship and boat building, mine timber, vehicle body, ladders, sporting goods, agricultural implements, boxes and crates for fruits and vegetables. Used as weatherboards and shingles when treated with preservatives.

Eucalyptus lumber is useful for interior trim, core stock, joinery, sleepers, piles, toys and novelties, turnery and wood-wool. Widely used for fuel wood and charcoal, fencing, electricity transmission, telegraph poles and posts, piles, axe and other tool handles. They have good potential as veneer, plywood, particleboard, pulpwood, hardboard, short fiber pulp for papermaking. Some of the trees are good as honey flora, shade, and wind-break, fire belts, as source of essential oils, amenity, ornamental and all-purpose activities in Ethiopia today.

Well-managed *Eucalyptus* from the perspective of declining indigenous timber species and raise of forest product demand, it is multipurpose and grateful species to Ethiopia. At present, only *E. globulus* has been used for both particleboard and hardboard productions in Ethiopia while such other potential and alternative species available in the country. Research has been undergoing by FPURP researchers on some *Eucalyptus* species to test their suitability for particleboard production.

Conclusions and Recommendations

The results revealed that the species have good timber quality. The air-dry density at 12% MC of homegrown *Eucalyptus* species ranged between 410 and 860 kg/m^3. *E. paniculata* showed the highest modulus of rapture value (147 N/mm^2) and *E. deglupta* the least (69 N/mm^2). *E. microcorys,* in terms of modulus of elasticity and compression strength indicated, respectively the highest values (17715 N/mm^2 and 76 N/mm^2) and *E. deglupta* the least values (8332 N/mm^2 and 33 N/mm^2). The wood durability study indicated that boards of *E. camaldulensis, E. globulus*, *E. grandis,* and *E. saligna* species compared to *C. lusitanica*, *P. patula*, *P. radiata*, *P.*

falcatus, H. abyssinica, *C. africana,* and *P. adolfi-frederici* were found more resistant against subterranean termite and fungal attack.

Eucalyptus species have potential to cover degraded areas quickly, bring high biomass fuel, construction wood, and high revenue for farmers. There is no competent and potential alternative substitute species, to blame and discard from planting and utilizing *Eucalyptus* species in Ethiopia. The best solution to reduce the side effects is to know where to plant and how to manage and rationally utilize based on the different wood characteristics for the different environmental services and versatile products.

Proper management and sustainable utilization of *Eucalyptus* species will increase quality of *Eucalyptus* lumber and relieve pressure on the endangered indigenous species such as *J. procera, P.falcatus, H. abyssinica*, *C. africana* and *P. adolfi-frederici* that have been covering about 85% of the demand in the country. Owing to their potential (fast growing, high yield, quality, good performance and timber characteristics, etc), some of the *Eucalyptus* species namely *E. globulus*, *E. camaldulensis*, *E. grandis*, *E. deglupta*, *E. regnans*, *E. microcorys*, *E. obliqua*, E. saligna, E. *viminalis*, etc with the right provenances need to be prompted, and planted as large scale plantations before losing them due to over maturity and exploitation and land use changes where *Eucalyptus* trees clear felled without replanting/retaining germ plasmas of such invaluable species.

Based on the results on the different wood characteristics, the following recommendations are forwarded: (i) home-grown *Eucalyptus* species that are comparable with other indigenous species can be used as substitute of the other species; (ii) *Eucalyptus* species generally classified non-durable to moderately durable. Thus, the long-term service life construction purposes for ground and soil contact applications from these *Eucalyptus* species requires adequate pressure impregnation treatment with the right environmentally safe preservative such as Tanalith E or Celcure AC preservatives, (iii) if delay of seasoned *Eucalyptus* lumber utilization for specific purpose is unavoidable, always store boards in a room, which is free from moisture and high heat so as to avoid shrinkage, movement, other defects and biodegrading problems, (iv) the fast growing (short-rotation) *Eucalyptus* species have to be harvested at the age of maturity at about 15-20 years old for saw log/lumber production in the country, and (v) it is expected from all target groups/actors to make the population aware and participate in the development, conservation, proper management including adequate spacing and final stocking, understanding the different basic wood properties and wise utilization of those potential *Eucalyptus* species grown in Ethiopia.

In order to promote the harmonious development of material and ecological economy, correct understanding and scientific research on the sustainable development problems of *Eucalyptus* plantation in Ethiopia is an instant task.

Finally, comparable *Eucalyptus* timber species with known exotic timbers and traditionally known indigenous tree species can be used as substitutes for specific purposes provided they have been well established, managed, matured enough, properly seasoned, the right density and mechanical properties at specified MC for the specific purpose selected, lumber properly handled, processed well and shortcomings overcame. Further research activities are important to fill the information gaps and promote rational utilization of these timbers in the different agroecological zones of Ethiopia.

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References

Abebe Haile Geberemariam, Million Bekele and Andrew Ridgewell, 2009. Small and medium forest enterprises in Ethiopia. IIED Small and medium forest enterprise series No.26. FARM-Africa and International Institute for Environment and Development, London, UK.

Adugna Zerihun. 1981. Adapatability of several *Eucalyptus* species in Hraarghe Adminstration Region. Eth.J. of Agr. Sci. Vol. III(1), Addis Ababa University, Debre Zeit.

Amare Getahun, Feyisa Abate, Belay Gebre.1990. A brief history of Forestry Research Center. Forestry research in Ethiopia 1890-1990. 45 pp.

Anonymous. 2004. The forestry sector in 2020. Country report-Ethiopia. http://www.fao.org/ DOCREP/004/AB582E/AB582E04.HTM. Accessed on: 19/11/2004.

Anonymous. 2010a. *Eucalyptus* species. From Wikipedia, the free encyclopedia. http://en.wikipedia.org/wiki/Eucalyptus. Accessed on Friday, January 29, 2010.

Anonymous. 2010b. List of *Eucalyptus* species. From Wikipedia, the free encyclopedia.http://en.wikipedia.org/wiki/List_of_Eucalyptus_species. Accessed on Monday, February 01, 2010.

Anonymous. 2010b. *Eucalyptus.* Academic dictionaries and encyclopaedias. Accessed on 10/9/2010.

Anonymous. 2010d. The Ecological, Economic and Social Effects of *Eucalyptus.* Proceedings. Regional expert consultation on *Eucalyptus.* http://www.fao.org/docrep/005/ac777e/ac777e08.htm. Accessed on 10/9/2010.

Armstrong M. 2003. Wood Quality. A review of wood quality requirements for processing and the development of non-destructive evaluation techniques for wood property traits. Hardwoods Queensland. Report No.6. Queensland Forestry Research Institute. Department of primary Industries. Agency for Food and Fibre Sciences. Queensland Government.

Bolza E, NH Kloot. 1963. The mechanical properties of 174 Australian timbers. Division of Forest Products Technological paper no.25. Commonwealth scientific and industrial Research Organization, Australia.

Bowen R M.1985. Selection and Adaptation of Tree Species for Plantation use in Diverse Ecosystems, Ethiopia. Consultant's Report ICD/UNDP/ETH/85/014. Parsons and Whittemore lyddon limited Croydon-England for Industrial council for Development

New York-USA and for United Nations Development Programme, Addis Ababa-Ethiopia.

Bryce JM. 1967. Commercial timbers of Tanzania. Tanzania Forest Division. Utilization section. Moshi, Tanzania, 139p.

Chudnoff M. 1980. Tropical timbers of the world. Forest Products Labouratory. Forest Service. US Department of Agriculture.. USA. 451pp.

CSIRO. 2002. EUCLID. *Eucalyptus* of Southern Australia. 2nd edition.

Demel Teketay. 2000. Facts and experiences on Eucalypts in Ethiopia and elsewhere: Ground for making wise and informed decision. In: Journal of the Ethiopian Wildlife and History Society. Addis Ababa, Ethiopia. No.1.pp 25-46.

Denig J, EM Wenger, Wt Simpson. 2000. Drying of Hardwood lumber. Forest products labouratory. Forest Service. United States. Department of Agriculture (USDA). General
Technical Report. PL-GTR-118. 138pp.

Desch HE. 1986. Timber, its structure, properties and utilization. 6th edition. HMSO, London. 410p.

Desata Hamito and Feyisa Abate.1994. Forestry Research Directory 1975-1994. Forestry Research Center. Addis Ababa, Ethiopia

Eaton RA, MDC Hale. 1993. Wood decay, pests and protection. London, 546pp.

Ethiopian Forestry Action Program.1994. The challenge for development. Volume II. Final report. Ministry of Natural Resources Development and Environmental Protection Addis Ababa, Ethiopia, 95 pp.

FAO.1988. The *Eucalyptus* dilemma. FAO . Rome, Italy.

FAO.1994. Wood preservation manual. Mechanical Wood Products Branch. Forest Industries Division. FAO Forestry Department. FAO Forestry paper/ FAO forestry paper 76. International Book Distributors, Dehradum, India.

Farmer RH. 1987. Handbook of hardwoods. Department of the environment. Building Research Establishment, Princes Risborough Labouratory. 2nd edition. London, 243p.

FDRE. 2007. Forest development, conservation and utilization proclamation. Proclamation. Number 542/2007. The Federal Democratic Republic of Ethiopia, Addis Ababa, Ethiopian.

Forest Products Labouratory. 1999. Wood handbook-wood as an engineering material. Forest Service. Gen. Tech. Rep FPL-GTR-113. Madison, WI: US, Department of Agriculture, 463 pp.

Getachew Desalegn. 1997. The analysis and application of potential timbers small clear specimens results in Ethiopia. M.Sc. thesis. Faculty of Forest, Geo and Hydro Sciences of Technische Universität Dresden, Germany, 127p.

Getachew Desalegn, Wubalem Tadesse, Worku Fekadu, Gemechu Kaba, Demel Teketay and Girma Taye. 2003. Effectiveness of protection measures on 32 timber species against subterranean termites and fungi at Zeway District, Zeway Research Station, and Central Ethiopia. Ethiop.J.Biol.Sci, 2: 189-216.

Getachew Desalegn. 2006. Some basic physical and mechanical properties of the valuable Hagenia abyssinica timber and their interactions: Implication for its rational utilization. Ethiop.J.Biol.Sci, 5(2)117-135, 2006. The Biological Society of Ethiopia, Addis Ababa, Ethiopia. Jan 10

Getachew Desalegn, Wubalem Tadesse, Demel Teketay, Worku Fekadu, Gemechu Kaba and Girma Taye. 2007. Performance of preservative treatments on 32 timber tree species against termites and fungal attack at Bako, southwestern Ethiopia. SINET: Ethiop. J. Sci., 30(2):103–116. Faculty of Science, Addis Ababa University.

Getachew Desalegn, Melaku Abegaz, Demel Teketay and Alemu Gezahgne. 2009. Timber properties and uses of 54 commercial indigenous and exotic timber tree species found in Ethiopia: A Handbook for Forest Industries, Construction Sectors, Foresters and Other Stakeholders (Unpublished report), Addis Ababa, Ethiopia.

Getachew Desalegn and Alemu Ggezaghne, 2010. Timber properties of *Eucalyptus* species, research report no. 81. Ethiopian Institute of Agricultural Research, Addis Ababa, Ethiopia.

Gjovik LR, DI Gutzmer.1986. Comparison of wood preservatives in stake tests (Progress report). United States Department of Agriculture. Forest service, Forest Products Labouratory, Research Note FPL-02. USA, 13 pp.

Haygreen JG, JL Bowyer. 1996. Forest Products and Wood Science. An introduction. 3rd edition. USA, 484p.

Highley TL. 1995. Comparative durability of untreated wood in use above ground. Journal of International biodeterioration and biodegradation. Elsevier Science Limited. Great Britain, pp. 409-419.

Hillis WE, AG Brown (eds). 1978. Eucalypts for wood production. CSIRO Australia, Griffin Press Limited, Adelaide, South Austria.

ISO 3133 (International Organization for Standardization). 1975. Wood-determination of ultimate strength in static bending. ISO International standard no.3133, Switzerland, 2p.

ISO 3387. 1976. Wood-determination of ultimate stress in static compression parallel to the grain. ISO International standard no. 3787, Switzerland, 2p.

ISO 3348. 1975. Wood-determination of impact bending strength. ISO International standard no.3348, Switzerland, 2p.

ISO 3350. 1975. Wood-determination of static hardness. ISO International standard no.3350, Switzerland, 2p.

ISO 3131. 1975. Wood-determination of density for physical and mechanical tests. ISO International standard no.3131, Switzerland, 2p.

ISO 3130.1975. Wood-determination of moisture content for physical and mechanical tests. ISO International standard no. 3130, Switzerland. 3p.

ISO 3129. 1975. Wood-sampling methods general requirements for physical and mechanical tests. ISO International standard no.3129. 1st edition, Switzerland, 4p.

ISO 3130.1975. Wood-Determination of moisture content for physical and mechanical tests. ISO International standard no. 3130. Switzerland. 3 pp.

ISO 3131. 1975. Wood-Determination of density for physical and mechanical tests. ISO International standard no.3131. Switzerland. 2 pp.

ISO/DIS 4469. 1975. Wood-Test methods-determination of radial and tangential shrinkage. ISO/DIS 4469 Standard no. 4469. Explanatory report. Switzerland. 3 pp.

ISO/DIS 4858. 1975. Wood- Test methods-determination of volumetric shrinkage. ISO/DIS standard no. 4858. Explanatory report. Switzerland. 4 pp.

Lamprecht H.1989. Siviculture in the tropics. Tropical forest ecosystems and their tree species-possibilities and methods for the long-term utilization. Technical cooperation (GTZ). Eschborn, Germany.

Lavers GM.1983. The strength properties of timber. Forest Products Research. Bulletin no. 50. 3rd edition. London. 60p.

Liu H, J Li. 2010. The Study of the Ecological Problems of *Eucalyptus* Plantation and Sustainable Development in Maoming Xiaoliang. Maoming College, Maoming 525000, China.

Louppe D, AA Oteng-Amoako, M Brink (eds). 2008. Plant Resources of Tropical Africa 7(1). Timbers 1. PROTA Foundation Wageningen, Netherlands/ Backhuys Publishers, Leiden, Netherlands/ CTA, Wageningen, Netherlands. 704pp.

Melaku Abegaz and Addis Tsehay.1988. Wood preservation in Ethiopia. Ministry of Agriculture. Natural Resources Conservation and Development Main Department. Wood Utilization and Research Center. Addis Ababa, Ethiopia, 22 pp.

Nicholas DD (ed). 1985. Wood deterioration and its prevention by preservative treatments. Volume 1, Degradation and protection of wood. Syracuse University Press. Syracuse wood science series, 5, New York. 380 pp.

NWPC standard (Nordic Wood Preservation Council). 1971. Testing of wood preservatives. Mycological test. A field-test with stakes. NWPC standard No. 1.4.2.1/71.

Purslow DF. 1976. Results of field tests on the natural durability of timbers (1932-1975). Building Research Establishment, Princes Risborough Labouratory. U.K., 13 pp.

Shrivastava MB. 1997. Wood technology. Vikas Publishing House, pvt ltd, New Delhi, India, 180 pp.

Sisay Nune. 2001. Short notes on bamboo. In: Kosso- a quarterly newsletter of the Ethiopian Foresters' Association . Addis Ababa, Ethiopia.

Tack CH. 1969. Uganda timbers. A list of the more common tree species and their properties. Ministry of Agriculture and Forestry. Forest Department. Printed by the government printer, Entebbe, Uganda. 138 pp.

Truneh Kide. 1987. Mechanical and physical properties of *Cordia africana*. B.SC. thesis. Swedish University of Agricultural Sciences.

Vernède HL. 1995. Forest resources of Ethiopia. Ministry of Agrculture, Addis Ababa, Ethiopia

Woody Biomass Inventory and Strategic Planning Project. 2004. Forest resources of Ethiopia. WBISSP, Addis Ababa, Ethiopia.

Webb DB, PJ Wood, JP Smith, GS Henman. 1984. A guide to species selection for tropical and sub-tropical plantation. Unit of tropical silviculture. Commonwealth Forestry Institute. University of Oxford. Tropical forestry papers No. 15. 2nd edition, Revised, 84-256 pp.

Willeitner H, W Liese. 1992. Wood protection in tropical countries. A manual of the know-how. Technical Cooperation of Germany (GTZ), Federal Republic of Germany, 228 pp.

WUARC. 1995. Commercial timbers of Ethiopia. Research report. Technical bulletin no.2 revised and enlarged edition. Ministry of Natural Resources Development and Environmental Protection. Addis Ababa, Ethiopia.

Analysis of *Eucalyptus* Role in the Livelihoods of Rural Households

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Abstract

Eucalyptus has become one of the most important livelihood sources for rural households. *Eucalyptus* production is rapidly expanding in every regions of the country. Despite such alarming expansion, it has received little institutional support. This is mainly because of limited stock of knowledge and understanding on the importance and contribution of *Eucalyptus* to livelihood of rural households. This case study was conducted at Anget Mewgia Peasant Association (North Shewa) to assess the contribution of *Eucalyptus* to livelihood. Focus Group Discussion (FGD) was conducted with a group consisting of 8 key informants to collect qualitative information. A structured questionnaire was also used to collect quantitative information from purposively selected 100 households. The study reveals that *Eucalyptus* (*Eucalyptus globulus*) being grown by 100% of households in the community has become number one contributor to household income. The contribution of *Eucalyptus* to household income is increasing during the last five years. Apart from its role in providing construction material and firewood to households, proportion of *Eucalyptus* contribution to the total annual household income at the year 2008/09 is 20%. In addition, between 2004/05 and 2009/10 land allocated by farm household for the production of *Eucalyptus* has increased by 30%. During the last 7 years, the price of *Eucalyptus* log has increased by 15 folds. The study also identifies and prioritizes major institutional, technical, economic related constraints that affect *Eucalyptus* enterprise development. Women are also identified to play significant role in *Eucalyptus* production and marketing.

Keywords: crop and livestock enterprises, household income, livelihood

Introduction

Eucalyptus, the most planted tree in the world, has been grown in East Africa for over a century. Through this time, people in the region have accumulated important local knowledge of its management. Expanded widely, today this tree dominates rural and urban landscapes. At the moment Ethiopia holds the largest *Eucalyptus* plantation in East Africa and is one of the pioneer countries that

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introduced the species. For smallholder growers, *Eucalyptus* suits their limited resources and yields more money than other tree crops. On top of this, the increasing demand for fuel wood and construction material has created a dependable market for *Eucalyptus* products. This certainly contributes to the steady expansion of *Eucalyptus* in the region (FAO, 2009). The cultivation of *Eucalyptus* gradually spread throughout Ethiopia, which is partly attributable to academic, research and development institutions including Alemaya College of Agriculture, Institute of Agricultural Research (IAR) and Chilalo Agricultural Development Unit (CADU) (Friis, 1995).

In Ethiopia, *Eucalyptus* species played and will play a tremendous role in alleviating the fuel and construction material problems in the country (Teshome 2007; Henery 1973). In some areas, planting *Eucalyptus globulus* overrides the production in crop yield and it makes returns to land 1.3-1.7 times, and returns to labour 1.2 - 1.5 times greater than sole wheat cropping (Selamyihun 2004). The other greatest positive contribution of *Eucalyptus* is replacing indigenous species for firewood, thereby, preventing further denudation of natural forests (Evans 1992). Some studies also indicated that *Eucalyptus* as one of the most important commercial plantation and pioneer tree species in successful ecological restoration of degraded lands (Yu 1994, 1995; Zhou et al. 2001).

Since its introduction, *Eucalyptus* in Ethiopia has been marred by controversies, surrounding its alleged negative environmental impacts and inability to provide the necessary productive and ecological services. The on-going debate on the potential benefits versus negative impacts has remained unsolved which led to scepticism to provide support to the development of *Eucalyptus* in Ethiopia. This case study was conducted by taking into account the arguments against *Eucalyptus* at present have undermined the contribution of this tree to the livelihood of smallholder farmers and its general socio-economic significance. The study analyzing the contribution of *Eucalyptus* to rural household livelihoods with an aim to provide a balanced view about the present role and its trend of contribution to rural households, for decision makers, development practitioners and concerned stakeholder who are in favour or against *Eucalyptus* in Ethiopia.

The objectives of the present study are to analyze the overall contribution of *Eucalyptus* to rural household income and livelihood; to identify gender roles in *Eucalyptus* production-marketing continuum and to identify major constraints that affect *Eucalyptus* enterprise development.

Methodology

A case study approach was used to examine the contribution of *Eucalyptus* to the livelihoods of rural households. Anget Mewgia, is a peasant association (PA) selected for the case study. The PA is found in North Shewa zone, Basona Worana Woreda, located 30 km east from Debreberhan the way to Ankober.

Data Sources and Collection Techniques

Both primary and secondary data sources were used. Primary sources include household survey and Focus Group discussion (FGD). Structured questionnaire was used to collect the data on the contribution of *Eucalyptus* to rural households, price trends and land allocation trends by households for *Eucalyptus* production. Two FGDs were conducted with men and women groups, each consisting of 8-10 individuals in order to generate information on non-income related benefits of *Eucalyptus* as well as constraints and challenges affecting *Eucalyptus* farming in the study area. The FGD members were selected based on their knowledge about the community. The structured questionnaire was designed to collect income related information from the purposively selected households.

Sampling size and techniques

One hundred households that grow and have already started selling *Eucalyptus* were purposively selected from the PA to generate information on the proportion of contribution of *Eucalyptus* to household income and land allocation trend to *Eucalyptus* farming.

Data analysis

Land allocation and household income proportion of *Eucalyptus* and price related data were analyzed using SPSS program assisted descriptive techniques. Gender related information and constraining factors of *Eucalyptus* production were analyzed using qualitative analysis techniques during focus group discussion.

Results and Discussions

Eucalyptus and livelihood

Eucalyptus planting started in 1979 by Lutheran Federation through its food for work program, followed by Farm Africa, which promoted *Eucalyptus* plantation in the Anget Mewgia PA. At the time community members were participating in the *Eucalyptus* planting program run by Lutheran, and the underlying interest for community participation was just receive wheat and edible oil offered for participant households (HH) in the program. The community members had little interest in *Eucalyptus* planting because of land tenure insecurity (*fear of frequent land redistribution*), and lack of awareness on its importance and limited market.

At present every households in the community have planted *Eucalyptus.* The underlying reason for having *Eucalyptus* by every household is that it is the only resource that any household in the community use for construction of houses and making farm implements. *Eucalyptus* is playing irreplaceable role to provide construction and farm implement resource for every farm household. HH harvest *Eucalyptus* on average at fourth year after planting; then every three years. Farmer usually plant 10,000 seedlings per hectare. The community members are aware of and have the knowledge that *Eucalyptus* can drain river and spring water. They have practice of planting *Eucalyptus* away from farmlands and water sources.

Eucalyptus market

HHs sells their *Eucalyptus* at farm, and farmers are price takers. Traders that regularly come at least twice a week set the price for the *Eucalyptus*. Few farmers have started transporting and selling their *Eucalyptus* in the nearby town market. Farm gate price of *Eucalyptus* is Br. 4/log and if farmers transport themselves and sell it at Debreberhan (the nearby town) market, the price goes up to Br. 9/log. Farmers who sells their *Eucalyptus* at the nearby town market earn more than 100% price advantage over those who sell at farm gate with additional 15-20% marketing cost (Transport and labour cost). The problem associated with the prevailing *Eucalyptus* market is that there is no standard being used for *Eucalyptus* product (log). On retail basis, buyer and seller agree price arbitrarily, there is not agreed market standard for log size and quality.

Price trends

The price of a commodity reflects nature of its demand (Gittinger, 1985). Due to increasing population and demand for fire wood and wood for constructions, the demand for *Eucalyptus* has increased both within and surrounding communities. Increasing importance of *Eucalyptus* in the study area is manifested through it increasing price trend (see fig. 1) during the last 7 years the price of *Eucalyptus* log has increased by 1500% and during the last four years 400%.

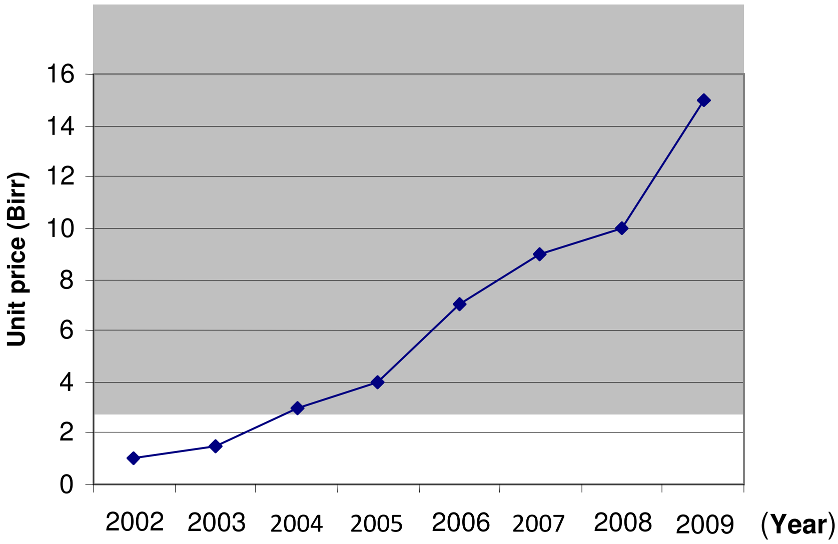

Fig 1: Price trend of *Eucalyptus* log

Land allocation for *Eucalyptus* production

Enterprise choice by farm households has direct link with decision over resource allocation (Gittinger, 1985). Increased allocation of resources to the production of *Eucalyptus* is one of the indicators for increased importance of *Eucalyptus* for livelihood. The average hectare of land allocated for *Eucalyptus* production is summarized in table 1. The study reveals an increasing trend of hectare of land allocated by farm households in Anget Mewgia community to produce *Eucalyptus* during the last 5 years. (See fig. 2). Between the year 2004 and 2009 land allocated by farm household for the production of *Eucalyptus* has increased by 30%.

Table 1: Summary of average hectare of land allocation by farm households for *Eucalyptus* production

Land allocated for *eucalyptus* (Over years)	N	Minimum (ha)	Maximum (ha)	Mean (ha)	SD
2009	100	.06	1.50	.3712	.28017
2008	100	.13	1.50	.3727	.27404
2007	100	.13	1.00	.3443	.21230
2006	100	.13	1.00	.3277	.19141
2005	98	.13	.63	.2853	.11405
2004	97	.13	.63	.2837	.11115

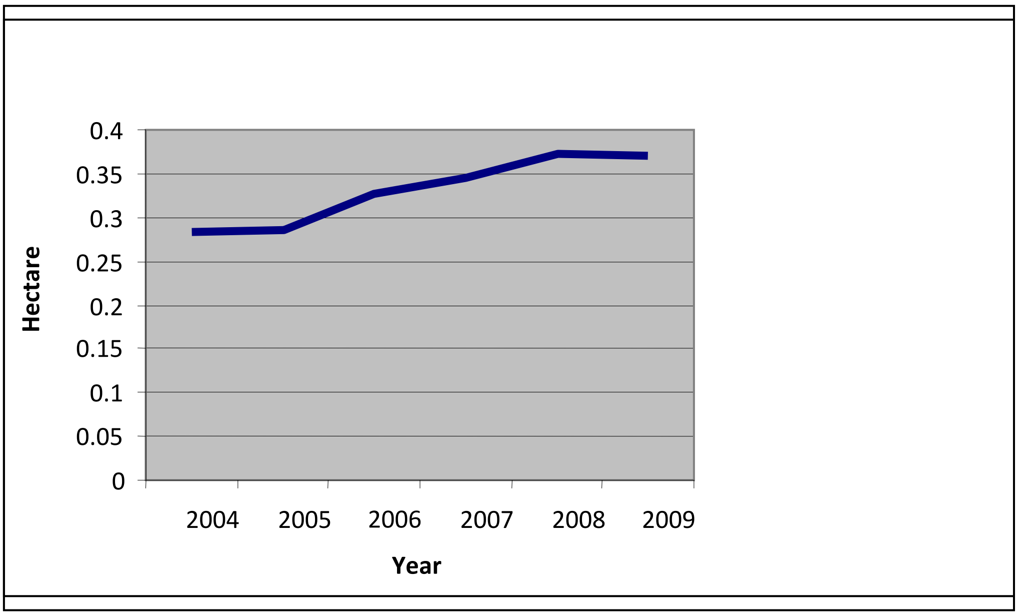

Figure 2: Land allocation trend for *Eucalyptus* production

Contribution of *Eucalyptus* for household income

Smallholder farmers both in Ethiopia grow *Eucalyptus* mainly for poles, fuel wood, construction wood, furniture making, and farm implements (Davidson

1989). The cultivation of *Eucalyptus* in the Anget Mewgia has also similar purposes. In the study area, dominated by poor household, *Eucalyptus* trees are cultivated with a priority objective of construction of housing and for household fuel wood needs and farm implements in order.

Eucalyptus generates substantial income to rural households. In central Ethiopia, *Eucalyptus* generated a quarter of annual cash incomes (Mekonnen et al 2007). The major income sources identified by the HHs in the Anget Mewgia PA includes *crop production, livestock, Eucalyptus, petty trading, remittances, non-agricultural wage, regular employment, temporary employment and other non farm incomes*. Of these major sources, income from *Eucalyptus* sale constitutes the largest share. The contribution of *Eucalyptus* to the total annual HH financial income at the year 2009 is 20% (Figure 3). The contribution of *Eucalyptus* to the household livelihood presented on figure 4 represent only its financial contribution, and its contribution in providing wood for construction and fuel are not calculated which would rise its overall contribution much higher than 20%.

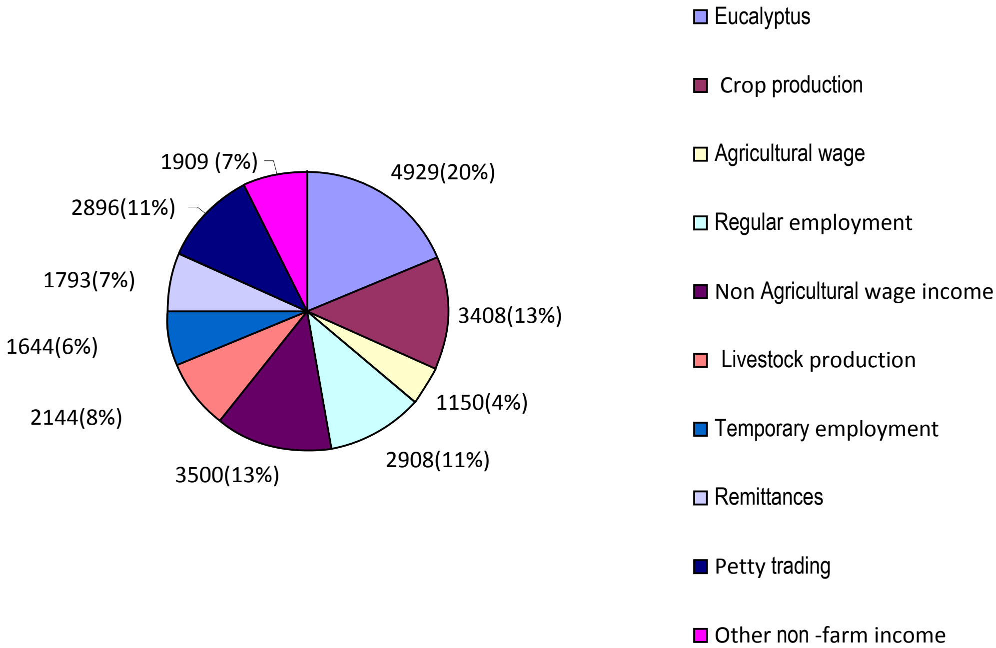

Fig 3: Proportion of HH income by Sources (Birr)

Gender roles in *Eucalyptus* production and marketing

Women play vital but unrecognized roles in crop production, household food security, and household nutrition, income generation, and natural resources management (World Bank, 2006). Digging holes, seedlings transporting, planting, hoeing, harvesting, transporting of logs, and marketing are the major tasks and activities involved in *Eucalyptus* enterprise/business. In this regard the involvements of women in *Eucalyptus* farming are enormous. The involvement of different men and women in *Eucalyptus* enterprise is presented on fig. 4.

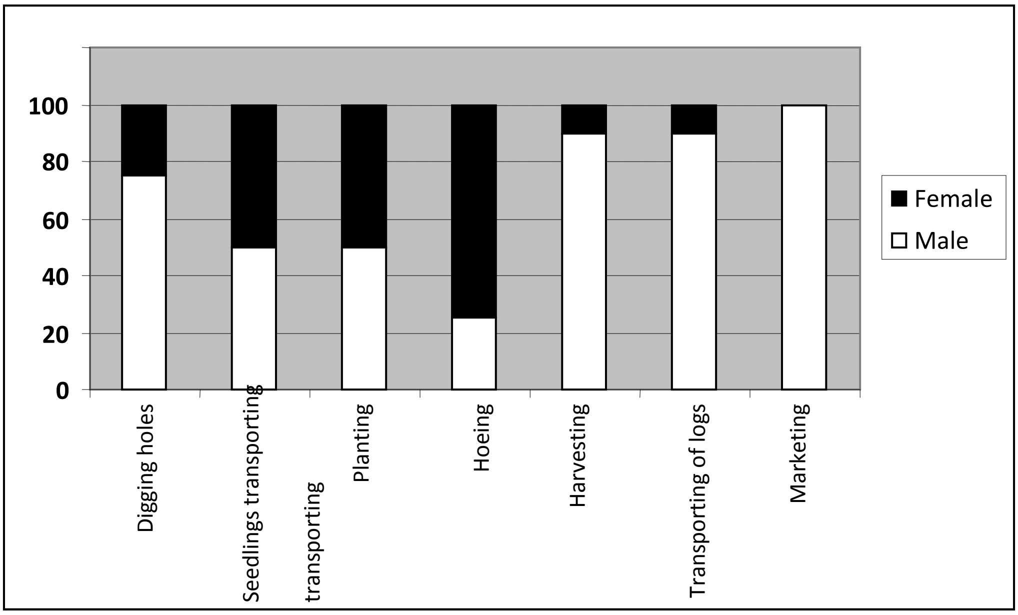

Figure 4: Gender roles and proportion of gender groups participation in *Eucalyptus* enterprise

Institutional arrangement for *Eucalyptus* development

Institutional support is key factor for sustainable *Eucalyptus* production and marketing. Community have received support from different institutions. At present, regarding *Eucalyptus* development, the community have identified *Woreda agricultural office, forestry research centre of the Ethiopian institute of agricultural research and private nursery owners*, as the only support-giving actors operating in the study area. The role of these institutions limited to distribution of seedlings, and lacks provision of technical support regarding *Eucalyptus* production and post harvest management as well as marketing.

Major constraints

The focus group discussion reveals the following factors affecting *Eucalyptus* enterprise development in the area.

- **Shortage of seedlings:** The supply of seedlings could not meet ever rising demand for *Eucalyptus* seedlings. The increased demand is resulted from increasing demand for *Eucalyptus* products due to increased populations and increasing demand for fire wood both from the local and surrounding low land communities;
- **Lack of access road to the *Eucalyptus* farm*:*** Many of the *Eucalyptus* farms are located very far away from the main road, which made it difficult to

transport logs. It takes 1.5 to 2 hours walk. Logs are transported to the main road by human shoulders.

- **Erratic rainfall induced moisture stress:** *Eucalyptus* production in the area is entirely dependent on rainfall. The area is experiencing erratic rainfall problems resulting in water stress in the area.

Conclusions and Recommendation

The proposition that crop and livestock are the only realistic driver for mass poverty reduction and rural development in most of the developing world including Ethiopia does not reflect the practical reality in Anget Mewgia PA. The ever-growing contribution of *Eucalyptus* to rural household income proves that *Eucalyptus* holds both real and potential role to play even larger than crop and livestock do to improve livelihood and financial income of rural household.

- Recognition must be given to the ever-increasing role of *Eucalyptus* to household income. In addition, all technical, institutional and policy support has to be given to realize and optimize the potentials of *Eucalyptus* to poverty reduction endeavours of the country.

- Any intervention that target *Eucalyptus* development must take into account the actual role women have in *Eucalyptus* development. Gender analysis must be done when designing and implementing technical, institutional and policy related support programs.

References

Davidson J. 1989. The eucalypt dilemma: argument for and against eucalypt planting in Ethiopia. The forestry research center, Addis Ababa. Seminar notes series no.1 Edy, John. 2001.

Evans J. 1992. Plantation Forestry in the Tropics: 2nd Edition. Oxford University Press, New York.

FAO. 2009: *Eucalyptus* in East Africa: The socioeconomic and Environmental Issues, FAO sub-regional office East Africa, March 2009, Addis Ababa.

Friis I. 1995. Myrtaceae. In Edwards, S., Mesfin, T., Hedberg, I. Editors. Flora of Ethiopia and Eritria, Vol 2 (2). Addis Ababa University, Addis Ababa

Gittinger. 1985. Economic Analysis of Agricultural Projects.

Henery PW. 1973. Notes on maps of the *Eucalyptus* plantations around Addis Ababa and the Menagesha State Forest, Ethiopia. ODA. London. Misc. Report 150,1-10.

Mekonnen Z, H Kassa, M Lemenh, BM Campbell. 2007. The role and management of *Eucalyptus* in Lode Hetosa district, central Ethiopia. Forest, Trees and Livelihood vol 17, 309-323

Selamyihun K. 2004. Using Eucalypts for Soil and Water Conservation in the Highland Vertisols of Ethiopia: Academic Dissertation. Wageningen, The Netherlands.

Teshome T. 2007. Is *Eucalyptus* Ecologically Hazardous Tree Species? Ethiopian Tree Fund Foundation. http://etff.org/Articles/ *Eucalyptus*.html, accessed on June 21, 2010.

World Bank. 2006. Gender and Rural Development (GENRD). "FY05 Gender Portfolio Review." Internal report, Agriculture and Rural Development, World Bank,Washington, DC.

Yu ZY. 1995. Ecology of the rehabilitation of vegetation on tropical coastal eroded land in Guangdong, China (in Chinese). Journal of Environmental Science 7, 74–84.

Yu ZY. 1994. Rehabilitation of eroded tropical coastal land in Guangdong, China (in Chinese). Journal of Tropical Forest Science 7, 28–38.

Zhou GY, JD Morris, JH Yan, ZY Yu, SL Peng. 2001. Hydrological impacts of reafforestation with *Eucalyptus* and indigenous species: a case study in southern China. *Forest Ecology and Management*. 5741, 1–14.

Essential Oil Yield from Leaves of *Eucalyptus grandis* and *Eucalpyus saligna* and their Commercial Applications

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Abstract

Over 50 *Eucalyptus* species were introduced to Ethiopia for various purposes especially for fuel wood and construction. Additionally they have industrial uses in the production of particle and fiberboards, which are the main and major raw material consuming part of these species. The *Eucalyptus* species are rich with essential oils, which are used in pharmaceutical, perfumery, and various industries. The use of *Eucalyptus* oil for pharmaceutical industry depends on the oil chemical composition and the species as well, oils rich with cineol greater than 80% and in perfumery industry the oil to b rich with citronellal. In Ethiopia, by hydrodistillation mechanism, the essential oil produced at pilot scale from *Eucalyptus globulus* and *Eucalyptus citrodora* are used in the detergent factories. The oil production from these species made from waste or felled big trees. The production of essential oils from biological material depends on the extraction techniques, plant species, and geographical location, age of materials (maturity), parts of the plant, season, and climatic factors. The constituents of the oils are mainly monoterpene and sesquiterpene hydrocarbons, oxygenated compounds derived from these hydrocarbons (alcohols, aldehydes, esters, ethers, ketones, phenols, and oxides). In the production of *Eucalyptus* oil the major raw material is leaf and therefore the biomass production of the leaf per hectare to be maximized.

Keywords: essential oil, *Eucalyptus,* monoterpens

Introduction

The genus *Eucalyptus* consists of over 500 species of trees. *Eucalyptus* varies in form from low shrubs and multi-stemmed trees less than 10 m in height to large single-stemmed trees more than 60 m tall. The production of lignotubers is a characteristic of many eucalyptuses and other tree species and this generally makes them respond to coppicing. The ability to grow *Eucalyptus* under a coppice system of management makes it suitable for its widespread all over the world. Thus, *Eucalyptus* grows under a wide range of climatic and edaphic conditions and this is one reason for the wide distribution of *Eucalyptus* into different countries in the world.

Non-timber forest products cover all the biological material (other than industrial round wood and derived products) that may be extracted from the forest and can be utilized by the household, marketed, or have cultural or religious significance. For the sake of information gap regarding to other use of *Eucalyptus* species with in the country this paper is limited to the volatile oil of this species.

Over 50 species of *Eucalyptus* tree species were introduced to Ethiopia for various purposes. *E. globulus* and *E. camaldulensis* are two of the most widely planted species were in the country (Davidson 1995). Together with genus *Pinus*, the two genera account for the larger part of exotic plantations of which the *Eucalyptus* plantations account over 58% (EFAP 1994). Among the introduced *Eucalyptus* species, 11 of them are well adapted to the Ethiopian climate and 6 of them: *E. camaldulensis, E. globulus, E. citrodora, E. saligna, E. grandsi, and E. triticornis* are widely distributed over the country (Davidson 1995, Friis 1995).Like pines, eucalypts are grown for timber, fuel wood, construction, and pole. Besides the timber value of *Eucalyptus,* it has different values from honeybee flower to chemical production i.e. essential oil. The leaves of many *Eucalyptus* species are well known for their oil production and known as eucalyptol oil (Sheila and Mude 1995).

Eucalyptus oils are obtained by steam distillation from the leaves of *Eucalyptus* and have aromas characteristic of the particular species. In most cases, the distillation of essential oil from *Eucalyptus* species come either from branches trimmed from the stems of eucalypts that are felled for timber, pole or fuel wood production. Steam for the distillation purpose is either generated in separate boiler in the case of large volume distiller or inbuilt within the tank in the case of small distiller (Yagodin et al. 1999). Oils produced from young leaves may vary from old ones in their physicochemical characteristics (Yagodin et al. 1999). Even trees within the same provenance may produce oils that are quite different to each other. In conifer species of the temperate zone, with an increase of tree age the volatile oil content drops in *Pinus sibirica* at the age of 20 -30 years has 3-3.5%, of 30-50 years ca 2% and when between 50-100 years 1.7%. *Eucalyptus* species vary morphologically from site to site and the oil production is heritable character (Davis 1989). The synthesis of essential oil components start in the young and growing buds of tree (Yagodin et al 1999). Yagodin et al (1999) recommend storage of leafy material for the production of biologically active compounds; this includes the essential oils as well, in summer time to be processed within 24hr and in wintertime in temperate regions up to five days for conifer species. Yields of oil from leaf vary somewhat between species but on a commercial scale are of the order of 1 percent on a "fresh" basis. Moreover, the production of an essential oil influenced by abiotic factors likes sunlight, soil character, and sloppiness, rooting system (Yagodin et al. 1999). Of more relevance to the economics of production is the yield of oil per hectare and this is dependent on the biomass production as well as the oil yield from the leaf. There may also be marked differences in oil yield and quality within a species according to the provenance origin of the seed (Haq et al. 2007).

Volatile oils are composed of different groups of compounds: acids, alcohols, aldehydes, ethers, and ketons with various structures grouped in to monoterpens, sesquiterpens, and diterpens. The *Eucalyptus* oils are classified according to their composition and main end-use to medicinal, perfumery and industrial. Of these, the most important in terms of volume of oil production and trade is the medicinal type, characterized by high cineole content in the oil and the perfumery oils that produced from *Eucalyptus citriodora* are in the greatest volume. The perfumery oil differs from the medicinal oils in containing citronellal, as the major constituent. The oil is employed in whole form for fragrance purposes, usually in the lower soaps, perfumes, and disinfectants.

Eucalyptus oil for medicinal use: This type of oil is rich with cineol (not less than 70% of the oil) and free from some unwanted compositions like phellanderene and valeric acid. Cineol rich eucalypt oil mainly used in the treatment of bronchial infections. Cineole is the compound that gives the *Eucalyptus* oil its characteristic odour, accompanied by small amounts of other components that vary from species to species.

The *Eucalyptus* oil for perfumery is the lemon-scented oil of *Eucalyptus citriodora* (citronellal variant) and the somewhat rose scented geranyl acetate rich leaf. In Ethiopia, the *Eucalyptus citriodora* oil distilled at the former Essential Oil Research Center now renamed to Wendo Genet Agricultural Research Center. The objective of this paper is demonstrates the essential oil yield of the two *Eucalyptus* species with respect to the age of leaves.

Table 1. Oil yield of some *Eucalyptus* species

Species	Major component (%)	Oil yield on fresh weight basis (%)
Medicinal oils		
E. camaldulensis	cineole, 10-90	0.3-2.8
E. globulus	cineole, 60-85	0.7-2.4
E. tereticornis	cineole, 45-45	0.9-1.0
Perfumery and flavoring oils		
E. citriodora	citronellal, 65-80	0.5-2.0

Source: Erich (1989) and Ermias et al, (2000).

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Methodology

Site description

Munesa Shashemene Forest enterprise (renamed as Arsi Forest enterprise) is located south of Addis Ababa at 240 km. The altitudinal gradients range from 1900 to 2700 m (http://www.munessa-forest.uni-halle.de/location/). The area has a bimodal nature rainfall, with unreliable minor rainy season from March to May and a major rainy season from July to September. The mean annual precipitation is 1,075 mm and the mean annual temperature is 15°C (Anonymous 2010). The forest has an estimated area ca 22,000 ha with over 6000 ha plantation forest and natural forest of over 15000 ha. The *Eucalyptus* plantation the enterprise has estimated to 1640 ha of *Eucalyptus globulus, E. grandis,* and *E. saligna* (Anonymous 1990).

Sample collection and method of analysis

Samples of *Eucalyptus grandis* and *Eucalyptus saligna* leaves were collected from Munesa Shashemene Forest enterprise (renamed as Arsi Forest Enterprise) ages of 1, 4, and 25 years *Eucalyptus* stands. Collected fresh leaves were stored in a deep freezer until the oil distillation. The essential oil of collected samples was distilled by Clevenger type apparatus for 3hr. the oil yields (w/w) are given in table 1. The oils were analyzed by Hewlett-Packard 6890 GC series equipped with FID and capillary columns. The column temperature was programmed at 50 $^{\circ}$ – 210 $^{\circ}$C at a rate of 3 $^{\circ}$C/min. The injector and detector temperature were 220 $^{\circ}$C and 270 $^{\circ}$C, respectively. The major components of the oils were identified by comparison of the retention time with those authenticate standards.

Results and Discussion

The leaves of *Eucalyptus* species at the distillation time have moisture contents of 45-50%. The oil yield varies from 1.1 to 2.13% presented in the table 2. The obtained oil was light yellowish. Results obtained from the analysis of the two *Eucalyptus* species shows that the major components of these species was α-pinene, the obtained result was completely in agreement with Ermias et al. (2000) for the same species.

Table 2. *Eucalyptus* leaf oil yield of different ages.

Characteristics	Age 2		Age 4		Age 25	
	E. grandis	*E. saligna*	*E. grandis*	*E. saligna*	*E. grandis*	*E. saligna*
Moisture content	59.54	58	58.29	59.52	53.82	54.27
Oil yield, %	1.54	1.51	2	1.1	2.13	1.1
* Refractive index n^{22}_{d}	1.4645	1.4720	1.4645	1.4720	1.4645	1.4720
* Rotation angel	+6.72	+5.02	+6.72	+5.02	+6.72	+5.02

*Note: * the refractive index and rotation angle were measured for combined oil*

Results obtained from the study of the two *Eucalyptus* species namely *E. grandis* and *E. saligna* α-pinene was identified as a major component 58.6% and 32.6% respectively. The essential oils of the two studied species were rich with pinene; they can be used as industrial raw material the chromatographic analysis shows that the volatile oil obtained from the *E. grandis* is poor in composition and rich in 1, 8-cineole in contrary to reports of Ermias et al (2000). In the leaves of *E. grandis* and *E. saligna* oil yield between the three ages there is no yield variation. The obtained result is in contrary to the conifer species and theoretical statements of Yagodin et al (1999).

The production of essential oil depends on the planting density and the yield of the species. The oil yield varies from report to report that for *E. citriodora;* Ermias et al (1999) stated 1% whereas Getnet (2004) reported 4%. Both authors sample sit collection was the same but detail-sampling parameters were not clear and factors for such a variation is not clear. The oil yield depends on the geographical location, climatic factors, age (maturity of plants), parts of the plant etc.

The country is importing essential oils of various plant sources from different countries, which are estimated over 36million Birr for almost 22000 tonnes of oils only for three months from May to August 2007. The CIF costs of 1kg essential oils vary from 161- 446 Birr (Ethiopian Custom Authority 2010). Among the import of essential oils, the majority of it, over 95%, to be consumed in the non-alcoholic or flavoured food additives. Even though the classification of import goods were not by plant source some of the products can be produced with in the country. One of the possibilities is that the production of *Eucalyptus* oil from the existing tree stands during the clear felling for poles and posts. Currently there are a number of private companies engaged in the production of essential oils from different biomass; however, these producers have no their own plantation farm. These may create a problem in sustainability of the products. The price of *Eucalyptus citriodora* oil is 513Birr per kg and 613Birr for *Cympogogen citrates.*

Conclusion

The oil of *E. grandis* and *E. saligna* can be used as industrial solvent as its major component is pinene. Report of Ermias et al (2000) that *Eucalyptus* species like *E. globulus, E. viminalis, E. triticornis, E. camaldulensis* rich with cineole, *and E. urophylla* and *E. citriodora* with citronella. Therefore the oil of these species can be used in either medicinal or perfumery with the fact that by controlling unwanted composing compounds in the oil for targeted purpose. The huge resource of the *Eucalyptus* species in the country and its use is mainly restricted to the wood only the leaf remains in the fields. Therefore, in such cases the waste material can be used in the production of essential oils. If intended in the essential oil production there should be taken further some investigation including

- leaf biomass yield and oil yield per hectare per year of selected species like *E. globulus, E. triticornis, and E. citriodora;*
- selecting and establishing plantations of high yielding species/provenances;
- Improving the efficiency of distillation process/units: the efficiency of distiller is improved through design either to reduce energy consumption or to oil yield; and
- determining the most appropriate time of harvesting age and harvesting time – the present result showed us that there is no variation in oil yield between the studied ages but on the other hand Yagodin et al (1999) on his report on Russian conifer species the yield affected by age.

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References

Anonymous. 1990. *Eucalyptus* species development and its lumber utilization in Ethiopia. (Workshop Amharic Version) Addis Ababa 1990 EC.

Anonymous. 2010. Munessa Forest–Location. http://www.munessa-forest.uni-halle.de/location/ accessed on July 1, 2010.

Davidson J. 1995. *Eucalyptus* tree improvement and breeding. Ministry of Natural Resources Development and Environmental Protection, Forestry Research Centre, Addis Ababa.

Davis K. 1989. *Eucalyptus* species and oil production: Proceedings of the *Eucalyptus* Oil Production. http://www.agric.wa.gov.au/PC_92516.html?s=1133456570. Accessed on 26-07-2010.

Erich V. Lassak 1989. The Australian *Eucalyptus* oil industry: past and Present. Proceedings of the *Eucalyptus* Oil Production. http://www.agric.wa.gov.au/PC_92519.html

Ermias Dagne, Daniel Bisrat, Markos Alemayehu and Tadele Worku 2000. Essential oils of twelve *Eucalyptus* species from Ethiopia. J.E.O.R, 12, 467-470

Ethiopian Custom Authority 2007. http://www.ethiomarket.com/ecua/index.htm accessed on 26-07-2010.

EFAP. 1994. Ethiopian Forestry Action Program. EFAP, Addis Abeba.

Friis I. 1995. Myrtaceae. In: Flora of Ethiopia and Eritrea. Eds., S. Edwards, M. Tadesse and I. Hedberg, Vol. 2, Addis Ababa.

Getinet Almaw. 2004. Utilization and Agricultural Significance of essential- and fatty-oil-bearing trees and shrubs in Ethiopia. In proceeding Conservation of genetic resources of non-timber forest products in Ethiopia. Ed. Wubalem tedesse et al 2004.

Haq Nawaz Bhatti, Zafar Iqbal, Shahzad Ali Shahid Chatha and Iftikhar Hussain Bukhari. 2007. Variations in Oil Potential And Chemical Composition of *Eucalyptus crebra* Among Different Districts Of Punjab–Pakistan. *Int. J. Agri. Biol., Vol. 9, No. 1,* 136-138.

Sheila S. Mude 1995. *Eucalyptus* oil extraction in central Victoria, Australia in Beyond timber: social, economic and cultural dimensions of non-wood forest products in Asia and the Pacific. FAO, Rome. http://www.fao.org/docrep/X5336E/X5336E00.htm

Yagodin VI, VA Virodov. 1999. Technology of biologically active substances of foliages. St. Petersburg, Russia, 80p. (in Russian)

Factors Influencing Leaf Oil Yield of *Eucalyptus* and *Corymbia* Species Growing in Ethiopia

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Abstract

Sources of variation in essential oil yields of myrtaceae family growing in Ethiopia were examined. The volatile leaf oils were analyzed from twenty mature trees growing in the arboretum of Wondo Genet. Further investigations were made on samples from managed stands of three prominent oil bearing species (*C. citriodora, E. globulus,* and *E. camaldulensis)* to understand the effects of different influencing factors on oil yield. The mean leaf oil yield of the studied species ranged from 0.20 to 5.23 % (dry weight bases). Seven out of the twenty species examined contained leaf oil below 1%, six species between 1% and 2%, three species between 2% and 3% and only four species have shown oil yield values above 3%. The mean oil yield at subgenus level varied significantly in the order of *Corymbia* (2.64%), *Symphyomyrtus* (1.82%), and *Monocalyptus* (0.79%). The result showed that, genotype is the most influential factors in determining leaf oil yield of the genera *Eucalyptus* and *Corymbia*. The influence of the season on leaf oil yield appeared to be species specific and no distinct seasonal trend of oil yield was evident from this study. Oil yield from *C. citriodora* found to be higher during summer followed by autumn and spring with lowest yield during winter. In the case of *E. globulus,* autumn appeared to provide the highest oil yield followed by summer and spring with the lowest yield recorded during winter. Oil yield from *E. camaldulensis* was higher in winter followed by spring and summer with lowest yield occurred in autumn. Leaf oil yield from juvenile leaf samples (0.49 - 4.08 %, dry weight) was higher than the corresponding mature leaves (0.77- 4.51%). The effect of leaf type was markedly significant in the case of *E. camaldulensis* than *E. globulus* and *C. citriodora*. Enriching the findings with further chemical analysis would provide a better insight on the impacts of the influencing factors in determining the overall oil production of myrtaceae family both in terms of quantity and in terms of quality.

Key Words: Leaf oil yield, season, species, subgenera, variation, volatile

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Introduction

Among various aromatic plants, the genus *Eucalyptus* consists of tall, magnificent, and evergreen trees with aromatic foliage rich in oil glands and is an excellent source of commercially important oil (Brooker and Kleinig 2006). *Eucalyptus* oil has been known for hundreds of years as anti-bacterial, anti-fungicidal and antiseptic in nature (Brooker and Kleinig 2006) and it has been harvested and traded for medicinal, perfumery and industrial uses since 1852 (Doran 1991). Moreover, its oil ranks superior in quality and has advantages over essential oils from other tree species, since it has multipurpose uses in perfumery, pharmaceutical, industries (Boland et al. 1991). *Eucalyptus* oil is also used in food flavouring, confectionery, detergent, aerosol, soap, chest rub, nasal and cough drops, inhalant, hand cleaner, perfume and as a solvent (Wood et al. 1994). *Eucalyptus* oil can also directly act as a natural insect repellent to provide protection against mosquitoes and other harmful arthropods (Batish et al. 2008).

Based upon chemical composition, the essential oils distilled from the leaves of *Eucalyptus* can be grouped into perfumery oils, medicinal oils, and industrial oils (Doran and Bell 1994; Kochhar 1998). The first group is known for their rich terpineol, citronellal, citronellol, geraniol, and eudesmol content and *E. citriodora* is known to be the main source of perfumery oil. The leaves of *E. citriodora* yield citronellal (55-80 %) and citronellol (15-20 %) as the major ingredients. Essential oils intended for medicinal use should contain about 70 to 85 % cineol or eucalyptol and obtained mainly from *E. globulus* (Kochhar 1998). *Eucalyptus* species with large content of phellandrene and piperitone are useful sources for industrial applications (Kochhar 1998). Nonetheless, findings such as from Lassak (1988) indicated that out of the more than 700 species of *Eucalyptus* probably less than 20 have ever been exploited commercially for oil production. For tropical growth conditions, species with marginal oil quality are suitably adapted (Doran and Bell 1994), which may limit countries wishing to expand *Eucalyptus* oil production. The common oil yielding *Eucalyptus* species include lemon-scented *Eucalyptus* (*E. citriodora*[2]), Tasmanian blue gum (*E. globulus*), blue mallee (*E. polybractea*), and river red gum (*E. camaldulensis*) (Green 2002). Essential oil from *Eucalyptus* species is among the world's top traded oils, and oil extracted from *E. citriodora* is one of the world's major oils in terms of trade volume (Green 2002).

Eucalypt oils are found in the leaves, fruits, buds, and bark of the tree. However, the most important commercial oil is isolated from the leaves (Boelens 1985). *Eucalyptus* leaves contain oil-bearing glands, which, if disturbed, give off aromatic odours (Doran and Bell 1994). These essential oils are complex mixtures of volatile organic compounds of possible value in industry (Doran and Bell 1994).

[2] *In this paper, being a synonym,* ***Eucalyptus citriodora / Corymbia citriodora and Eucalyptus maculata / Corymbia maculata*** *are used interchangeably*

Eucalyptus oil is obtained commercially in a relatively simple process involving steam distillation of the leaves.

The yield of oil production in any given situation will be determined by the rate at which foliage biomass accumulates between successive harvests and the concentration of oil in the leaves. On the other hand, biomass production in oil plantations is strongly influenced by the climatic and edaphic features of a given planting site, and the quality of establishment of plantings (Wildy et al. 2000; Whiffin, 1989). The bioactivity of the essential oil depends upon the type and nature of the constituents and their individual concentration (Brooker and Kleinig 2006) and the concentration of such specific constituents in the leaf are found to be highly determined by genotype (Barton et al. 1991). However, the environment may also influence the oil yields. Leaf oil yield further varies markedly between seasons and in relation to site-specific edaphic factors including season, location, climate, soil type, leaf age, fertility regime, the method used for drying the plant material, and the method of oil extraction (Doran and Bell 1994).

Eucalyptus is the most preferred and widespread plantation species for fuel wood and construction material production in Ethiopia (Pohjonen and Pukkala 1990; Zerfu 2002). The planting of *Eucalyptus* trees in Ethiopia has been expanding rapidly from state owned plantations to community woodlots and household compounds (Jagger and Pender 2000). Moreover, growing *Eucalyptus* at a farm level has become very popular among some farmers. In some cases, it partially or completely replaced annual crops (FAO 1988). The planting rate is increasing due to the high demand for eucalypt wood. The use of *Eucalyptus* leaves such as *E. globulus* as traditional medicine has been a long custom especially in the rural parts of Ethiopia. Since long time ago, it is also a custom to use leaves of *Eucalyptus* in, around mourning places to refresh the air, and as insect repellents. Similar applications of Eucalypt leaves in flavour and fragrances, as condiment or spice, in medicines, as antimicrobial / insecticidal agents, and protect stored products is found in many parts of the world (Bakkali et al. 2008). Among the number of species available in the country, *E. globulus, C. citriodora,* and *E. camaldulensis* are promoted for essential oil production at least at pilot scales. The dominant production system in Ethiopia is traditional coppice system in which the wood part is used as fuel and the leaf part is usually extracted for essential oil. According to FAO (1995), one of the main advantages of using Eucalypts species for essential oil production is its ability to respond effectively to coppicing, which is central to the economic production of oil. Despite the available potential of *Eucalyptus* species to contribute towards the country's economy in essential oil sector, the present amount of oil production is considerably small and the major end users are small-scale detergent producers. Moreover, information on essential oil production in general and on yield influencing factors in particular is highly deficient. To that end, this study aims at investigating the influence of species, season of harvest, and leaf type on essential oil yield and production from *Eucalyptus* and *Corymbia* species.

Methods

Site descriptions and sample collection

The study area, Wondo Genet, is found in the eastern African rift zone (7° 06′ N to 7° 11′ N, 38° 5′ E to 38° 07′ E), southeast of the town Shashemene. The altitude ranges between 1700 - 2100 m. The mean annual temperature varies between 17 and 19 °C and it receives a mean annual precipitation of about 1200 mm on a bimodal distribution pattern. The main rainy season occurs between June to September and the short rain, which contributes about one third of the annual rainfall, is in the period between March and April. The soil is well-drained loam and sandy loam, shallow at steep convex slopes but deep at low altitude (Eriksson and Stern 1987). Samples of adult leaves were collected from randomly selected plants both from the arboretum of Wondo Genet College of Forestry and Natural Resources (WGCF-NR) and from stands of Wondo Genet agricultural research centre. Leaf samples were labelled and sealed in a plastic bag before they were transported to the labouratory of Essential Oils Research Center (EORC) for further preparation and oil extraction.

Species: For the first part of the study, twenty different species were selected to determine leaf oil yield. These were *E. resinifera*, *E. delegatensis*, *E. paniculata*, *E. pilularis*, *E. dunni*, *E. camaldulensis*, E. *robusta*, *E. nitens*, *E. microcorys*, *E. globulus*, *E. grandis*, *E. propinqua*, *E. deanei*, *E. terticornis*, *E. saligna*, *E. botryoides*, *E. urophylla*, *E. maculata (syn. Corymbia maculata*, *E. cloeziana*, *E. citriodora (syn. Corymbia*[3] *citriodora)*. To verify the variation in leaf oil yield at the subgenus level, species are further categorized into three main subgenera (*Monocalyptus, Symphyomyrtus*, and *Corymbia)*.

Season: for the determination of impacts of season of harvest on leaf oil yield, leaf parts were collected from mature trees at the mid of each month between Dec 2005 to Nov 2006. Each month, leaf samples were collected from randomly selected trees from stands of *C. citriodora, E. globulus,* and *E. camaldulensis*.

Leaf types*:* the third segment of the study examined variation in oil yield of leaf biomass of different maturity stages. Leaf samples were collected from three species (*C. citriodora, E. globulus,* and *E. camaldulensis*). Excluding seedling leaves, samples were categorized into three different leaf types[4] (*juvenile,*

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[3]In a major taxonomic revision of the blood-wood group of eucalyptus, Hill and Johnson placed the blood-woods in a new genus Corymbia with 113 described species (Hill and Johnson, 1995). Corymbia is a genus separated from the genus Eucalyptus in 1995.

[4]In the works from Florence three leaf types are recognized in the development of Eucalyptus plant: Juvenile (including seedling leaves), intermediate and mature (adult) leaves (Florence 1996). On the other hand, in the works of Boland et al. 1984, seedling leaves and juvenile leaves are treated separately and four leaf types are recognized: seedling, juvenile, intermediate, and adult leaf types. In both works it is suggested that no definite transitional point between the phases.

intermediate and *mature)* mainly based on observation, physical characteristics and leaf size. Twelve samples from each of the three ontogenetic leaf stages were taken.

Sample preparation and oil extraction

Leaves were collected from branches harvested at approximately two-thirds of tree height. Mature leaves from each sample were removed from branches, cut into 1-2 cm^2 pieces, and 250 grams lot taken for oil extraction. Fresh leaf samples were subjected to hydro-distillation for 3 hours using a Clevenger-type apparatus to extract the oils. At the end of extraction, oils were collected and weighed. Oil yield for each sample was calculated on a leaf dry weight basis (g/g DB) and expressed in percentage dry matter. A portion of the freshly weighed leaf samples (100 g) were dried to a constant weight at 50 ^{o}C for moisture content determination. The oven-dried weight was then measured and finally the moisture content was determined and expressed on percentage basis.

Statistical analysis

Data were summarized and analyzed by species type. They were also subjected to Analysis of Variance (ANOVA) to examine the level of variation in oil yield. For ANOVA and other statistical investigations, SPSS 16 (SPSS Inc. Chicago, USA) was employed. In the case of significant results, multiple comparisons were performed using pair-wise comparison. All references to the significance are at the $P=0.05$ level unless other was stated.

Results

Variation in leaf oil yield with species

Leaf oil yield of 20 different species of the genus *Eucalyptus* and *Corymbia* growing in the arboretum of Wondo Genet College of Forestry was analyzed based on the mean percentage oil yield of each species. As presented in Table 1, species have shown large variability in oil yield.

The mean leaf oil yield of the studied species ranged from 0.20 to 5.23 % (dry weight). The highest concentrations were found in *E. globulus* (5.23%), subsequently followed by *C. citriodora* (3.57%), *E. nitens* (3.52%) and *E. dunni* (3.43%). On the other hand, *E. paniculata* (0.20%) and *E. pilularis* (0.23%) showed significantly lower leaf oil yield ($p<0.05$). Results from analysis of variance confirmed that the overall difference in oil yield between species is strongly significant ($P<0.001$).

Regarding the comparison among subgenera, results revealed the presence of significant variation in leaf oil yield between the three groups (*Symphyomyrtus, Monocalyptus,* and *Corymbia*). The yield from *Symphyomyrtus* species ranged from 0.20 – 5.23%, 0.23 - 1.65% in *Monocalyptus* and 1.7 - 3.57% in *Corymbia* (dry weight). The variation between the subgenus was not significant. Mean leaf oil yield was high in *Corymbia* species followed by *Symphyomyrtus* and *Monocalyptus* (Table 2). Likewise, strongly significant differences in oil yield amongst the individual species were found (p<0.001).

Table 1: Average leaf oil yield of 20 different myrtaceae species growing in Ethiopia

Species	Mean leaf oil yield (%w/w DB)	SD
E. paniculata	0.20*a*	0.15
E. pilularis	0.23*a*	0.50
E. cloeziana	0.49*ab*	0.15
E. urophylla	0.50*ab*	0.36
E. terticornis	0.55*abc*	0.52
E. propinqua	0.65*abc*	0.85
E. grandis	0.99*bcd*	0.21
E. microcorys	1.17*cde*	0.26
E. robusta	1.19*cde*	0.36
E. camaldulensis	1.51*def*	0.27
E. resinifera	1.61*defg*	0.38
E. delegatensis	1.65*efg*	0.40
C. maculata	1.70*efg*	0.21
E. saligna	2.00*fgh*	0.52
E. botryoides	2.20*gh*	0.23
E. deanei	2.48*h*	0.57
E. dunni	3.43*i*	0.28
E. nitens	3.52*i*	0.49
C. citriodora	3.57*i*	0.21
E. globulus	5.23*j*	0.21

Note: Each value for the species represents the mean oil yield of the samples collected from mature trees. Values designated by different letters (a-j) denote significant difference (p<0.05) in yield between species using Tukey's pair-wise comparison. Species sharing the same letter are not significantly different at P < 0.05.

Table 2: Variation in leaf oil yield between different subgenera

	Mean oil yield	SD
Monocalyptus	0.94a	0.78
Symphyomyrtus	1.82ab	1.37
Corymbia	2.64b	1.02

Note: Each value for the subgenera represents the mean oil yield of the samples collected from mature trees in Ethiopia. Subgenera sharing the same letter are not significantly different at P < 0.05.

Variation in leaf oil yield with season

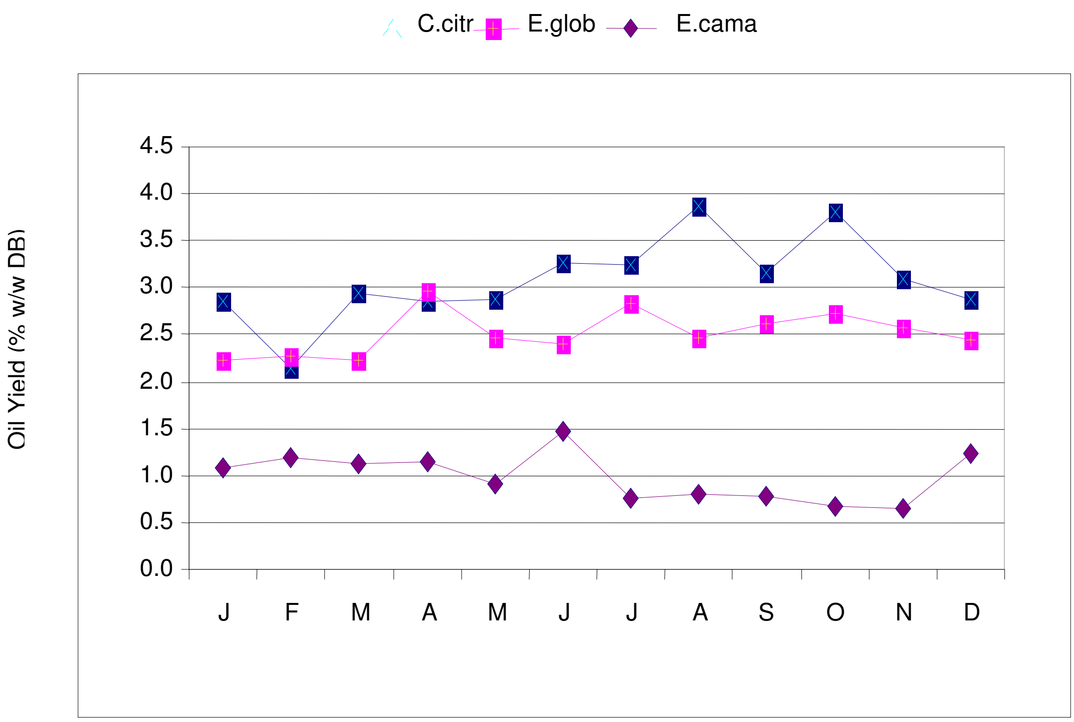
To understand the differences in oil yield with season, samples from three different species (*C. citriodora, E. globulus, and E. camaldulensis*) were analyzed based on mean leaf oil yield. The monthly average oil yield is illustrated in Figure 1. Different degrees of variation in oil yield occurred throughout the seasons. Results from ANOVA analysis revealed that seasonal variation does not alter oil yield significantly ($p>0.05$). Across the seasons, *C. citriodora* showed significantly higher oil yield than *E. globulus* and *E. camaldulensis*. On the other hand, having a maximum yield of 1.5 %, which is far below the lowest values recorded for the other two species, *E. camaldulensis* displayed significantly low leaf oil yield (Figure 1).

Table 3: Seasonal variation in oil yields (%) among three different species

Species	Spring	Summer	Autumn	Winter
C. citriodora	2.89	3.46	3.35	2.62
E. globulus	2.55	2.56	2.63	2.32
E. camaldulensis	1.06	1.01	0.70	1.17

Oil yield from *C. citriodora* was highest during summer followed by autumn and spring and showed lowest yield in winter (Table 3). In the case of *E. globulus,* autumn appeared to provide the highest oil yield followed by summer and spring with lowest yield recorded during the wintertime. Contrary to the other two species, oil yield from *E. camaldulensis* was high in winter followed by spring and summer with lowest value harvested in autumn. Hence, no obvious seasonal pattern in leaf oil yield between seasons is evident from the current study.

Figure 1: Monthly mean oil yield of three main essential oil producing *Eucalyptus* species in Ethiopia



Variation in leaf oil yield with leaf type

To determine the impacts of leaf types (juvenile, intermediate, mature) on oil yield, data were analyzed from three prominent essential oil producing species in Ethiopia. Results showed that the response in leaf oil yield due to differences in leaf type varied among species. In the case of *C. citriodora* and *E. globulus*, no significant difference in oil yield was evident between leaf types, whereas, yield variation was significant in *E. camaldulensis*. The mean oil yield of juvenile leaf samples ranged from 0.49 - 4.08 % (dry weight); 0.77- 4.14% in the intermediate leaf samples and mature leaf samples ranged from 0.77-4.51. *C. citriodora* had the highest mean oil yield values for both juvenile (3.0%); intermediate (2.98%) and mature (2.95%) leaves amongst the three species examined; and *E. camaldulensis* showed the lowest leaf oil yield (1.42% for juvenile; 1.11% for intermediate and 0.9% for mature leaves). Furthermore, juvenile and adult leaves of *E. camaldulensis* had shown significant differences ($P<0.05$) in oil yield: juvenile leaves had higher oil production than adult leaves.

The variation in oil yield between the different leaf types was significant in the case of *E. camaldulensis,* however, no significant differences were observed between the leaf types *C. citriodora* and *E. camaldulensis.* Considering the overall performance of all leaf types of the three species, *C. citriodora* provided the highest oil yield and *E. camaldulensis* provided the lowest oil yield for all leaf types.

Discussion

Genotype is found to be one of the main influential factors of leaf oil yield. Oil yield from the 20 species examined for this study differed significantly. Many previous studies including those of Barton et al. (1991), Doran, and Matheson (1994), reported that leaf oil content of *Eucalyptus* is strongly controlled by genotype. Species growing in Wondo Genet area had shown a large variation in mean oil yield ranging from 0.2 - 5.23 %. According to Doran and Bell (1994), to consider a species for commercial oil production and development, it should normally contain abundant oil (equal to approximately 3 % dry weight). In this study, seven out of the twenty species found to contain leaf oil below 1%, six species between 1 and 2%, three species between 2 and 3% and only four species possessed oil yields above 3% on a dry weight basis. Among the major essential oil producing tree species growing in Ethiopia, *E. globulus and C. citriodora* with respective leaf oil yield of 5.23 % and 3.57 % they strengthens the economic feasibility of using them for essential oil production. In case of *E. camaldulensis*, the yield (1.51 %) is low for economic production and hence better yielding varieties has to be found. Depending on the market demand and presence of the required chemical ingredient, *E. nitens (3.52%)* and *E. dunni* (3.43%) can also be considered for essential oil production in the country.

Despite the fact that all the 20 species found at the same site growing under similar condition, they revealed a variable leaf oil yield. The result indicates that such variation arises from genotypic differences than environmental, edaphic, and other management factors. The result agrees with a number of early observations by Penfold et al. (1948), Williams and Home (1988) and Murtagh and Etherington (1990) who showed that trees sampled from a similar location can differ in oil yield. The significant variation in leaf oil yield between species observed in this study suggests that selection of the right species is an important first step before commencing essential oil production.

Mean leaf oil yield from *Corymbia* species is greater than that of *Symphyomyrtus* species; and *Monocalyptus* species appear to have the lowest oil yield (Table 2). The findings are comparable with a similar study conducted in Tasmania, which has confirmed the mean oil yield from *Monocalyptus* (0.1-3.1%) (Li et al. 1995) is lower than *Symphyomyrtus* (0.8-5.3%) species (Li et al. 1996). Nevertheless, the reason behind those differences among the subgenera is not well understood. The lack of statistical significance between the groups seems to happen due to the uneven and insufficient replication of samples under each subgenus.

The present study showed no distinct seasonal pattern in oil yield of the studied species. Similar results have been reported in some previous works. For example, Congrong et al. (2000) found that highest emission rates of volatile leaf oils from *Eucalyptus* were common in summer and lowest in winter. On the other hand, some Eucalypt species showed higher emission rates in autumn than in spring and still others followed a reverse pattern. In another study, leaf oil from *E. camaldulensis* revealed no significant difference between summer and winter periods (Doran and Brophy 1990). Thus, the pattern is presumed to be site and species specific. Though there is no distinct trend in seasonal variation, leaf oil was found to fluctuate across seasons. Many prior studies proved that oil yield changes in response to variations in the environmental conditions, mainly season (Williams and Home 1998; Murtagh and Etherington 1990). This may depend on the prevailing climatic conditions of the site of origin and if oil concentration is related to tree water status then the values may vary accordingly.

Oil yield from *C. citriodora* was highest during summer and lowest during winter. Similar findings have been reported by Doran and Bell (1994) and Da Silva et al. (2006). Sangwan et al. (2001) also attested that leaf oil yield is increased in the wet period following a dry season and then fell with approaching to the next dry season. The other possible reason would be greatest accumulation of recently mature leaf biomass with high oil yield values expected to occur in the canopy when light temperature and water are not limiting growth (List et al. 1995) which coincides with the summer time in the study area.

The oil yield from *E. globulus* was highest during autumn, which could be attributed to the possibility for the species to exploit the favourable growth conditions due to the short rainy season in the study area. As said earlier and asserted by many other researchers, oil yield tend to be lower during winter. In that respect, it appeared that *E. camaldulensis* followed a different path from the usual trend showing highest oil yield during the winter period. However, it is presumed that it benefited from a typical climatic characteristics of the study area in which the rain and favourable growth condition usually be extended towards the late summer and early autumn seasons.

Furthermore, due to prevalent dry periods in the country, leaching of oil might be substantial from drought-affected foliage during late summer and autumn, thus exacerbating seasonal differences. As such, phenomena usually happen in irregular manner, no clear variation was observed between seasons. The other possible reason is the influence of climatic differences on efficiency of enzymes, which could possibly alter oil yield. Nonetheless, generalization of such results requires an investigation based on a long term cumulative data.

The variation in oil yield among the different leaf types was not significant in cases of *C. citriodora* and *E. globulus.* The result was consistent with the findings of Li et al. (1996) in which juvenile leaves were not significantly different from that of intermediate and mature leaves. Contrary to the other two species, *E. camaldulensis* had shown significant differences ($P<0.05$) in oil yields between juvenile and adult leaves, with the juvenile oil yield greater than that of mature leaves. In some previous works, it was found that leaf oil is related to physiological age of leaves (Doran and Bell 1994). Beyond that, in the works of Weiss (1977), leaf oil yield from *Eucalyptus* has been found to be independent of leaf types. In general, even though it has been said that aged leaves yield less oil than recently matured leaves (Doran 1991), there is a high level of variability in the direction and extent of these changes.

The variation among leaf types of the three species may have ontogenetic origin. However, as juvenile leaves were usually sampled from beneath the forest canopy, difference in the environmental conditions between juvenile, and intermediate and mature leaf samples are expected. Hence, whether the yield variations observed in the present study relates to environmentally induced factors or has a true ontogenetic base has to be tested against a range of species and habitats.

Yield results from different leaf types showed variable trends amongst species of the same subgenus. However, the variation was significant only in the case of *E. camaldulensis in which* juvenile leaves provided higher oil yield than mature leaves. The result agrees with what has been reported by Li et al. (1995) in which they identified that in many Tasmanian species, juvenile leaves tend to produce higher oil yield than mature leaves (Li 1993). The findings suggest that the pattern of ontogenetic change in oil yield may be an important difference between species. A related result was obtained on *C. citriodora*, which has proved that young leaves frequently have greater oil content than mature ones (Sangwan et al, 2001). Owing that older leaves in the canopy are prone to damages by different causes including drought (Wildy et al. 2000); the finding may be attributed to those damages and to the leaching of the volatile leaf oils. Moreover, mature leaves are more scleromorphic and thus may have more tissue that does not contain oil glands.

Conclusions

Among the major essential oil producing tree species growing in Ethiopia, *E. globulus and C. citriodora* appear to be promising species for essential oil production. *E. nitens* and *E. dunni* also showed a good potential to be considered as candidate species for leaf oil production depending on the presence of the required chemical ingredients.

From the present study, it can be concluded that genotype is the most influential factor in determining leaf oil yield of *Eucalyptus* and *Corymbia* species. Hence, it indicates that species selection is crucial prior to embarking into commercial essential oil production from *Eucalyptus* and *Corymbia* species; because a considerable variation in oil yield between species would largely affect the profitability of *Eucalyptus* plantation and overall productivity. The influence of season on leaf oil yield appeared to be species specific and no distinct trend of oil yield due to season was evident from the study. Hence, the present finding suggests that generalization of seasonal trends in oil yields needs to be investigated based on a long-term cumulative data set.

The other important finding in the present study is that the juvenile leaf samples of all three species produced significantly higher oil yields than the mature leaf samples. Hence, avoiding aged leaves and collecting recently matured leaves can significantly reduce the variation that may arise due to differences in leaf types. In general, it is recommended that enriching the findings on leaf oil yield with chemical analysis could provide a better insight of the influencing factors in affecting the overall oil production, both in quantity and quality.

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References

Bakkali F, S Averbeck, D Averbeck, M Idaomar. 2008. Biological effects of essential oils—a review. Food Chem. Toxicol. 46, 446–475.

Barton AFM, PP Cotterill, MIH Brooker. 1991. Heritability of cineole yield in *Eucalyptus Kochii*, a malle species endemic to Western Australia. Silv. Gen. 40, 37-38.

Batish DR, HP Singh, RK Kohli, S Kaur. 2008. *Eucalyptus* essential oil as a natural pesticide. Forest Ecol. Manage. (In Press), doi:10.1016/j.foreco.2008.08.008

Boelens M.H, 1985. Essential oils and aroma chemicals from *Eucalyptus* globulus labill. Perf. and Flav. 9, 1-14.

Boland DJ, MIH Brooker, GM Chippendale, N Hall, BPM Hyland, RD Johnston, DA Kleinig, JD Turner. 1984. Forest Trees of Australia. Thomas Nelson and CSIRO: Melbourne.

Boland DJ, JJ Brophy, APN House. 1991. *Eucalyptus* Leaf Oils. Use, Chemistry, Distillation and Marketing. Inkata Press, Melbourne/Sydney.

Brooker MIH, DA Kleinig. 2006. Field Guide to *Eucalyptus.* Vol. I . South-eastern Australia, Third edition. Bloomings, Melbourne, Victoria, Australia. 383 p

Congrong H, F Murray, T Lyon. 2000. Seasonal variations in monoterpene emissions from *Eucalyptus* species, Chemosphere: Global Change Science 2, 65-76.

Da Silva PHM, JO Brito, FG Da Silva Junior. 2006. Potential of eleven *Eucalyptus* species for the production of essential oils. Sci. agric. (Piracicaba, Braz.*)*, 63, 85-89.

Doran JC. 1991. Commercial sources, uses, formation, and biology. *In:* Boland DJ, JJ Brophy, APN House (eds.), *Eucalyptus* Leaf Oils, Use, Chemistry, Distillation and Marketing. Inkarta Press, Melbourne, pp. 11–28.

Doran JC, JJ Brophy. 1990. Tropical red gums - a source of 1,8-cineole-rich *Eucalyptus* oil. New For.4, 25-46.

Doran JC, RE Bell. 1994. Influence of non-genetic factors on yield of monoterpenes in leaf oils of *Eucalyptus camaldulensis*. New For. 8, 363 - 379.

Doran JC, AC Matheson. 1994. Estimates of genetic parameters and gains expected from selection for monoterpene yields in *Eucalyptus camaldulensis* plantations. New For. 8, 155-167.

Eriksson H, Stern. 1987. "A soil study at Wondo Genet Forestry Resources Institute, Ethiopia". M. Uppsala, Sweden.

FAO. 1988. Food and Agriculture Organization of the United Nations, *Eucalyptus* dilemma, Rome.

FAO. 1995. Non Wood Forest Products: Flavors and Fragrances of plant origin. Food and Agriculture Organization of the United Nations, Rome.

Florence RG. 1996. Ecology and Silviculture of Eucalypt Forests. CSIRO publishing.

Green C, 2002. Export Development of Essential Oils and Spices by Cambodia. C.L. Green Consultancy Services, Kent, UK.

Hill KD, LAS Johnson. 1995. Systematic studies in the eucalypts - 7. A revision of the bloodwoods, genus *Corymbia* (Myrtaceae). Telopea 6: 185–504.

Jagger P, J Pender. 2000. The role of trees for sustainable management of less-favoured lands: the case of *Eucalyptus* in Ethiopia. Environment and Production Technology Division, International Food Policy Research Institute, EPDT Discussion Paper No. 65. Washington, DC,

Kochhar SL. 1998. Economic Botany in the Tropics, 2nd Edition. Macmillan India Ltd., New Dehli.

Lassak EV. 1988. The Australian *Eucalyptus* oil industry, past and present. Chem. Aust.55, 396-398.

Li H, 1993. Photochemistry of *Eucalyptus* spp. and its role in insect-host-tree selection. Ph.D. thesis, University of Tasmania, Australia.

Li H, JL Madden, BM Potts. 1995. Variation in volatile leaf oils of the Tasmanian *Eucalyptus* species I. Subgenus *Monocalyptus.* Biochem. Syst Ecol. 23, 299-318.

Li H, JL Madden, BM Potts. 1996. Variation in volatile leaf oils of the Tasmanian *Eucalyptus* species I. Subgenus *Symphyomyrtus.* Biochem. Syst Ecol. 24, 547-569.

List S, PH Brown, KB Walsh. 1995. Functional anatomy of the oil glands of *Melaceuca altemifolia* (Myrtaceae). Aust.J.Bot.43, 629-641.

Murtagh GJ, RJ Etherington. 1990. Variation in oil concentration and economic return from tea-tree (*Melaleuca alternifolia* Cheel) oil. Austr. J. Exp. Agric.30, 675–679.

Penfold AR, FR Morrison, HHG McKern. 1948. Studies in the physiological forms of the Myrtaceae. Part II: The occurrence of physiological forms in *Melaleuca alternifolia* Cheel. In: Researches on Essential Oils of the Australian Flora. Vol. I, Part II. Museum of Technology and Applied Science, Sydney, pp. 18–19.

Pohjonen V, T Pukkala. 1990. *Eucalyptus globulus* in Ethiopian forestry. Forest Ecology and Management. 36, 19–31.

Sangwan NS,AHA Farooqi, F Shabih, RS Sangwan. 2001. Regulation of essential oil production in plants. Plant Growth Regulation. 34, 3-21.

Weiss EA. 1997. Essential oil crops. CAB International, pp 24-58.

Whiffin T. 1982. Variation and evolution in the genus *Flindersia* (Rutaceae). Review of methods for geographic variation analysis of volatile oil data. Aust. J. Bot. 30, 645-657.

Wildy DT, JS Pate, JR Bartle. 2000. Variation in composition and yield of leaf oils from alley-farmed oil mallees (*Eucalyptus* spp.) at a range of contrasting sites in the Western Australian wheatbelt. Forest Ecology and management. 134, 205-217.

Williams LR, VN Home. 1988. Plantation production of oil of *Melaleuca* (tea tree oil) — a revitalized Australian essential oil industry. Search 19, 294–297.

Wood I, P Chudleigh, K Bond. 1994. Developing New Agricultural Industries - Lessons From the Past, Rural Industries Research and Development Corporation, Research Paper Series No. 94/1, 86-92.

Zerfu H. 2002. Ecological impact evaluation of *Eucalyptus* plantations in comparison with agricultural and grazing land-use types in the Highlands of Ethiopia. Ph.D. dissertation, Institute of Forest Ecology, Vienna University of Agricultural Sciences, Vienna, Austria, 1–81.

Effects of extracts from leaves of *Eucalyptus globulus* Labill. on seed germination and early growth of *Olea europaea* L. subsp. *cuspidata*

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Abstract

There is sufficient information that shows natural regeneration of some indigenous woody plants inside plantations of *Eucalyptus* species. In contrast, it is argued that species of *Eucalyptus* suppress the germination and growth of various tree species. In this study, effects of extracts from *E. globulus* leaves on seed germination and early growth of *Olea europaea* subsp. *cuspidata* were investigated under laboratory conditions. The aqueous extracts of *E. globulus* were assayed at 1, 5, 10, 25 and 50% to test for their allelopathic effects. All the aqueous extracts except 50% extract increased germination percent of seeds and lengths of the emerging radicles and plumules compared to the control. The extracts from 1 to 25% increased percentage germination by 4-18%, radicle length by 12-59% and plumule length by 6-27%. Fifty percent leaf extract reduced germination by 11% and plumule length by 13%, while it increased radicle length by 3%. Furthermore, the aqueous extracts had no effect on mean germination time of the seeds. Our results revealed that, given its regeneration ecology and the stimulatory effects of leaf extracts of *E. globulus*, *O. europaea* can form seedling banks, i.e. population of slowly growing seedlings, inside plantations of *E. globulus*. This, therefore, suggests that plantations of *E. globulus* can play significant roles for the restoration of *O. europaea* forest in the degraded areas of Ethiopia.

Keywords: allelopathy, plantation, restoration, stimulatory effect

Introduction

Allelopathy is an interaction among plants by means of chemical compounds that are released into the environment and exists widely in natural plant communities (Gressel and Holm, 1964). The interaction includes both inhibition and promotion (Rice, 1984). Allelochemicals can be present in any part of the plant like leaves, stems, roots, flowers, and seeds. They can also be found in the surrounding soil. They are released into the environment by several mechanisms such as leaching from the above ground parts, root exudation, stem flow, volatilization, and dry residue decomposition.

In Ethiopia, forest plantations consist of, mainly, species of *Eucalyptus.* Due to their high popularity currently, there is rapid expansion of plantations of *Eucalyptus* species in the highlands of Ethiopia. However, the expansion of *Eucalyptus* seems to cause great concern as various *Eucalyptus* species are claimed to have detrimental effects on indigenous plant communities (del Moral and Muller, 1969; May and Ash, 1990; Lisanework Nigatu and Michelsen, 1993) even though the effect may depend on many factors including site conditions and management practices (May and Ash, 1990; Feyera Senbeta, 1998; Yitebitu Moges, 1998; Eshetu Yirdaw, 2002; Desalegn Tadele, 2004).

The effects of allelochemicals on germination and growth of plants may occur through their interference in cell division, energy metabolism, mineral uptake, and biosynthetic processes (Rice, 1984). Through these actions, allelochemicals may play a role in shaping plant community structure. *Eucalyptus* species have been reported to contain chemicals and these chemicals have inhibited the growth of some plants (del Moral and Muller, 1970; Jayakumar et al., 1990). However, previous investigations of the allelopathic potential of the trees have primarily been concerned with agricultural crops (Lisanework Nigatu and Michelsen, 1993; Selamyihun Kidanu, 2004). Moreover, in Ethiopia, little attention has been given to allelopathy as determinant of crop production and productivity (Selamyihun Kidanu *et al*., 2004, 2005; Tilashwork Chanie, 2009) and plant community structure (Feyera Senbeta, 1998; Yitebitu Moges, 1998; Eshetu Yirdaw, 2002; Mulugeta Lemenih, 2004; Tilashwork Chanie, 2009).

The objective of this study was, therefore, to investigate the effects of leaf extracts of *Eucalyptus globulus* on germination and early growth of the plumules Shoot and radicles of seeds of *Olea europapea* subsp. *cuspidata* (hereafter referred to as *Olea*) in order to identify the ecological significance of allelopathy in the establishment of *O. europaea* in plantations of *E. globulus*.

Materials and Methods

Extract preparation

Mature leaves were collected from trees of *E. globulus* planted around Bahir Dar University, northern Ethiopia. The leaves were sun-dried and ground into minute sizes using a vegetative grinder.

The aqueous extracts were prepared by soaking 20 g of dried leaves (powder) in 400 ml of distilled water using 500 ml container. Each container was shaken for 10 seconds and kept at room temperature for 24 hours. The resulting aqueous extracts were filtered through two layers of Whatman No. 1 filter paper and then some extracts were diluted to generate concentrations of 1, 5, 10, 25 and 50% and stored in the dark place in conical flasks until required (Watson, 2000; Hoque *et al*., 2003).

Germination test

Seeds of *Olea* were obtained from the Forestry Research Center (FRC), Addis Ababa. The seeds were de-coated and surface sterilized with 15% sodium hypochlorite for 20 min (Tinnin and Kirkpatrick, 1985). They were then rinsed with distilled water. Four replicates, 25 seeds each, were prepared for treatment using sterile Petri dishes (90 mm) lined with sterile Whatman no. 1 filter paper. Seeds were evenly distributed on the filter paper and 4 ml of each extract solution was added to each Petri dish. The 100 seeds, in four replicate of 25 seeds, used as control were treated with only distilled water of the same amount. Moisture in the Petri dishes was maintained by adding 2 ml of aqueous extract or distilled water as required. The experiment was carried out until no seed germinated for a week (a total of 20 days). The seeds were considered germinated upon the emergence of the radicle. Germinated seeds were counted daily and the lengths of the radicles and plumules were measured at the end of the experiment.

Data Analyses

The results were quantified as germination capacity, mean germination time and radicle or plumule extension (% of control). Germination capacity (GC), mean germination time (MGT), relative elongation ratio (RER) of radicle and plumule and percent inhibition or stimulation were calculated following Rho and Kil (1986), Bewley and Black (1994) and Saxena *et al*. (1996) as:

GC (%) = (No. of germinated seeds / total No. of seeds sown) x 100

$$\textbf{MGT}\ (\text{days}) = \sum (t_i n_i) / \sum n_i$$

Where t_i is the number of days starting from the date of sowing and n_i is the number of seeds germinated on each day

RER of shoot = (Mean shoot length of tested plant/Mean shoot length of control) x 100

RER of root = (Mean root length of tested plant/ Mean root length of control) x 100

Percentage inhibition or stimulation = 100 – (percentage germination in aqueous extracts/percentage germination in distilled water) x 100

Percentage data were arcsine transformed before analysis (Zar, 1984), all the data were subjected to Analyses of Variance (ANOVA) to identify statistically significant differences in mean percentage germination, germination time, and growth in lengths of radicle and plumule among the seeds treated with different leaf extract solutions of *E. globulus* and the control. Significance levels among treatment means were compared using Tukey's Honestly Significant Difference Test at 5% level of significance.

Results

Effect of leaf extracts on germination of seeds

Compared to the control, the treatments from 1 to 25% stimulated germination 17.7% to 4.4% (Table 1). The percentage germination for these treatments ranged from 88% to 78%. Only some 75% of the seeds of the control were able to germinate (Fig. 1). Fifty percent extract reduced germination by 11.1%.

Table 1 Mean seed germination time (MGT) (days) and percentage of inhibition (-) or stimulation (+) of seed germination of *O. europaea* subsp. *cuspidata* subjected to treatments with different concentrations of leaf extracts of *E. globulus*.

Extract concentration (%)	MGT ± SD	Inhibition/stimulation (%)
0	8.6 ± 0.13[a]	
1	8.1 ± 0.06[a]	+17.7
5	8.5 ± 0.20[a]	+15.6
10	8.5 ± 0.25[a]	+13.3
25	9.0 ± 0.49[a]	+4.4
50	9.4 ± 0.56[a]	-11.1

Values in the same column with similar letters are not significantly different (P=0.05).

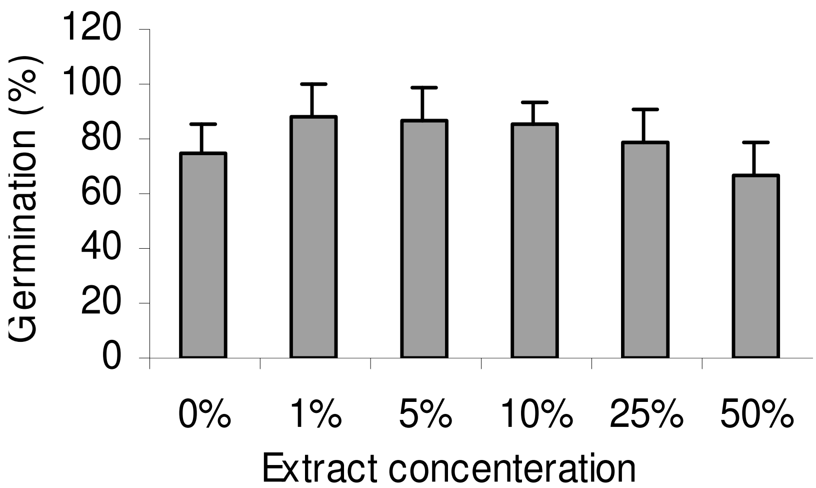

Figure 1. Germination capacity (%) of *O. europaea* subsp. *cuspidata* in response to treatments with different concentrations of leaf extracts of *E. globulus* (Bars indicate ± SD).

The different concentrations of leaf extracts from *E. globulus* did not significantly (P = 0.147) alter average time of seed germination (Table 1). However, increased extract concentration resulted in somewhat longer mean germination time.

Germination was relatively faster for seeds treated with lower leaf extract concentrations (1, 5 and 10%) than the others.

In all the treatments, including the control, germination started within 4 days and stopped within 14 – 16 days (Fig. 2). Lower extract solutions (1, 5 and 10%) speeded up germination compared to the control and other treatments.

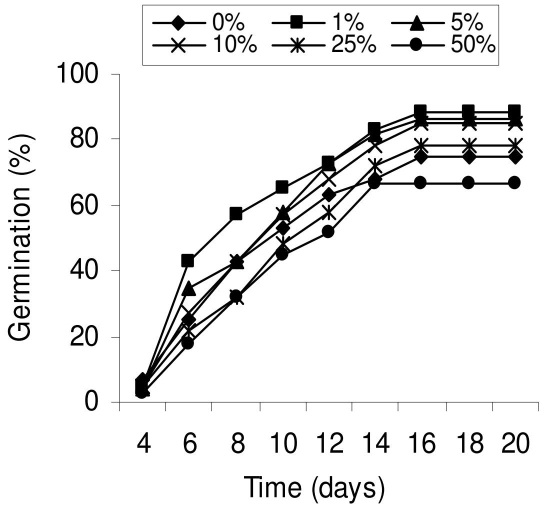

Figure 2. The time taken by seeds of *O. europaea* subsp. *cuspidata* to germinate after treated with different concentrations leaf extracts of *E. globulus*.

Effect of leaf extracts on growth of radicle and plumule

The seeds treated with the leaf extracts developed longer radicles than those of the control after 20 days from the start of the experiment (Table 2). Seeds treated with various concentration, except 50% extract, also had longer plumule. Fifty percent concentration of the leaf extract reduced plumule length. Radicle and plumule length tended to decrease with increasing extract concentration. At lower concentrations, i.e. 1 and 5 %, the seeds formed significantly longer roots (P = 0.001) and shoots ($P < 0.01$). Maximum elongation ratios (RER) of roots (159.1%) and shoots (127.1%) were found at 1% concentration and the minimum were (102.7 and 87.2% for roots and shoot, respectively) at 50% treatment (Fig. 3).

Table 2 Root and shoot elongation (mm) of seeds of *O. europaea* subsp. *cuspidata* in response to treatments with different concentrations of leaf extracts of *E. globulus* (Mean ± SD)

Extract concentration (%)	Root	Shoot
0	14.9 ± 4.5[a]	18.8 ± 5.9[a]
1	23.7 ± 10.8[b]	23.9 ± 7.5[b]
5	21.8± 7.1[b]	23.6 ± 5.7[b]
10	18.9 ± 8.2[a]	22.4 ± 7.3[a]
25	16.7 ± 6.3[a]	20.0 ± 6.5[a]
50	15.3 ± 7.9[a]	16.4 ± 3.9[a]

a, not significantly different; b, significantly different (P=0.05) from controls according to Tukey's HSD Test

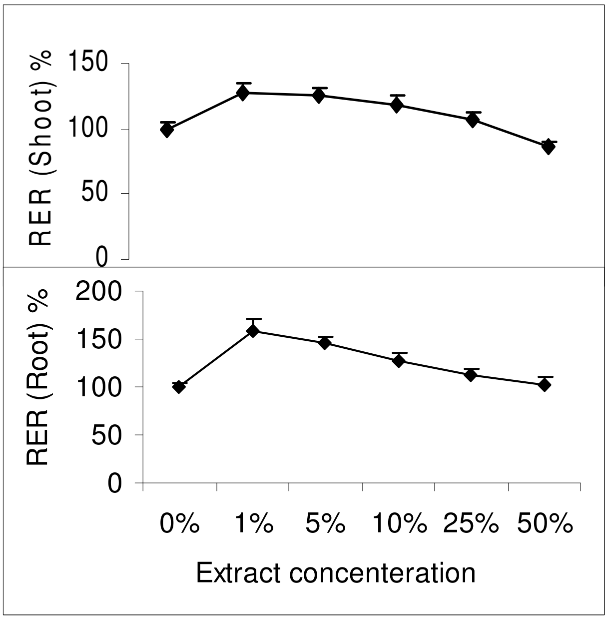

Figure 3. Relative elongation ratio of shoots and roots of seeds of *O. europaea* subsp. *cuspidata* treated with different concentrations leaf extracts of *E. globulus*.

Discussion

It is interesting that although 50% dilution seemed to reduce germination and plumule elongation of seeds of *Olea*, concentrations below this level promoted both germination and extension of radicle and plumule. This indicates that the *Eucalyptus* leaf extracts exerted a positive action affecting germination capacity of the seeds and growth of their plumules and radicles. However, the influences of the extracts were more or less proportional to concentrations: the magnitude of stimulation decreased with increasing extract concentration.

The highest concentration (i.e. 50% extract) slightly reduced percent germination and extension of plumule. The mechanism for the reduction could be attributed to osmotic effects of the extract. In their investigation on allelopathic properties of coffee, Masresha Fetene and Solomon Habtemariam (1995) reported osmotic effects of high concentration extracts inhibit 10% to 20% of lettuce seed germination. Haugland and Brnand (1996) also showed that osmotic potential of solutions inhibit germination and growth of several plant species. If the reduction is due to allelochemicals, they may not cause the same effect in the field since concentration of these substances is probably greater in aqueous extracts than under natural conditions in the field (Rice, 1984); or they may be bound and made unavailable by soil particles (Dalton *et al*., 1983); or decay may reduce allelopathic effects of leaf litter (May and Ash, 1990). Selamyihun Kidanu (2004) also showed that allelochemicals from decomposing litter fall did not accumulate in sufficient concentration under *Eucalyptus* tree canopy to affect seed germination and root growth of the test plants.

The extracts did not delay the onset of germination. In all extract concentrations and the control, germination commenced four days after the date of sowing. The germination in this study started earlier compared to the one reported by Legesse Negash (1993), which was within 5-7 days. The early onset of germination may have resulted because of the relatively high room temperature. Moreover, the different concentrations of leaf extracts did not significantly affect mean germination time of the seeds. However, increasing extract concentration resulted in a delay in germination.

E. globulus has been reported to contain allelochemicals that can suppress growth of other plants (Jayakumar *et al*., 1990; May and Ash, 1990; Lisanework Nigatu and Michelsen, 1993; Babu and Kandasamy, 1997).These chemicals are highly important to study the vegetation composition as they can alter species composition (del Moral and Muller, 1969; May and Ash, 1990). In this study, the aqueous leaf extracts of *E. globulus* below 50% solution stimulated germination of seeds and growth of their radicles and plumules. This may be due to the case that allelopathic effects are selective and can cause diverse effects on different plants (Stowe, 1979; Rice, 1984; Cruz-Ortega *et al*., 2002; Morita *et al*., 2005). However, more investigations are required to understand better the underline causes and actual mechanisms involved in the differential effects of the leaf allelochemicals on different species.

It is possible that leaves of *E. globulus* will provide some benefit to the germination of seeds and early growth of seedlings of *Olea*. The results showed that *Olea*, with stimulated germination and seedling growth, is less susceptible to allelopathic effects of *E. globulus*. So, seeds of *Olea* may germinate and develop into seedlings close to *E. globulus* trees. This has already been demonstrated by several studies (Feyera Senbeta, 1998; Yitebetu Moges, 1998; Demel Teketay, 2000; Feyera Senbeta and Demel Teketay, 2001, 2002; Feyera Senbeta et al., 2002; Mulugeta Lemenih and Demel Teketay, 2004; Mulugeta Lemenih et al., 2004). For instance, Eshetu Yirdaw (2002) reported the recruitment of *Olea* in plantations of

E. globulus in the highlands of Ethiopia. Desalegn Tadele (2004) also documented the establishment of secondary indigenous vegetation inside *Eucalyptus* plantations. Moreover, the species is shade-tolerant (Masresha Fetene and Yonas Feleke, 2001), and its seed germination apparently occurs in undisturbed forest (Demel Teketay,1996). The regeneration ecology of the species coupled with the stimulatory effects of leaf extracts of *E. globulus* suggest that *Olea* can form seedling banks, i.e. population of slowly growing seedlings (Demel Teketay, 1996), inside *E. globulus* plantations. Currently, the species is under heavy exploitation and mainly found within protected areas, such as church compounds (Legesse Negash, 1990; Alemayehu Wassie, 2002, 2007; Alemayehu Wassie et al., 2005). As a result, plantations of *E. globulus* can play significant roles for the restoration of *Olea* forests in the degraded highland areas of Ethiopia.

The results of this study showed that *Olea* responded positively to the water extracts from leaves of *E. globulus*. Though labouratory bioassays are important to single out allelopathic effects, it is important to examine the significance of these results under field conditions. Moreover, the allelopathic effects of *Eucalyptus* species may be species specific and concentration dependent. Thus, testing several species of native plants in various concentrations would provide broader assessment of allelopathic effects of *Eucalyptus* on the establishment of indigenous vegetations in *Eucalyptus* plantations.

References

Alemayehu Wassie. 2002. Opportunities, constraints and prospects of the Ethiopian Orthodox Tewahido Church in conserving forest resources: the case of churches in South Gonder, Northern Ethiopia. MSc thesis, Swedish University of Agricultural Sciences, Skinnskatteberg, Sweden.

Alemayehu Wassie. 2007. Ethiopian church forests: opportunities and challenges for restoration. PhD thesis in Wageningen University, The Netherlands.

Alemayehu Wassie, Demel Teketay, N Powell. 2005. Church forests in North Gonder Administrative Zone, Northern Ethiopia. *Forests, Trees and Livelihoods* 15: 349-373.

Babu RC, OS Kandasamy. 1997. Allelopathic effects of *Eucalypus globulus*Labill. on *Cyperus rotundus* L. and *Cynodon dactylon* L. *Journal of Agronomy and Crop Science* **179**: 123-126.

Bewley JD, M Black. 1994. Seeds: physiology of development and germination. Plenum Press, New York, 445 pp.

Cruz-Ortega R, D Ayala-Cordero, AL Anaya. 2002. Allelochemical stress produced by aqueous leachate of *Callicarpa acuminate*: effects on roots of bean, maize and tomato. *Physiologia Plantarum* **116**: 20-27

Dalton BR, U Blum, SB Weed. 1983. Allelopathic substances in ecosystems: Effectiveness of sterile soil components in altering recovery of ferulic acid. *Journal of Chemical Ecology* **9**: 1185-1201.

del Moral R, CH Muller. 1970. The allelopathic effects of *Eucalyptus camaldulensis*. *American Midland Naturalist* **83**: 254-282.

del Moral R, CH Muller. 1969. Fog drip: A mechanism of toxin transport from *Eucalyptus globulus*. *Bull. Torrey Bot. Club* **96**: 467-475.

Demel Teketay, . 1996. Seed ecology and regeneration in afromontane forests of Ethiopia. Acta Universitatis Agriculture Sueciae, Silvestria, 4. Umeå, Sweden.

Demel Teketay. 2000. Facts and experience on eucalypts in Ethiopia and elsewhere: ground for making wise and informed decision. *Walia* 21: 25-46.

Desalegn Tadele. 2004. Growth and establishment of seedlings of indigenous species inside plantations and the adjacent natural forest. MSc thesis, Addis Ababa University, Addis Ababa.

Eshetu Yirdaw. 2002. Restoration of native woody species using plantation species as foster trees in the degraded highlands of Ethiopia. PhD Dissertation. University of Helsinki, Helsinki.

Feyera Senbeta. 1998. Native woody species regeneration under the canopy of tree plantations at Munessa - Shashemene Forest Project Area, Southern Oromia, Ethiopia. MSc thesis, Swedish University of Agricultural Sciences, Skinnskatteberg.

Feyera Senbeta, Demel Teketay. 2001. Regeneration of indigenous woody species in the canopies of tree plantations in central Ethiopia. *Tropical Ecology* 42: 175-185.

Feyera Senbeta, Demel Teketay. 2002. The potential of tree plantations to foster regeneration of indigenous woody species in degraded lands of Ethiopia. In Demel Teketay and Yonas Yemshaw (eds.) "*Forests and Environment*", *Proceedings of the Fourth Annual Conference of Forestry Society of Ethiopia, 14-15 January 2002*. Forestry Society of Ethiopia, Addis Ababa. pp. 51-58.

Feyera Senbeta, Demel Teketay, BÅ Näslund. 2002. Native woody species regeneration in exotic tree plantations in Munessa-Shashemene Forest, Ethiopia. *New Forests* 24: 131-145.

Gressel JB, LG Holm. 1964. Chemical inhibition by weed seeds and the nature of inhibition by *Abutilon theophrasti*. *Weed Research* **4**: 44 -53.

Haugland E, LO Brnand. 1996. Experiments on bioassay sensitivity in the study of allelopathy. *Journal of Chemical Ecology* **22**: 1845-1859.

Hoque ATM, MB Uddin, R Ahmed, MK Hossain. 2003. Suppressive effect of aqueous extracts of Azadirachta indica leaf on some initial growth patrameters of six common agricultural crops. Asian journal for plant sciences **2**(10): 738-742.

Jayakumar M, M Eyini. 1990. Allelopathic effects of *Eucalyptus globulus* Labill. in groundnut and corn. *Comparative Physiol. Ecol*. **15**: 109-113.

Legesse Negash. 1990. Ethiopia's indigenous forest species and the pervasive effects of deforestation. *SINET Newsletter* **14**: 1-6.

Legesse Negash. 1993. Investigation on the germination behavior of wild olive seeds and the nursery establishment of the germinants. *SINET: Ethiopian Journal of Science*, **16**(2): 71-81.

Lisanework Nigatu, A Michelsen. 1993. Allelopathy in agroforestry systems - the effects of leaf extracts of *Cupressus lusitanica* and three *Eucalyptus* spp. on four Ethiopian crops. *Agroforestry Systems* **21**: 63-74

Masresha Fetene, Solomon Habtemariam. 1995. Investigation on allelopathic properties of coffee (*Coffea arabica* L.) leaves, pulp and tree canopy soil. *SINET: Ethiopian Journal of Science* **18**: 51-65.

May F, J Ash. 1990. An assessment of the allelopathic effect of *Eucalyptus. Australian journal of botany* **38**: 245-254.

Morita S, M Ito, J Harada. 2005. Screening of an allelopathic potential in arbor species. *Weed Biology and Management* **5**: 26-30.

Mulugeta Lemenih. 2004. Effects of land use changes on soil quality and native flora degradation and restoration in the highlands of Ethiopia. PhD Dissertation. Swedish University of Agricultural Sciences, Uppsala.

Mulugeta Lemenih and Demel Teketay. 2004. The role of plantation forests in fostering restoration of native flora and fauna at degraded sites in Ethiopia. *Ethiopian Journal of Biological Sciences* 3: 81-111.

Mulugeta Lemenih, Taye Gidyelew and Demel Teketay. 2004. Effects of canopy cover and under-canopy micro-climate factors of tree plantations on the composition, density and growth of native woody species in the southern highlands of Ethiopia. *Forest Ecology and Management* 194: 1-10.

Rho BJ, BS Kil. 1986. Influence of phytotoxin from *Pinus rigida* on the selected plants. *J. Nat. Sci*. **5**: 19-27

Rice EL. 1984. Allelopathy. 2nd edition. Academic Press, New York. PP. 422.

Saxena A, DV Singh, NL Joshi. 1996. Autotoxic effects of pearl millet aqueous extracts on seed germination and seedling growth. Journal of Arid Environments **33**: 255-260.

Selamyihun Kidanu. 2004. Allelopathic potential of *Eucalyptus globulus* in a tree-crop production system on highland vertisols in Ethiopia. PhD Thesis, chapter 6: 91-108; WUA, Netherlands.

Selamyihun Kidanu, Tekalign Mamo, L Stroosnijder. 2004. *Eucalyptus*–wheat interaction on Ethiopian nitosols. *Agricultural systems* **80**: 151-170.

Selamyihun Kidanu, Tekalign Mamo, L Stroosnijder. 2005. Biomass production of *Eucalyptus* boundary plantations and their effect on crop productivity on Ethiopian highland Vertisols. *Agroforestry Forum* **63:** 281–290

Stowe LG. 1979. Allelopathy and its influence on the distribution of plants in an Illinois old field. *Journal of Ecology* **67**: 1065-1085.

Tilashwork Chanie 2009. The effect of *Eucalyptus* on crop productivity, and soil properties in the koga watershed, western Amhara region, Ethiopia. MSc thesis presented to the Faculty of the Graduate School of Cornell University, U.S.A.

Tinnin RO, LA Kirkpatrick. 1985. The allelopathic influence of broadleaf trees and shrubs on seedling of Douglas fir. *Forest Science* **31**: 945-952.

Watson K.2000. The effect of *Eucalyptus* and Oak leaf extracts on California NativePlants. Enviromental sciences program-college of natural resources, University of California, Berkeley.

Yitebetu Moges. 1998. The role of exotic plantation forests in fostering the regeneration of native trees in an afromontane forest area in Ethiopia. MSc. thesis, Wageningen Agricultural University, Wageningen.

Zar HJ. 1984. Biostatistical data analysis. Prentice Hall, Englewood Cliffs, New Jersey, Pp. 718.

Chapter II

Community Needs and Point of Views: Social and Environmental Debate

Growing Eucalypt by Smallholder Farmers in Ethiopia

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Abstract

The genus *Eucalyptus* predominates tree-planting practices among smallholder farmers in Ethiopia. The genus is introduced to the country over a century ago, but it is showing an alarming expansion throughout rural Ethiopia in recent decades. Eucalypt is preferred over other species due to a number of merits that address the need of the farmers. Most farmers describe it as 'life saviour', 'safety net,' or 'tree bank' as it is converted easily and quickly to cash whenever needed. Despite the alleged ecological demerits, which farmers are also well aware of, expansion is on going and justified until the current wood and income shortage of smallholder farmers will subside. Eucalypt growers claim that there is no equally productive, adaptive, and demandable species to replace or substitute it. Farmers are confining perceived environmental impacts by developing locally adaptive stand management techniques such as trenching and site selection. From farmers perspective benefits from growing eucalypt far outweigh ecological costs from its impacts. Under current market condition, Eucalypt growing provides far better return on investment than any alternative land uses. The growing scarcity of wood products from natural sources on the one hand, and the need to satisfy household wood and cash needs on the other are the major drivers of planting eucalypt. Eucalypt is contributing to private forest development, supporting households to becoming wood self-sufficient and provide considerable cash income. Indeed, Eucalypt is a great asset that is contributing to rural development and poverty reduction in Ethiopia. Therefore, making decisions about eucalypt on the basis of perceived ecological impacts only is not advisable, rather the choices of poor households and the economic impacts that the plant is bringing on their welfare is equally important and justified to consider.

Keywords: ecological impacts, eucalypt, farm forest, income, profitability, perception, wood products.

Introduction

While natural forests and woodlands are shrinking in cover and stock, population and wood demands for different purposes are growing fast creating large gaps between demand for and the supply of forest products in Ethiopia. The common response to such a problem has been establishment of plantations of fast-growing tree species. Since the second half of the 19th century, successive governments in Ethiopia promoted plantations, though to a varying degree, so as to compensate for the declining supply of woods from natural forests (Henery 1973; Pohjonen and Pukkala 1990; Demel et al. 2010). However, the rate of Reforestation/ Afforestation (RA) in the country is very slow compared to the rate of deforestation (Melaku 2003; Negussie 2004). Most past RA works were driven by the State, NGOs, and aid agencies. These agents retreated from promoting plantations since the mid 1980s. Instead, smallholder farmers have taken the lead in expanding tree plantings in the form of farm forests (Jagger and Pender 2000; Woldeamlak 2002, 2003; Negussie 2004; Tesfaye 2005; Jagger et al. 2005; Zenebe et al. 2007; Dereje 2009).

Retaining some indigenous tree species in various forms of agroforestry systems have been common farmers' tree cultivation tradition in Ethiopia. Ethiopian farmers have also engaged in tree planting practices on a small scale, in either rows or patches as woodlots, around fields, in homesteads or other open areas. This practice of farm forestry is expanding at a high rate throughout rural Ethiopia, particularly in the highlands. Many fast-growing exotic tree species have been introduced to the country, and many found promising including several Eucalypt species (Henery 1973; Pohjonen and Pukkala 1990). The sale of eucalypt products is generating high income, increasing food security and diversifying smallholder-farming system (Woldeamlak 2003; Jagger et al. 2005; Zenebe et al. 2007). Given its versatility, farmers argue that there is or will exist hardly a species that can easily replace or substitute eucalypt. The objective of this paper is to shed some light on farm forestry practices, with particularly emphasis on eucalypt growing experiences among Ethiopian smallholder farmers. Specifically the paper focuses on (i) trend of eucalypt tree growing, (ii) socio-economic drivers for eucalypt planting, (iii) profitability of eucalypt growing vis-à-vis its financial return upon investment compared to alternative land uses, and (iv) perception of eucalypt among various actors.

Methodology

The information presented in this paper is based on extensive literature review, long years of teaching, and research experiences of the author and extensive field observation. Information on why, where and how eucalypt is grown, and the perceptions of various stakeholders on the genus are accumulating, thanks to the expanding higher education system in Ethiopia. These literatures are reviewed and the state of the art knowledge of eucalypt growing in the country is captured. In some of these studies the author was directly involved. Furthermore, recently the author has made an extensive field observation and informal discussions throughout the northern highlands of Ethiopia, particularly in Amhara and Tigray Regional States, which enriched the information presented in this paper.

Findings

Extent and trends of eucalypt plantings by smallholders

Diverse tree species can be observed on farmers' managed landscapes in Ethiopia (Tesfaye 2005; Motuma et al. 2008). However, eucalypt always dominate in terms of stem density (per hectare or per farm) and preference ranking (Table 1) throughout the highlands. Eucalypt woodlot is expanding rapidly due to the growing demands for its wood products. In most places in the highlands of Ethiopia (north and south) the growing demand for wood and wood products is inspiring farmers to convert farm plots to eucalypt woodlots (Negussie 2004; Dereje 2009). Major expansions are of recent decades. For instance, the study of Dereje (2009) in Arsi Negelle district, south central highland, reveals that 52% of current eucalypt growers engaged in the practice during the last 15 years (Fig.1). Studies of Tesfay (1996) from Tigray, Asaye (2002) from Gondar, Demamu (2002) from Wollo, Mesele (2004) from south and Zenebe et al. (2007) from central Ethiopia all confirm the increasing trend of eucalypt growing in their respective study areas in recent decades.

Table 1. Dominance of Eucalypt in farmer's tree planting practice in various sites throughout Ethiopia

Site	Household size surveyed	Percent planting trees	Average stem number per household	Share of eucalypt (%)	Source
Basona Werena (North Showa)	150	78%	693	99	Zeleke 2008
Sodo Zuriya (South)	150	75%	993	88	Zeleke 2008
Gurage highlands	150	100%	112.1-1970.5*	100	Negussie 2004
Chemoga (Gojam)	133	100%	307	80	Woldeamlak 2003
Lode Hetosa (Arsi Highland)	65	100%	nd	100	Zenebe et al. 2007
Arsi Negele (south central)	180	100%	nd	91	Dereje 2009
Tigray (Eastern Zone)	50	98%	214.5	98	Tesfay 1996
Sidama Area	50	100%	2301-2326**	56-98	Mesele 2002
North Gondar	40	100%	nd	98	Asaye 2002

nd = denotes no data available

Eucalypt is also integrated into traditional multi-story agroforestry systems of southern Ethiopia (Figure 2). In these traditional agroforestry systems, eucalypt stems are the most dominant than compared to other tree species both indigenous and exotic. For instance, the study of Tesfaye (2005) in Sidama showed that *E. camaldulensis* stem accounts for 61% of the total stem density, while 116 other tree species altogether represented only 39% of the stem density per farm. Mesele (2002) reported that the proportion of *Eucalypt* stems in tree stocks of a household could be as high as 98% in Shebedino area of Sidama Zone.

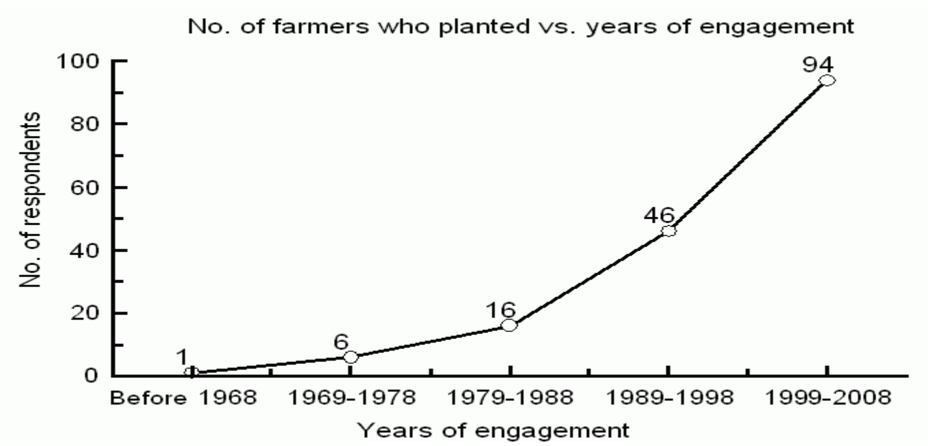

Figure 1. Expansion of eucalypt planting as farm forest in Arsi Negele district, central Ethiopia (**Source:** Dereje 2009).

Figure 2. Eucalypt in the traditional agroforestry systems of southern Ethiopia (photo by Zebene Asfaw and Zeleke Ewnetu).

In Amhara Regional State, out of the 92,000 ha of land covered with eucalypt nearly 67 % is farm forests developed by smallholder farmers (personal communication: Amhara Regional State Forest Enterprise). Some farmers in the Region establish eucalypt in the form of taungha system by growing crops with eucalypt seedlings until the trees grow tall and close canopy (Fig.3). By such a system, farmers partially compensate for the subsistence gap likely to be created by converting farm plots to eucalypt woodlots.

Figure 3. Eucalypt farm forests in Amhara Regional States (Right photo: Eucalypt at landscape level in rural South Gondar; Left photo: new eucalypt establishment with maize crop).

Socio-economic drives for planting eucalypt

Rural landscapes, particularly those close to human settlements and main roads, throughout the highlands of Ethiopia appear greener than the outfields because of eucalypt farm forests. A number of factors motivate farmers to plant eucalypt trees although the factors vary from sites to site based on ecological and socio-economic circumstances. The most common factors for planting eucalypt are two: wood scarcity both for construction and fuel wood and thus the need to satisfy household subsistence demand, and to generate cash income. In some communities, eucalypt trees are regarded as insurance resource or life saviour, since they are cut and readily converted to cash during critical needs (Mesele 2002). In other societies, such as the Gurage, planting eucalypt is a privilege and obligation of all households not only for meeting household wood requirements and generate cash revenues but to preserve social pride and reputation (Negussie 2004). Eucalypt woodlots also bestow a considerable reputation and social value to the owner, and these reputations depend very much on the size of the woodlots.

Scarcity of natural forests to provide wood for construction and fuel, and the high opportunity cost of using cow dung and crop residue as substitute for energy makes plantings of fast growing species, principally eucalypt, a commendable response in most places throughout the highlands of Ethiopia Today in many places, own grown eucalypt wood covers most of the construction wood needs of households and constitutes a substantial part of fuel wood consumptions (Woldeamlak 2003; Negussie 2004; Zenebe et al. 2007). For instance, 45 % of interviewed households in Chemoga watershed in Gojam estimated that between 75 and 100 % of their demand for fuel wood is met by privately planted trees;

while a further 20% indicated that these trees meet 50–75 % of their fuel wood needs (Woldeamlak 2003). In Gurage highland wood demand for construction of the wood-extensive traditional tukuls (about 50 m^3 of eucalypt wood each representing trees of 3 to 40 years of age), and the scarcity of wood sources from natural sources for such construction makes planting of eucalypt quite imperative (Negussie 2004). In Arsi highlands of central Ethiopia, eucalypt wood grown by farmers supply 86 % of firewood, 31% of charcoal, l00 % of leaves and twigs for firewood and 100 % of poles used by urban dwellers. In rural areas the wood from eucalypt contribute to 92% of poles, 74% of timber, 85% of firewood, 40% of charcoal, 83% of posts and 91% of farm implements. On market days, on average 74% of the firewood, 100% of the poles, 100% of the posts and 21% of charcoal taken to town is of eucalypt grown as farm forests (Zenebe et al. 2007).

Farmers also grow eucalypt for income generation. In areas, such as northern, central, and southern highlands of Ethiopia where natural forests have been impoverished eucalypt farming is contributing up to 25 % of household cash income (e.g. Tesfay 1996; Minda 2004; Zenebe et al. 2007). For poor households of some areas income up to 72 % is reported to be contributed from eucalypt sale (Zenebe et al. 2007). The lucrative cash income generating from eucalypt is driving conversion of farmlands in many areas (e.g. Mesele 2002; Dereje 2009). In some places such s Tigray Region conversion of farm plots are checked by State policies, which otherwise farmers would have preferred to do so (personal communication with farmers in Atsibi, Tigray region). Discussion with farm communities in Debre Tabor and Meket areas of Amhara Regional State indicate that eucalypt cultivation is a principal strategy for asset building and securing household cash need. In general, the above findings indicate that eucalypt has the potential to raise farm incomes, reduce poverty, increase food security, and diversify smallholder-farming systems.

Eucalypt being a resilient species to successfully establish on marginal sites such as degraded and erosion prone grounds like gully banks, inside gullies as well as on farmlands that lost crop production potential, it stands as the best choice to make economic uses of marginal lands (Berhanu et al. 2003; Woldeamlak 2003). Establishment of eucalypt trees, therefore, appears to be the last in an agro-ecological succession of land-use types, which also suggest that eucalypt are often planted in areas too degraded for crop production (Woldeamlak 2003; Dereje 2009). While making economic uses of such marginal lands, eucalypt also reduces landslide and soil erosion, and in some cases, eucalypt woodlots are established for land reclamation purposes on plots that otherwise cannot support the growth of other vegetation (Negussie 2004). In addition to the contribution of eucalypt to household wood demand and raise their farm income, it has become a major source of building materials (poles and posts) supporting the construction and energy sector throughout Ethiopia. Today eucalypt from smallholder farms contribute a significant proportion in the timber market and large-scale trade in construction poles, posts, and transmission poles throughout Ethiopia (Figure 4).

Figure 4. Eucalypt woods for transmission poles and construction poles and posts in Ethiopia (Photo by Mulugeta Lemenih)

Profitability of eucalypt growing

Eucalypt is grown for many purposes among which income is one. Often farmers grow it on lands that have little other use options such as farm boundary (demarcation of farm plots), on degraded parts of their land holdings or in small woodlots at front yard or in garden. In some cases and since recent years, however, conversions of croplands, enset or coffee fields to eucalypt are becoming common (Mesele 2002; Dereje 2009). Reasons for conversion are better return from eucalypt than crop farming (Woldeamlak 2003; Dereje 2009). This implies that households determine their land use portfolios based upon potential benefits and costs given their environmental and economic resource endowments.

Planting eucalypt is financially more rewarding compared to agricultural alternatives be it crop or livestock across various environmental and socio-economic settings. Using survey data from Tigray Jagger et al. (2005) found that growing eucalypt yields a high-expected rate of return, well above 20% in most circumstances, than cropping. Negussie 2004) indicated a substantially higher profitability of growing eucalypt, up to 514 % compounded profit, over tef (*Errograstic tef*) production over 7 years period in Gurage highlands. The study of Tesfaye (1996) shows a Net Present Value (NPV) of 56014 Birr/ha for eucalypt woodlot as compared to 6337 Birr/ha (at 15% discounting rate) from barley over 12 years period. In central Ethiopia Daba (1998) also showed a NPV from eucalypt cultivation to range from 11,945 – 74,966[5] Birr/ha (based on soil conditions), which in all cases is 10 fold greater than return from different agricultural crops such as barely, wheat and hey. Other studies by Demamu (2002) from Wollo, Minda (2004) from Wollo, Asaye (2002) from Gondar and Zerihun (2002) from Shewa all reported similar findings. The above studies confirm that even if eucalypt woodlots do not offer cash income on year-to-year basis like agricultural crops, the average cash income from growing eucalypt is greater over the rotation than agricultural production. The long gestation period, as compared to agricultural crops, nevertheless, represents a major overriding risk factor for smallholder

[5] *Calculated at 10% discount rate*

farmers. This suggests that policy makers and development actors need to consider credit provision to farmers to fill the income gap that will be created during the transformation of land use from crop to tree farming.

Management of eucalypt woodlots

Farmers are well versed with how to manage and optimize benefit from eucalypt woodlots while reducing its ecological impacts (Zenebe et al. 2007; Dereje 2009). Their management includes selection of planting site, managing interaction between eucalypt woodlots and crops, planting density, coppice reduction and the like. Eucalypt woodlots are managed on short rotation basis of 5 to 10 years. Given the small land holding, farmers plant it at an extraordinary high density of 10,000 to 25,000 stems/ha (Zerihun 2002; Tesfaye 2005; Zenebe et al., 2007), and even in some cases up to 40,000 stems/ha. Farmers also plant eucalypt either as woodlot, rows or as scattered trees depending on land availability. The most dominant forms of planting are woodlots, line (row planting) as farm-boundary, scattered planting in multi-story home garden agroforestry, coffee shade or as live fence. Farmers also employ different technical management practices such as trenching to isolate the woodlots from other land uses (Figure 5). Farmers also practice hoeing, thinning and coppice reduction to manage their eucalypt woodlots.

Figure 5. Planting and managing eucalypt woodlots by smallholder farmers in Ethiopia (Photo by Dereje Jenbere)

Perception of different bodies on eucalypt

Despite the wide socio-economic and environmental benefits that eucalypt renders, there is still diverging opinion on the usefulness of the genus among different agents. Some totally oppose, some supports and still others have reservations on the planting of the genus. Interestingly, farmers and development agents alike support the continued planting of the genus. For instance, farmers in Debre Tabor (South Gonder) and Meket (North Wollo) describe eucalypt as ‘life saviour, insurance crop, grantor of stable life and a means out of poverty’ (personal communication), and they are not only supportive of eucalypt planting but are doing it at large. In Atsbi, Tigray Region farmers indicated that had it not been for the strong policy of the Regional State that forbid converting farm plots to eucalypt woodlots, they would have liked to plant eucalypt all over their farm lands since it fetches more cash and better living to their households (personal communication). Urban dwellers that benefit from the species either in cash or in kind are also positive about planting and expanding it. Development agents and most field experts that observe the usefulness of the species in addressing the socio-economic needs of farmers are also positive in most of the cases. The study by Zenebe et al. (2007) in Arsi highlands report that 86.4% of the farmers, 90% of urban dwellers, 57.1% of agricultural bureau experts, 50 % of development agents and 33.3% researchers support the planting of Eucalypt, while 0% (none) of the politicians did. Similarly, in 1997 the Regional Government of Tigray imposed a ban on *Eucalyptus* tree planting on or near farmlands. The ban was instituted by concerns about the potential negative environmental externalities associated with Eucalypt, and the desire to reserve farmland for crop production (Jagger and Pender, 2000).

Farmers are not very blind of the ecological impacts of the species. Many studies indicate that farmers are conscious and concerned about its impacts. For instance, the study of Dereje (2009) show that 57.8% of interviewed households perceived that expansion of eucalypt will have ecological problems in the future. Some of the ecological impacts identified are lowering of crop yield from competition, undergrowth suppression, lowering of water table, soil degradation, and impact on food availability to farm households if conversion continues. Most of these impacts identified by farmers overlap with arguments that environmentalists use to object eucalypt growing. Indeed, whether the impacts listed by farmers are environmentalists' influence or observation from their own experiences are difficult to know. On the other hand, many of the allegations against eucalypt and other exotics, e.g. the allegation of hampering native biodiversity, are unscientific and disproved by many recent research findings (Feyera and Demel 2001; Eshetu 2002; Feyera et al. 2002; Mulugeta 2004; Mulugeta and Demel 2005). Other allegations such as nutrient depletion and high water consumption are also unjustified on the ground that eucalypt is the most efficient water and nutrient utilize compared to most plant species.

The future of eucalypt in Ethiopia's landscape

In Ethiopia high population growth, adverse effects from climate change, deforestation, wood and other forest product scarcity and unabated land degradation will continue to be major issues for the foreseeable future. The value of forest import, which amounts at the present to some 430 million Birr annually, will continue to grow given the increasing economic development and the growing construction sector in the country. With eucalypt, there is an enormous genetic potential that help address some of the aforementioned issues and to meet the growing demands of wood products in the nation. The uniquely fast growing and coppicing abilities of eucalypt merit its expansion to address the looming gap between wood demand and supply and to also address the problem of continued deforestation by acting as a buffer and substitute. Interestingly, there is increasing understandings of the ecological pros and cons of eucalypt better than before and most importantly, the biodiversity impacts are unequivocally disproved (Mulugeta and Bongers 2010). Rather eucalypt is considered as a foster species that nurse the rapid re-colonization of native species when planted on barren and degraded lands. Furthermore, its soil rehabilitation effects are positive including soil erosion mitigation when established on degraded and eroded landscapes (Fig. 6), and indirectly through the replacement of cow dung and crop residues use as fuel. Globally, the use of eucalypt for industrial and social forestry is growing and Ethiopia is no exception and need not be exceptional. A very good example comes from Alaje forest and Maichew chip wood factory in Tigray Regional State. Here eucalypt is grown to feed the chip wood factory that produces particle and laminated boards that are supplied on domestic market as well as exported.

Figure 6. Eucalypt planted on degraded land and gully for checking soil erosion in Debre Tabor (South Gondar).

The recent forest policy of Ethiopia provides farmers tax incentives that are proportionate to the number of trees they plant. The government also encourages the private sector to invest in forestry. It has lifted controls on pricing and marketing of forest products, paving the way for an open and competitive market for wood. Farmers now face little restriction in selling tree products except some hurdles on transporting (checkpoints). However, the future of eucalypt plantation expansion rests on changing attitude towards the species. Enabling conditions with regard to policies and guidelines across different aspects of development, management and marketing of forests and forest products; increasing security of land and tree resources, for example, forestland certification including the right to manage, harvest, transport and market wood and non-wood products produced from own forests and specific guideline on eucalypt planting are needed. Improving marketing chains and expanding value added processing facilities (forest industries) to guarantee farmers a stable and sustainable market is very essential. Credit provision to smallholders is one of the most crucial issues needed to encourage them to f engage further in tree growing.

Conclusions

In Ethiopia, eucalypt is the major species grown as small-scale forestry by smallholder farmers. Eucalypt growing in such a practice is contributing significant amount of building materials (poles and posts) and fuel wood. Eucalypt is thus playing an important role in developing the objectives of farm forestry in Ethiopia such as creating new sources of forest produce in rural areas (firewood, charcoal, building poles and small timber), help farm owners by growing useful trees including those that can be sold as cash crops, conserving soil and water and providing greener landscape among others. By doing so, it is contributing significantly to the conservation of biodiversity rich natural forests or at least in lowering the rate of their deforestation. It is also contributing to poverty reduction and insuring food security for millions of rural households throughout the highlands of Ethiopia. Consequently, the introduction of eucalypt species is Ethiopia is a great success. Despite the alleged negative ecological externalities of eucalypt, which need to be verified scientifically, which farmers are well aware of, they continue growing it because they found no better alternative to satisfy their wood demand and improve their livelihoods. Farmers are quite unwise to grow eucalypt if they were not sure of its benefits. Unfortunately, the current attitudes of local authorities and environmentalists could affect the potential benefit of eucalypt to smallholder farmers in the future. While improper management such as planting in wrong sites and improper tending may make eucalypt environmentally detrimental, they also have many potential ecological benefits, direct and indirect, including reduced run-off and erosion, biomass provision, reducing pressure on natural forests and substituting cow dung and crop residue in fuel wood use. It is better o make decisions on whether to plant eucalypt by weighing farmer's choices as well as balancing the impact against the benefits.

References

Assaye Asnake. 2002. Yield and Economics of Growing *Eucalyptus camaldulensis* by Smallholder Farmers of Amhara Region: The Case of Gondar Zuria District, North Gondar, Ethiopia. MSc thesis, ISSN 1402-201X (2002:57). Swedish University of Agricultural Sciences, Skinnskatteberg, Sweden.

Berhanu Gebremedhin, J Pender, Tesfay G. 2003. Community natural resource management: the case of woodlots in Northern Ethiopia. *Environment and Development Economics* 8: 129–148.

Daba Wirtu. 1998. The economics of growing *E. globulus* (labill.) in the highlands of Oromiya, Ethiopia. MSc thesis, Swedish University of Agricultural Sciences, Skinnskatteberg, Sweden.

Demamu Mesfin. 2002. Economic analysis of *E. globulus* plantation in the former Dessie fuel wood project, South Wollo, Ethiopia. MSc thesis, Swedish University of Agricultural Sciences, Skinnskatteberg, Sweden.

Demel Teketay, Mulugeta Lemenih, Tesfaye Bekele, Yonas Yemshaw, Sisay Feleke, Wubalem Tadesse, Yitebitu Moges, Tesfaye Hunde, Demeke Nigussie. 2010. Forest Resources and Challenges of Sustainable Forest Management and Conservation in Ethiopia. *In:* Bongers F, Tennigkeit T (eds). Degraded forests in Eastern Africa: management and restoration. Earthscan Publ. Pp. 19-63

Dereje Jenbere. 2009. The expansion of *Eucalyptus* plantation by small holder farmers and its drivers: the case of Arsi Negelle district, southern Oromia Ethiopia. MSc thesis, Hawassa University, Wondo Genet College of Forestry and Natural Resources, Awassa.

Eshetu Yirdaw. 2002. Restoration of the native woody – Species diversity, using plantation species as foster trees, in the degraded highlands of Ethiopia', PhD dissertation, Viikki Tropical Resources Institute, University of Helsinki, Helsinki.

Feyera Senbeta, Demel Teketay. 2001. Regeneration of indigenous woody species under the canopy of tree plantations in Central Ethiopia. *Tropical Ecology* 42: 175–185.

Feyera Senbeta, Demel Teketay, B Å Näslund. 2002. Native woody species regeneration in exotic tree plantations at Munessa-Shashamane forest, Southern Ethiopia. *New Forests* 24: 131–145.

Gebremedhin Teklu. 2003. Expanse of plantation forest in Ethiopia. An outcome of more than half a century's effort. MoA, Addis Ababa, Ethiopia.

Henery PW. 1973. Notes on maps of the *Eucalyptus* plantations around Addis Ababa and the Menagesha State Forest, Ethiopia.. ODA. London. Misc. Report. 150:1-10.

Jagger P, J Pender, Berhanu Gebremedhin. 2005. Trading Off Environmental Sustainability for Empowerment and Income: Woodlot Devolution in Northern Ethiopia. *World Development* 33: 1491–1510.

Jagger P, J Ponder. 2000. The role of trees for sustainable management of less favored lands: the case of *Eucalyptus* in Ethiopia. *EPTD Discussion paper No. 65*. International Food policy Research Institute, Washington, D.C. USA.

Melaku Bekele. 2003. Forest property Rights, the Role of the State, and Institutional Exigency: the Ethiopian Experience. Doctoral Dissertation, Swedish University of agricultural sciences, Uppsala, Sweden

Meselle Negash. 2002. Socio-economic aspects of farmers' *Eucalyptus* planting practices in the Enset-Coffee based agroforestry system of Sidama, Ethiopia. The case of Awassa and Shebedino Districts. MSc thesis, Swedish University of Agricultural Sciences, Skinnskatteberg, Sweden.

Minda Teshome. 2004. Economics of growing *Eucalyptus globulus* on farmers' woodlot: the case of Kutaber District, South Wollo, Ethiopia. MSc thesis, Hawassa University, Wondo Genet College of Forestry, Awassa.

Motuma Tolera, Zenebe Asfaw, Mulugeta Lemenih, E Karltun. 2008. Woody species diversity in a changing landscape in the south-central highlands of Ethiopia. *Agriculture, Ecosystem and Environment* 128: 52 -58

Mulugeta Lemenih. 2004. Effects of land use changes on soil quality and native flora degradation and restoration in the highlands of Ethiopia. Implications for sustainable land management. *Acta Universitatis Agriculturae Sueciae, Silvestria*, vol 306, PhD thesis, Swedish University of Agricultural Sciences, Department of Forest Soils, Upsala, Sweden

Mulugeta Lemenih, F Bongers. 2010. The role of plantation forests in fostering ecological restoration: experiences form east Africa. In: Bongers F, Tennigkeit T (eds) Degraded forests in Eastern Africa: management and restoration. Earthscan Publ. pp. 171-220

Mulugeta Lemenih, Demel Teketay. 2005. Effect of prior land use on the recolonization of native plants under plantation forests in Ethiopia. *Forest Ecology and Management* 218: 60–73.

Munishi PKT. 2007. The *Eucalyptus* Controversy in Tanzania. Paper Presented at TAF Annual General Meeting (AGM) 23rd – 24th, Dodoma, Tanzania.

Negussie Achalu. 2004. Farm Forestry decision making strategies of the Guraghe households, Southern-Central highlands of Ethiopia. PhD Dissertation. Institut fur Internationale Forst-Und Holzwirtschaft Technische Universitat Dresden.

Pohjonen V, T Pukkala. 1990. *Eucalyptus globulus* in Ethiopia forestry. *Forest Ecology and Management* 36:19-31.

Shyam Sunder S, S Parameswarappa. 1989: Social Forestry and *Eucalyptus. Economic and Political Weekly* 24: 51-52.

Tesfay Teklay. 1996. Problems and prospects of tree growing by smallholder farmers. A case study in Feleghe-Hiwot locality, Eastern Tigray. MSc thesis, Swedish University of Agricultural Sciences, Skinnskatteberg, Sweden.

Tesfaye Abebe. 2005. Diversity in homegarden agroforestry systems of Southern Ethiopia. Tropical Resource Management Papers, No. 59. Wageningen University, The Netherlands.

Turnbull JW. 1999. Eucalypt plantations. *New Forests* 17: 37-52.

Woldeamlak Bewket. 2002. Land cover dynamics since the 1950s in Chemoga watershed, Blue Nile basin, Ethiopia. *Mountain Research and Development* 22: 263–269.

Woldeamlak Bewket. 2003. Household level tree planting and its implications for environmental management in the northwestern Highlands of Ethiopia: a case study in the Chemoga Watershed, Blue Nile basin. *Land Degradation and Development* 14: 377–388

Zeleke Ewnetu. 2008. Smallholder Farmers' Decision Making in Farm Tree Growing in the Highlands of Ethiopia. PhD dissertation, Oregon State University, USA.

Zenebe Mekonnen, Habtemariam Kassa, Mulugeta Lemenih, B Campbell. 2007. The role and management of *Eucalyptus* in Lode Hetosa District, Central Ethiopia. *Forests, Trees and Livelihoods* 17: 309-323.

Zerihun Kebebew. 2002. Profitability and household income contribution of growing *Eucalyptus globulus* to smallholder farmers. MSc thesis, Swedish University of Agricultural Sciences, Skinnskatteberg, Sweden.

Eucalyptus Trees and the Environment: A new perspective in times of climate change

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Abstract

Eucalypt planting has been expanding very fast in Ethiopia over the last decades although the debate on its alleged ecological disadvantages continues among experts from various disciplines. Experts with forestry background tend to argue that eucalypts have been and continue to be important for rural and urban people in supporting their livelihoods. On the other hand, environmental scientists and biologists generally argue that *Eucalyptus* is damaging the environment, therefore, must be banned from being planted in the country. These two divergent arguments are not often based on scientific data, thus, may not reflect the reality on the ground. Therefore, the claims on eucalypts should be verified by scientific data. In this paper, a broad review on the status of eucalypt growing in Ethiopia, an account of scientific evaluation of its effects on the environment and an up-to-date view on Genera *Eucalyptus* in this era of climate change have been presented. The focus remains on defending the unjustified criticisms, and bringing in the current renewed interest on eucalypts in times of global warming.

Keyword: carbon sequestration, *Eucalyptus* controversy, climate mitigation, biodiversity, soil quality, water consumption

Introduction

Many fast-growing exotic tree species have been introduced to Ethiopia, and many of which are promising including several *Eucalyptus* species (Henery 1973; Teklu 2003). *Eucalyptus* was first introduced in Ethiopia in 1895, with the objectives of meeting ever-increasing demand for construction poles and firewood in Addis Ababa, the then seat of King Menelik II. Today, while the debates among experts continue on its alleged ecological disadvantages, growing eucalypts is expanding very fast in the country, particularly by smallholder farmers. The preference to eucalypt trees is due to a number of its advantages gained from the species in terms of addressing the needs of farmers. They are preferred more than others due to their fast-growth, coppicing ability, easy silvicultural management, unpalatability by animals, good demand for its wood with reasonable prices, and their adaptations to a wide range of ecological conditions. Eucalypts growers claim that there is no equally productive and adaptive species to replace or substitute them. From farmers perspective benefits from growing eucalypts far outweigh its environmental costs.

This paper attempts to provide answers to the following questions. Are the debates surrounding *Eucalyptus* founded on data or is it dominated by propaganda? Is *Eucalyptus* particularly bad for the environment in terms of soil degradation, water consumption, and biodiversity conservation? Where would it be inappropriate to plant it? What is the current outlook on plantation forests in general and eucalypts in particular in other countries? Is *Eucalyptus* an option for mitigation of global warming? The objective is to challenge the unjustified criticisms and updating experts and practitioners on the new perspective of the genus *Eucalyptus* in other parts of the world in times of global warming.

Methodologies for Information Collection

The approach used to collect information was mainly reviewing published articles and grey literature reported from Ethiopia. The Internet has also been an important tool to access information from organizations working on eucalypts. This refers particularly to information collected from Aracruz (Brazil), the owner of largest eucalypt plantations in the world.

Findings from Literature Review

Growing *Eucalyptus* in Ethiopia

The introduction of *Eucalyptus* and other exotic tree species to Ethiopia is a great success (Henry 1973; Davidson 1989). It is true that exotic tree plantations have played and will continue to play a tremendous role in alleviating the fuel and construction material problems in Ethiopia. *Eucalyptus* was first introduced in Ethiopia in 1895, with the objectives of meeting the ever-increasing demand for construction poles and firewood in Addis Ababa, the then seat of King Menelik II. The construction of rural and urban houses in Ethiopia over the century has been dominated by eucalypts. The current construction industry also consumes large quantity of wood, of which eucalypts are dominant, with little prospect for a competitive substitute for these trees in the near future. The emerging export markets in the neighbouring countries and the Middle East is encouraging for production of more eucalypt poles and posts, since Ethiopia has favourable environmental conditions for the planting of eucalypts from which the country will benefit from such lucrative markets.

Eucalypt growing is expanding very fast in many parts of Ethiopia, particularly by smallholder farmers. Studies of Tesfaye Tekaly (1996) from Tigray, Asaye Asnake (2002) from Gondar, Demamu Mesfin (2002) from Wollo, Mesele Negash (2004) from southern Ethiopia and Zenebe Mekonnen et al. (2007) from central Ethiopia all confirm the increasing trend of eucalypt growing in their respective study areas. Two species of *Eucalyptus,* namely, *E. globulus* and *E. camaldulensis* are widely planted, although *E. saligna* and *E. grandis* are also showing increasing importance (Selamyihun and Gezhagne 2004).

A number of factors motivate farmers to plant trees, although the factors may vary from site to site based on ecological and socio-economic circumstances. The most common factors for planting eucalypt are wood scarcity both for construction and fuel wood and thus the need to satisfy household subsistence demand, and to generate cash income (Lemenih and Ewnetu 2010). Planting eucalypts is financially more rewarding in Ethiopia as compared to agricultural alternatives such as crop or livestock production across various environmental and socio-economic settings. For example, the survey data from Tigray (Jagger et al., 2005) indicated that growing eucalypts yields a high-expected rate of return of well above 20% in most circumstances than cropping.

Eucalyptus and the environment

Eucalyptus trees and water consumption:

Considering the hydrological influence of trees, there are several factors that influence the amount of rainfall that reaches the forest soil. First, it is the amount of water intercepted by the canopies of the trees. Of the amount of this water that reaches the soil surface, part is absorbed and part runs off directly to streams and rivers. Of the amount of water absorbed, part evaporates from the soil and part is used by plants, to grow and to reproduce. This part is called "transpiration" which occurs in the leaves. The evaporation (soil) and transpiration (plants) processes may be combined, and known as "evapotranspiration," which reflects the amount of water a plant uses per unit of area. The water that is absorbed into the soil can also reach the underground water table (the portion of soil that is saturated with water).

The misconception on *Eucalyptus* species consuming much more water more than any other tree species and agricultural crops and with consequent drying of streams has been disproved (Davidson 1989). There are quite a number of research results, which revealed that *Eucalyptus* species are efficient water users. For instance, Davidson (1989) reported that on a "leak proof hectare" at Nekemte (with annual rainfall of 2158 mm), *E. saligna* and *E. grandis* could produce 46.6 m^3/ha/yr without drawing on water reserves (rainfall only) compared to 16.4, 16, 12.4 m^3/ha/yr biomass production for the coniferous, acacia and broadleaf species, respectively. The results suggest that for the same amount of water consumed *Eucalyptus* produces higher amount of biomass that is economically profitable and acceptable. According to Davidson (1989), *Eucalyptus* species need, on average, 785 liters of water to produce a kg of dry biomass as opposed to agricultural crops that consume 1000 to over 3000 liters of water to produce a kg of dry biomass.

Another study on hydrological impacts of *Eucalyptus* was that conducted by Aracruz (Brazil) (http://www.aracruz.com.br/eucalipto/en/), the owner of the largest *Eucalyptus* plantations in the world. The studies specifically related to its hydrological cycle have been an important part of the work by the National Institute of Space Research (INPE) and by CISRO. These studies showed that from 1998 to 2004, evapotranspiration (average water consumption by *Eucalyptus*) was 1,092 mm/year (liters/m²/year) which is similar to the average amount of rainfall

(1,147 mm/year) and approximately the same average consumption of the native forests (1,167 mm/year). Studies on other crops such as coffee, sugarcane, and citrus fruits show similar water consumption to that of the eucalypt trees in the Aracruz watershed. One of the most interesting results of the studies in Brazil was that climates with an annual rainfall of over 1200 mm have a supply of water compatible with demand of eucalypts and, thus, the planted eucalypt forests do not negatively influence the outflow of streams and rivers.

Another insight from the study was the fact that the water table in the Aracruz watershed is in depths over 15 meters while the average depth of roots of eucalypt trees does not exceed 2.5 m suggesting that their roots do not reach the water table. However, the rooting depth of plants can vary depending on various factors such as age, edaphic, climatic conditions, underlining the need for making site-specific evaluations on water consumption. Nevertheless, under the Brazilian conditions, it was observed that, eucalypt plantations are more efficient than native forests in converting water into wood. *Eucalyptus* grows faster while consuming the same total amount of water as native trees. The average efficiency of eucalypts is estimated at 0.43 m³ of water/kg of wood, compared to 1.3 m³ of water/kg of wood in the trees of the Atlantic Natural Forest.

Eucalyptus is not particularly water demanding, but it consumes water for supporting the fast growth rate, especially in water stressed climates. Owing to this, there is a need to exclude eucalypts planting in watershed development. Thus, foresters or watershed managers should decide whether wood production or water is more important in a particular environment. Fortunately, *Eucalyptus* is still not reproduced naturally; rather people should assist its regeneration artificially. This provides an opportunity to manage the species in terms of where and how to grow it.

Eucalyptus trees and soil quality

There are frequent questions about the impact of eucalypt trees on the soil — whether they exhaust soil fertility or cause erosion. In most countries, the current model for planting eucalypts calls for “minimum impact soil preparation.” The equipment used for this does not expose deeper soil layers to the surface, which avoids an inversion of the upper soil layers. It also keeps the soil protected from rain and sunlight by leaving a vegetable blanket formed by the leaves, branches, roots, and bark residue from harvested trees.

Soil fertility is a key issue that has been getting attention from professionals involved with eucalypt plantations in tropical areas. The low natural reserve of nutrients in the soils, the fast growth of the trees, and high productivity with ever-shorter cycles justify this interest. Nevertheless, eucalypts demand smaller amounts of fertilizer [192 kg macronutrients (Ca, Mg, K, N, and P) /ha/ year] to complete their growth cycles and are one of the most efficient crops with regard to the conversion of nutrients into usable biomass. This is significantly lower than the nutrient requirements of other agricultural crops of 322 to 470 kg macronutrients /ha/ year (http://www.aracruz.com.br/eucalipto/en/). Clearly, if the sustainable production of these crops could be assured in the tropical environment, the sustainability of eucalypt plantations can easily be guaranteed.

Similarly, soil fertility analysis proved that soil fertility is improving in eucalypt plantations reflecting positively on the sustainability of wood production. During the period from 2004-2008, the phosphorous, potassium, calcium and magnesium contents available in the planted soils rose by 57%, 13%, 31% and 45%, respectively. A nutrient survey showed the final balance for most nutrients is positive. Nitrogen was the only nutrient with a slightly negative balance. It has broadly been indicated that as compared to geochemical surveys of agricultural areas in Europe and the United States, the flow of nutrients in the experimental watershed of eucalypts was low. This is mostly due to the small amount of nutrients required by eucalypts in comparison with other crops.

Soil erosion monitoring at Aracruz also showed that soil losses in eucalypt plantations varied between 0.6-1.0 t of soil/ha/year. These values were much below the estimated tolerance limits for the region (between 10-13 t/ha/year). They were also smaller than the losses for some of the main agricultural crops planted in the area. Overall, the consensus reached among the leading experts on *Eucalyptus* today is that, with today's knowledge, environmental care, and procedures, degradation of soil does not occur in tropical forestry. In other words, eucalypts plantations when properly managed do not exhaust soil nutrients.

Eucalyptus trees and biodiversity

Balancing economic development with environmental sustainability is a global challenge. This balance becomes more complex as the world's population grows – and people demand goods whose production involves the use of natural resources. An important element in any discussion about the sustainable use of natural resources is the protection of biodiversity. Large areas of tropical biomes have since been deforested, directly affecting biodiversity.

Several studies in Ethiopia have evaluated the potential of *Eucalyptus* as foster plantations for biodiversity conservation and native forest regeneration. The results invariably showed the positive impact of eucalypt plantations on plant diversity in humid and sub-humid areas (Yitebitu Moges 1998; Lemenih and Bongers 2010). Many of the allegations on species of *Eucalyptus* and other exotics, e.g. the allegation of hampering native biodiversity, are unscientific and disproved by many recent research findings (Yitebitu Moges 1998; Senbeta and Teketay 2001; Yirdaw 2002; Senbeta et al. 2002; Mulugeta Lemenih et al. 2004; Mulugeta Lemenih and Demel Teketay 2005). Light crowns of eucalypts have an advantage to let the penetration of sunrays to the forest floor contributing positively to undergrowth development. There is now increasing knowledge of the ecological pros and cons of eucalypts better than before and most importantly the biodiversity impacts are unequivocally disproved. Rather eucalypts are considered as a foster species that nurse the rapid re-colonization of native species when planted on barren and degraded lands.

Similarly, a study in Brazil (Aracruz eucalypt plantations) showed that over 550 species of birds have been classified (http://www.aracruz.com.br/eucalipto/en/). Birds are considered excellent biological indicators of the quality of the environment, because they react to the slightest environmental imbalances. Of these, 74 species were identified as endangered species in the world. The data from this monitoring leads to the conclusion that eucalypt plantations allow the maintenance of animal communities in the studied locations due to their supply of natural shelter, food, and conditions for reproduction. Plant diversity has also been monitored. Species of native trees are protected and classified. The surveys have identified the existence of 558 species of trees in the native forests, and 125 in the sub-story of the eucalypt plantations. Therefore, the general belief that eucalypts creates "green desert" is unjustified.

Current Outlook on Plantation Forests

Ever since our world has been a world, native forests have been indiscriminately exploited by man. There has been an ever-increasing demand for wood, coupled with the mistaken belief that the world's natural resources are inexhaustible. This situation has been no different in Ethiopia. Natural forests are is finite and exhaustible, and with this reality, the importance of planted forests as an ecological alternative for our planet becomes more critical. Although forest plantations have been criticized in the past, today they are more valued as they can guarantee the coexistence of the remaining natural forests.

Today, forest plantations are increasingly being recognized as a key component of mitigating global climate change. Afforestation and reforestation are the key elements of the Clean Development Mechanism under the Kyoto protocol. Forest plantations play a strategic role in maintaining balance. Forests emit and sequester $CO_{2:}$ about 20% of global CO_2 emissions are contributed by deforestation while trees are also contributing to reduce atmospheric carbon dioxide, which is mostly responsible for global warming (the greenhouse effect). Carbon dioxide from the atmosphere is captured by the planted trees and converted into high-value wood and oxygen. The high-value wood provides essential products for society (paper for books, personal hygiene, furniture, medicinal and aromatic essences, wood for generation of energy, and construction wood. Also, trees protect water resources by enhancing hydrological functions of landscapes and help combat the drying of the land (desertification). They are also part of a complex ecosystem that shelters and feeds wildlife (insects, birds, reptiles, and mammals) — as well as several species of plants.

In some countries such as Brazil and South Africa, forest plantations presently rank high in their economies, contributing to the generation of jobs, income, collection of taxes, and a positive foreign exchange. In Brazil in 2005, forest plantations were contributing to a turnover of US$36 billion, corresponding to 4.5% of the Brazilian Gross Domestic Product (GDP). In Ethiopia, given the limited size of native forests of about 3.6% (WBISPP 2002) planted forests are also the realistic option for forest development that meets the increasing demand for wood and other forest products. Indeed, there exists every reason for promoting forest development and other tree-based food production systems in light of widespread land degradation, deforestation, climate change, and daunting fire wood shortages in the country.

It has only been in recent times that the importance of trees for the balance of nature was understood. Nevertheless, today, thanks to progress in science and ecological awareness, the vision of the world society has changed. As a society, we no longer accept the continued cutting of native forests because we know that this creates environmental problems and can compromise our very survival on the planet. With this knowledge, the sustainable planting and responsible harvesting of new forests (plantations) has come to represent a double benefit for society: it helps to preserve the environmental balance and contributes to the generation of wealth.

New Perspectives on *Eucalyptus* Trees in Times of Global Warming

The Earth's atmosphere is made up of a number of different gases. Some of these gases — known as Greenhouse Gases (GHG) — play an important role in the regulation of our planet's temperature, because they are able to absorb and release heat. The greenhouse effect is a natural phenomenon that warms the planet to a temperature that allows the existence of all living things. However, that warming effect is increasing rapidly today – putting life at risk. Human activities such as the burning of fossil fuels result in the emission of several GHG, principally carbon dioxide (CO2), methane (CH4), and nitrous oxide (N2O).The contribution of each of these gases to global warming in the next century based on the estimates of emissions (Hadley Centre 2005) is 63% by CO_2, 24% by CH_4, 10% by N_2O, and 3% by other GHGs. The principal gas, CO_2, will be responsible for almost two-thirds of the expected future warming. It is the most important GHG contributor created by human activities – now and in the future.

For the scientific community there are two main alternatives to try to improve this situation: 1) reduce the emissions of greenhouse gases into the atmosphere; and 2) remove these gases from the atmosphere once they are in place. The term "carbon sequestration" is the most used when talking about the removal of greenhouse gases from the atmosphere. Forests have everything to do with this. Trees are able to remove (sequester) CO_2 through the process of photosynthesis. The majority of CO_2 is transformed into biomass (trunk, branches, leaves, and roots). The amount of carbon in the soil (up to 1 meter in depth) is greater than the amount of carbon in the atmosphere and all aboveground vegetation combined. Therefore, any discussion regarding forests, whether planted or native, must include the appropriate handling of the soil.

Eucalyptus trees do an excellent job of sequestering CO_2 because they efficiently store carbon in all their live biomass. Especially in the tropics, where sun and rain are abundant, extremely high conversion of CO_2 occurs in the biomass. With such high efficiency, it is only natural that eucalypt trees grow quickly and with high productivity. Eucalypt plantations are more efficient than even native forests in terms of carbon sequestration. The average growing cycle (from planting of seedlings to harvesting) of *Eucalyptus* for pulp production is seven years. Trees do not absorb the same amount of CO_2 throughout their lives. Young trees have a higher growth rate and, consequently, accumulate more carbon. Trees in a preserved native forest require energy only for their sustenance, while trees in planted eucalypt forests are in an on-going growth cycle, because every year new trees are planted.

Conclusions

Eucalyptus produces wood quickly to meet society's needs, and also helps preserve native forests. *Eucalyptus* trees are highly profitable and take a shorter period to reach harvesting age and require little human action on the land during this period. They can be cultivated in areas of low natural fertility and do not demand a great deal of nutrients and agricultural chemicals when compared to other crops. With rapid growth, eucalypts help to absorb carbon dioxide from the atmosphere and return oxygen to the atmosphere. With the growing interest in tree planting for climate change mitigation, the time has once again come for eucalypts. Clearly, the role of eucalypt plantations is fundamental to our efforts to neutralize the effect of greenhouse gases responsible for the warming of the Earth. Despite endless debates surrounding *Eucalyptus,* it holds a great promise for the future in terms of economic development and climate change mitigation, although management should carefully address the problems associated with the eucalypt trees under certain climatic conditions.

Many of the allegations on species of *Eucalyptus* are not scientifically supported and are disproved by many recent research findings. Rather, water use efficiency of eucalypts is far better than most agricultural crops. Also with good management, eucalypt planting supports the protection and conservation of biodiversity. The belief that eucalypts consume lots of water and creates a green desert is thus unjustified. Finally, the contribution of eucalypt trees to the sustainable development of Ethiopia is significant owing to its economic profitability and its role in household food security. However, the position or the attitude of some experts on this most important tree species – *Eucalyptus* - has to change.

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References

Aracruz Corporate Communications Department. 2008. *Eucalyptus* trees and the environment. Available at: http://www.aracruz.com.br/eucalipto/en/. Accessed in September 2009.

Asaye Asnake. 2002. Yield and Economics of Growing *Eucalyptus camaldulensis* by Smallholder Farmers of Amhara Region: The Case of Gondar Zuria District, North Gondar, Ethiopia. MSc thesis, Swedish University of Agricultural Sciences, Skinnskatteberg, Sweden.

Demamu Mesfin. 2002. Economic analysis of *E. globulus* plantation in the former Dessie fuel wood project, South Wollo, Ethiopia. MSc thesis, Swedish University of Agricultural Sciences, Skinnskatteberg, Sweden.

Davidson J. 1989. The *Eucalyptus* dilemma. Arguments for and against *Eucalyptus* planting in Ethiopia. The Forestry Research Centre Seminar Note Series No. 1, Addis Ababa.

Hadley Centre. Climate Change and the Greenhouse Effect - A briefing from the Hadley Centre. Governo do Reino Unido.2005.http:// www.metoffice.gov.uk/research/hadleycentre/pubs/brochures/2005/climate_greenhouse.pdf. Accessed in April 2007.

Henery PW. 1973. Notes on maps of the *Eucalyptus* plantations around Addis Ababa and the Menagesha State Forest, Ethiopia.. ODA. London. Misc. Report. 150:1-10.

Jagger P, J Ponder. 2000. The role of trees for sustainable management of less favored lands: the case of *Eucalyptus* in Ethiopia. *EPTD Discussion paper No. 65*. International Food Policy Research Institute, Washington, D.C. USA.

Jagger P, J Pender,B Gebremedhin. 2005. Trading off Environmental Sustainability for Empowerment and Income: Woodlot Devolution in Northern Ethiopia. *World Development* 33: 1491–1510.

Lemenih M, F Bongers. 2010. The role of plantation forests in fostering ecological restoration: experiences form east Africa. In: Bongers F, Tennigkeit T (eds) Degraded forests in Eastern Africa: management and restoration. Earthscan Publishers.

Mesele Negash. 2002. Socio-economic aspects of farmers' *Eucalyptus* planting practices in the Enset-Coffee based agroforestry system of Sidama, Ethiopia. The case of Awassa and Shebedino Districts. MSc thesis, Swedish University of Agricultural Sciences, Skinnskatteberg, Sweden.

Mulugeta Lemenih, Demel Teketay. 2005. Effect of prior land use on the recolonization of native plants under plantation forests in Ethiopia. *For. Ecol. Manage. 218: 60–73*.

Mulugeta Lemenih, Zeleke Ewnetu. 2010. Small Scale Forests Managed by Smallholder Farmers in Ethiopia. Review paper, CIFOR, Ethiopian Office.

Mulugeta Lemenih, Taye Gidyelew, Demel Teketay. 2004. Effects of canopy cover and understory environment of tree plantations on species richness, density and sizes of colonizing native woody species in southern Ethiopia. *For. Ecol. and Manage*. 194: 1-10.

Selamyihun Kidanu, Gezahegn Ayele. 2004. Farm Practices and economics of *Eucalyptus globulus* boundary plantings on highland Vertisols in Ethiopia Agriculture and Human Values, PhD Thesis, Chapter 5 (71-86), Wageningen University of Agriculture.

Senbeta F, D Teketay . 2001. Regeneration of indigenous woody species under the canopy of tree plantations in Central Ethiopia. *Tropical Ecology* 42:175–185.

Senbeta F, D Teketay, B-Å Näslund. 2002. Native woody species regeneration in exotic tree plantations in Munessa-Shashemene Forest, Ethiopia. *New Forests* 24: 131-145.

Teketay D, M Lemenih, T Bekele , Y Yemshaw, S Feleke, W Tadesse, Y Moges, T Hunde D Nigussie. 2010. Forest Resources and Challenges of Sustainable Forest Management and Conservation in Ethiopia. In: Bongers F, Tennigkeit T (eds) Degraded forests in Eastern Africa: management and restoration. Earthscan Publ.

Teklu G. 2003. Expanse of plantation forest in Ethiopia. An outcome of more than half a century's effort. Ministry of Agriculture and Rural Development, Addis Ababa, Ethiopia.

Tesfay Teklay. 1996. Problems and prospects of tree growing by smallholder farmers. A case study in Feleghe-Hiwot locality, Eastern Tigray. MSc thesis, Swedish University of Agricultural Sciences, Skinnskatteberg, Sweden.

WBISPP. 2002. Woody Biomass Inventory and Strategic Planning Project: Forest resource of Ethiopia; a sustainable plan for the sustainable development, conservation and management of the woody biomass resources. MoA, Addis Ababa, Ethiopia.

Yirdaw E. 2002. Restoration of the Native Woody – Species Diversity, Using Plantation Species as Foster Trees, in the Degraded Highlands of Ethiopia. PhD Dissertation, Viikki Tropical Resources Institute, University of Helsinki, Finland.

Yitebitu Moges. 1998. The role of exotic tree plantations for fostering the regeneration of native forests in Ethiopian Highlands. MSc thesis, Wageningen University and Research Centre, The Netherlands.

Zebene Mekonnen, Habtemariam Kassa, Mulugeta Lemenih, B Campbell. 2007. The role and management of *Eucalyptus* in Lode Hetosa District, Central Ethiopia. *Forests, Trees and Livelihoods* 17: 309-323.

Rehabilitation of Degraded Lands through Participatory Tree Planting in Wayu and Anget Mewgia Kebele, North Shewa, Ethiopia

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Abstract

The paper examines the findings of rehabilitation of degraded lands through participatory tree planting carried out in the years 2007 and 2008. The specific objectives were to assess farmers' willingness and preference of tree species for planting in their unproductive agricultural lands; to evaluate the growth rate of introduced cuttings of *Eucalyptus globulus* from Spain in comparison with Ethiopian provenance in a degraded farmland. 219,826 seedlings of different species were raised in the nursery and distributed to 86 farmers. They were planted in 30 hectares of degraded and abandoned agricultural lands owned by these farmers. Even though seedlings of different species were also raised and distributed, eucalypt had a lion share accounting for 88 % and 90% of the total number of seedlings in the first and second year, respectively. This is due to the farmers' interest in growing *Eucalyptus* species. Among the distributed seedlings, *E. globulus* had the highest survival percentage (95%). *Eucalyptus* was grown in degraded lands with a dual purpose of rehabilitation and income generation. Farmers in the project area are highly motivated to plant *E. globulus* in their degraded agricultural lands instead of using them for crop production or plantation of indigenous species, which is associated with an expectation of an early economic return from the sale of its poles. *E. globulus* can be planted in farmers' unproductive lands to both improve their livelihood and to rehabilitate their degraded lands.

Keywords: Degraded land; *Eucalyptus globulus;* Farmers; Provenance; Rehabilitation

Introduction

Trees have multiple roles in rural livelihoods, where they provide significant economic and ecological benefits. Trees can augment a household's income through sales of wood products and can contribute to risk management by diversifying agricultural outputs and spreading risks of agricultural production failure (Zenebe et al. 2010). *Eucalyptus* trees are relatively fast growing and profitable. The rates of return for farmers' investments in eucalypts are often above 20% (Jagger and Pender 2003).

In Ethiopia Eucalyptus, species played and will play a tremendous role in alleviating the fuel and construction material problems in the country (Tesfaye 2007; Henry 1973). Holden et al. (2003) analyzed the potential of tree planting to improve household welfare in the poorer areas of the Amhara region of Ethiopia and their result indicated the potential of planting *Eucalyptus* trees as a strategy to reduce poverty in a less-favoured area of the Ethiopian highlands. In some areas, planting *E. globulus* overrides the production in crop yield and it makes returns to land and returns to labour 1.3-1.7 times and 1.2 -1.5 times greater than sole wheat cropping (Selamyihun 2004). The other greatest positive contribution of Eucalyptus is replacing indigenous species for firewood, thereby, preventing further denudation of natural forests (Evans 1992). Some studies also indicated the potential of *Eucalyptus* as one of the most important commercial plantation and pioneer tree species for successful ecological restoration of degraded lands (Yu 1994, 1995; Zhou et al. 2001). On the other hand, *Eucalyptus* is criticized because of the following: the species do not provide organic matter and depletes soil nutrients needed by agricultural crops; it depletes water resources and competes with agricultural crops; it suppresses ground vegetation resulting unsuitable for soil erosion control; the leaves of *Eucalyptus* are not palatable and cannot be used as fodder species; and people raise issues related to its allelopathic effects (Jagger and Pender, 2000). Due to fears of the negative aspects, some countries restricted or banned planting *Eucalyptus* (Poore and Fries 1985). Similarly, some administrative regions like Tigray have banned the planting of *Eucalyptus* on farmlands (CNST 1997).

According to FAO (1988) eucalypt plantations have become a subject for argument in some countries because the needs of local people and the forestry objectives likely to be achieved by planting eucalypts have not been well matched. In other countries eucalypt plantations are making a very good contribution to the needs of the community because the advantages obtained outweigh the disadvantages; it would be quite unwise to grow *Eucalyptus* if they were not beneficial to the majority of local people. Generally, *Eucalyptus* in Ethiopia is highly favoured for planting by farmers and it is common to see the trees in most agro-ecological zones of the country. The objectives of the research were to recognize farmers' preference and to raise seedlings for the rehabilitation of degraded lands. The findings can be used by policy makers or other similar projects to promote tree planting in degraded areas.

Materials and Methods

The project area

The project was implemented in Wayu ena Anget Mewgia Kebele, in North Shewa. It is located 35 km southeast of Debrebirhan town and 165 km northeast of Addis Ababa (Figure 1). The project area is characterized by rugged topography, with mountain peaks and deep valleys, intersected by a few gentle slopes. It has an average altitude of 2750 meters above sea level. The area has two rainy seasons, namely: *meher* (long rains), usually lasting from June to the beginning of September, and *belg* (short rains), which usually falls between January and April. *Belg* production is very important in the Kebele since frost is a common occurrence during *meher* season. Nevertheless, *belg* season is highly unreliable being characterized by variability and delay or absence of rain.

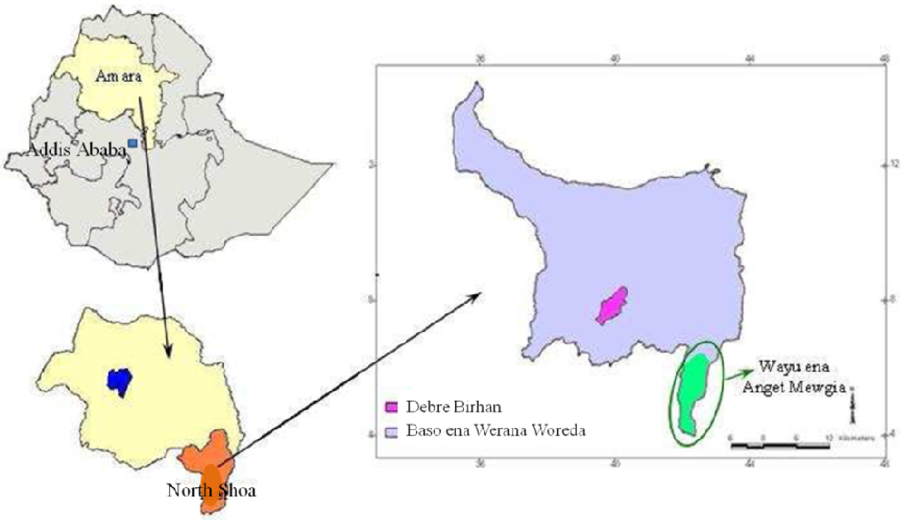

Figure 1. The project area

Mixed farming i.e. crop production with animal husbandry is a common practice. The main crops grown include *Hordeum vulgare* (barley), various types of *Triticum aestivum* (wheat), *Phaseolus lunatus* (beans), *Pisum sativum* (peas), *Lens culinaris* (lentils) and *Linum usitatissimum* (linseed). *H. vulgare* and *P. lunatus* are the most important crops for the farmers in terms of consumption and market. Most farmers allocate crops for self-consumption as compared to those used for selling and generating incomes. The average land holding is 2 ha. The main livestock types are cattle, sheep, goats, donkeys, horses, and mules. Dung is used for fuel. The farmers in the study area generate income or cash for clothing, paying taxes and covering other basic expenses from livestock.

Soil fertility in the area has been declining over time. The two main reasons given are deforestation (most of the soil is left uncovered) and unsustainable farming. At present, not more than 2% of the area is covered with forests and trees. *Eucalyptus globulus* is observed as a big plantation around most individual land holdings. Traditionally the fertility of the soil was maintained by using manure, crop rotation, and ash. The use of dung for soil fertility management seems to be an old practice in this area. Nowadays, only the dung of sheep, goats, and draft animals (mules, horses, and donkeys) is used for preparing manure. Cow dung is entirely used to make dung cakes, which are widely used in the Kebele as sources of fuel and cash to buy salt, coffee, and other commodities.

Description of the project and method of implementation

The project was implemented by Universidad Politécnica de Madrid, Spain, in collaboration with the Forestry Research Center (FRC), Ethiopia. The objectives were: a) to raise seedlings in the nursery based on the local community species preference for planting in their degraded lands, and b) to evaluate growth and land rehabilitation potential of *E. globulus*—introduced from Spain. Prior to implementation, the objectives of the project were presented to the local community and concerned officials. Farmers who were interested in planting trees in their degraded lands were selected by the Kebele leaders. Suitability and size of lands for this purpose were assessed by the project team, and development agents. Farmers were interviewed in order to know the tree species, which were preferred. Then, seedlings of chosen and available species were raised in the nursery using plastic pot and managed until out planting. Planting holes were prepared at a spacing of 1.5 x 1.5 m and seedlings were managed (weeding, hoeing, and cultivation) by the respective owners of the lands.

Planting of cuttings and seedlings in degraded lands

To compare the growth of different provenances of *E. globulus* on degraded lands, cuttings introduced from Spain (clone codes 354 with 102 ramets and 334 with 91 ramets) and seed-originated seedlings from Ethiopia (27 seedlings) were planted at a spacing of 2 m × 2 m.

Data Collection

The survival of the seedlings, the attitude of farmers involved in the project and problems that they have faced in tree planting were understood through informal discussion. Planted seedlings on the farmers' land were periodically observed and pictorially documented. Seedling survival in randomly selected farmers' land was also assessed in the second year of the project. Diameter at 40 cm above the ground and height of cuttings and seedlings of the 2 provenances were collected in January 2008 (one year after planting). Calliper and hypsometer were used to measure diameter and height, respectively.

Data analysis

Excel worksheet was used to compile the data. Survival of seedlings was analyzed in percentage. Diameter and height increment of trees were presented using graphs. Tree species preferences of farmers to plant in their degraded lands were systematically compiled.

Results and Discussion

Number of seedlings raised and distributed to farmers

A total of 219,826 seedlings of different species were raised in the nursery based on the preference of individual farmers (Table 1). The number of tree seedlings raised and distributed to the farmers varied from year to year. In 2007, about 112,762 seedlings of 5 species were distributed to 40 farmers (3 of them were women). Similarly, 107,064 seedlings of 4 species (Table 1) were raised and delivered to 46 farmers (2 of them were women) in 2008. The distributed seedlings were planted in 30 ha of degraded farmers' lands. Even though different seedlings of tree species have been raised and distributed to farmers, *Eucalyptus* had a lion share (88 % and 90 % in the first and second year, respectively). This is due to the farmers' interest to grow eucalypt species.

The number of female farmers involved in tree planting was low. This is associated with the division of labour in the community. In most cases, women are restricted in household activities while men are responsible for farm and other off-farm businesses. This division of responsibilities indicates how the role of women in tree planting is low. Hence, the involvement of women in tree planting should be increased through awareness creation and other mechanisms.

Table 1. Number of seedling of different species and provenances grown in the nursery and delivered to individual farmers for planting in degraded lands in the years 2007 and 2008

Species	2007		2008	
	No of seedlings	Proportion (%)	No of seedlings	Proportion (%)
E. globulus (Ethiopia)	69,468	61.6	80,205	74.9
E. globulus (Spain)	29,819	26.4	16,213	15.1
Sesbania sesban	2,585	2.3		
Casuarina equisetifolia	2,560	2.3		
Grevillea robusta	2,580	2.3		
Cupressus lusitanica	5,750	5.1		
Pinus canariensis			6,971	6.5
Olea africana			3,000	2.8
Juniperus procera			675	0.6
Total	112,762		107,064	

Farmers' preference of tree species

Farmers often prefer species whose silvicultural characteristics are well known, and species that have well-defined end uses and good markets. *E. globulus* is the preferred species due to its fast growth rate, ability to coppice and expectation of an early and high economic return from the sale of its poles. They also witnessed that some farmers who had *Eucalyptus* planted in their lands brought higher income. *Eucalyptus globulus* had higher survival rate (90%) in selected individual farmers land. Other planted indigenous and exotic species such as *S. sesban, C. equisetifolia, G. robusta, C. lusitanica, P. canariensis, O. africana* and *J. procera* had generally poor survival (< 10%), which might be associated with the degradation effect of the land, and also with frost problems. Farmers have a traditional knowledge of protecting trees from frost by putting big stones, grasses, and soils around the planted seedlings. The seedling survival assessment result showed that *E. globulus* is one potential species to grow in degraded lands. It resistances to frost and wind damage shows the species can play an important role in rehabilitating degraded lands. Identification of farmers preferred species prior to raising and distributing tree seedlings is very important to avoid failures. Farmers were concerned to manage planted trees because of their involvement in the tree selection, seedling raising, and other processes. The participatory approach of the project helped also to create positive competition among farmers to be best managers of planted trees. Farmers were aware of the impacts of *Eucalyptus* on agricultural crops and because of that; they planted it at a far distance from the crop fields.

Farmers have realized that the spacing used (1.5m × 1.5m, 4,500 seedlings/ha) was quite important for a faster growth of the eucalypts and it allows growth of grasses in its underneath as compared with their traditional spacing (<1m × 1m). In the second year of planting the farmers started to mow grasses and carry them out for their livestock. In many parts of the country, Eucalyptus is planted with a very high planting density (0.5 m × 0.5 m and up to 40,000 seedlings per hectare). The high planting density makes eucalypts grow thinner. It also affects the growth of other species under the plantations. Therefore, training farmers on the effect of narrow spacing in tree planting is important.

Growth of cuttings and seed-originated seedlings

The mean annual height of *E. globulus* clone 354, *E. globulus* clone 334, and *E. globulus* seed-originated seedlings were 1.99 m, 1.94 m and 0.87m, respectively. The diameters were 3.13 cm, 3.04 cm and 3.59 cm (Figure 2). There is a clear difference on the height growth and diameter increment between seed-originated seedlings (Ethiopian provenance) and cuttings (Spanish provenances), which may be associated with the provenances. Both cuttings grow faster than seed originated seedlings. On the contrary, seed-originated seedlings achieved a higher diameter increment than the cuttings. The statistical test result showed that there is no significance difference ($P < 0.05$) in the diameter increment and height growth between the cuttings of Spanish provenances. However, making a definitive conclusion is not possible due to the differences in the origins of the seedlings (cuttings and seedlings) and the lack of proper experimental design in the trial, variability in the number of plantings and the different performance of seed-originated seedlings and cuttings. Besides, the Spanish clones were originated from superior individuals. However, it can give a clue as one research area for further future works.

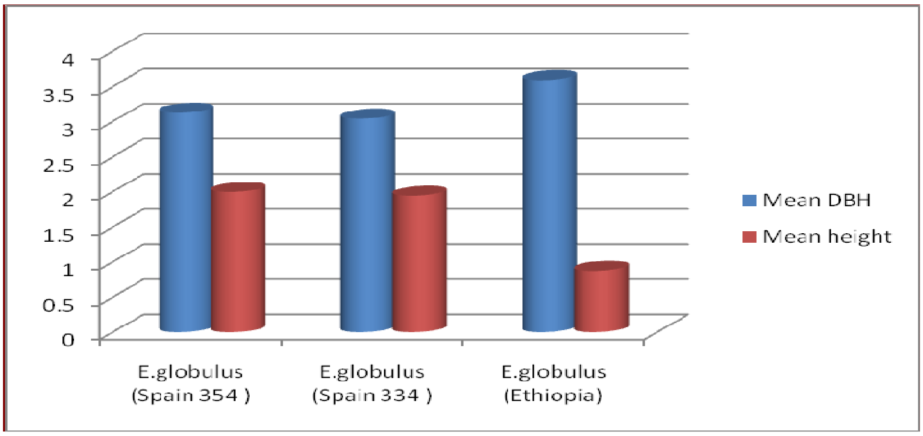

Figure 2. Height (m) and diameter (cm) of cuttings and seedlings of *E. globulus* established in a degraded land after one year of planting

Conclusion and Recommendations

Keeping the interest of farmers in participatory tree planting to rehabilitate degraded lands is important as an integral part of any rural development program. Trees provide the community with construction wood, fuel wood, food, income, and environmental benefits. The project showed that *E. globulus* was highly preferred by farmers for planting in their degraded lands. The growth of cuttings and seed-originated seedlings of *E. globulus* on degraded lands, their biomass production; their land rehabilitation potential should be compared and further studied.

Acknowledgment and Dedication

The Authors acknowledge Universidad Politécnica de Madrid, Spain, for its financial support of the Project. The Forestry Research Center (FRC), Ethiopia, is also acknowledged in its support of field vehicles and forest seeds. Our gratitude also goes to ENCE, Spain, for providing us cuttings and seeds of *E. globulus*. We thank also North Shewa Zone and Wayu ena Anget Mewgia Wereda Agricultural Bureaus for their kind cooperation in all the steps of the project. Our special thanks extended to Mr. Kifle Asfaw and the nursery workers (Gebriye, Fikirte and Meles) for their energetic involvement in nursery activities.

This paper is dedicated to Ms. Margarita Burón, who passed away in a car accident in Ethiopia, during her travel from the project area to Addis Ababa, on 12 June 2007, at about 10 km from Debre Birhan town. Mrs. Burón was one of the promoters and initiators of this project. She had many value adding and calibrating ideas for the project.

References

CNST (Council of the National State of Tigray). 1997. The National State of Tigray Rural Land Proclamation No. 23/1997. Council of the National State of Tigray, Mekele.

Evans J. 1992. Plantation Forestry in the Tropics: 2nd Edition. Oxford University Press, New York.

FAO. 1988. *The Eucalyptus Dilemma*. FAO, Rome. 26pp

Henery PW. 1973. Notes on maps of the *Eucalyptus* plantations around Addis Ababa and the Menagesha State Forest, Ethiopia. ODA. London. Misc. Report 150,1-10.

Holden S, S Benin, B Shiferaw, J Pender. 2003. Tree planting for poverty reduction in less-favored areas of the Ethiopian highlands. Small-Scale Forest Economics, Management and Policy 2(1): 63–80.

Jagger P, J Pender. 2000. The Role of Trees for Sustainable Management of Less Favored Lands: The Case of *Eucalyptus* in Ethiopia. Environment and Production Technology Division Discussion Paper No. 65. Washington, DC: International Food Policy Research Institute.

Jagger P, J Pender. 2003. The role of trees for sustainable management of less-favored lands: the case of *Eucalyptus* in Ethiopia. Forest Policy and Economics 5(1), 83–95.

Poore MED, C Fries. 1985. The Ecological Effects of Eucalypts: Forestry Paper 59. Rome, Italy.

Selamyihun K. 2004. Using Eucalypts for Soil and Water Conservation in the Highland Vertisols of Ethiopia: Academic Dissertation. Wageningen, The Netherlands.

Teshome T. 2007. Is *Eucalyptus* Ecologically Hazardous Tree Species? Ethiopian Tree Fund Foundation. http://etff.org/Articles/ *Eucalyptus*.html, accessed on June 21, 2010.

Yu ZY. 1995. Ecology of the rehabilitation of vegetation on tropical coastal eroded land in Guangdong, China (in Chinese). Journal of Environmental Science 7, 74–84.

Yu ZY. 1994. Rehabilitation of eroded tropical coastal land in Guangdong, China (in Chinese). Journal of Tropical Forest Science 7, 28–38.

Zenebe G, M Alemu, K Menale, K Gunnar. 2010. Household Tree Planting in Tigrai, Northern Ethiopia:Tree Species, Purposes, and Determinants. Environment for Development, Addis Ababa.

Zhou GY, JD Morris, JH Yan, ZY Yu, SL Peng. 2001. Hydrological impacts of reafforestation with *Eucalyptus* and indigenous species: a case study in southern China. Forest Ecology and Management. 5741, 1–14.

Regeneration of *Coffea arabica* and Quality of Coffee Found in an *Eucalyptus grandis* Plantation

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Abstract

The paper focuses on the impact of *E. grandis Hill* ex Maiden on the natural regeneration of C. *arabica* L. and on its cup quality as compared with the adjacent natural forest coffee. The objectives were to assess the natural regeneration status of *C. arabica* under *E. grandis* plantation in comparison with its adjacent natural forest, and examine and compare the coffee quality (Green quality (Odour + defect) + Cup quality (Acidity + Body + Flavour)) of natural forest coffee and the *E. grandis* plantation coffee. For data collection, twenty plots, with an area of 20 m × 20 m for each, were established in both of *E. grandis* plantation and adjacent natural forest, independently. In each plot, all coffee plants diameter and height were recorded. Numbers of seedlings were counted in five sub-plots (4 m^2) established at the corners and the centre of each major plot. For the coffee quality test, beans were collected in both forest types independently and its quality assessed in the coffee and tea quality-liquoring laboratory following the standard procedure. The analysis result indicated that the density of coffee plants in the plantation was 1,022 stems/ha, while it was 1,042 stems/ha in the natural forest. The number of coffee seedlings in the *E. grandis* plantation was 3,350 seedlings/ha while in the natural forest it was 7,000 seedlings/ha. The quality test result indicated that the green quality of coffee beans found in the natural forest was 35%, while it was 33% in those collected in the plantation. The Cup quality was 45% in both the natural forest and the *E. grandis* plantation. There was no significant difference on the bean size of coffees collected from both the natural forest and the *E. grandis* plantation. Finally, coffee beans harvested from the natural forest and plantation was assigned in the category of grade two exportable standard coffees. To utilize *E. grandis* as a shade tree for coffee, further investigations with regard to moisture competition, root interaction, and allelopathic effects were recommended.

Keywords: *Coffea arabica*, *Eucalyptus grandis*, Natural forest, Quality, Regeneration

Introduction

Plantation forests adjacent to exposed remnants of indigenous forest can provide shelter, accommodate edge-specialist species and generalist forest species that would benefit from any forest type (Christian *et al*., 1998; Norton, 1998). It can also have catalytic effect on regeneration of some species and used as a management tool to reclaim degraded lands, (Lugo 1997; Yitebitu 1998;

Engelmark 2001; Eshetu 2002; Feyera et al. 2002; Mulugeta and Demel 2004; Mulugeta et al. 2004). However, some plantation species like Eucalyptus has attracted the most criticism (Evans 1992). Some of the critics associated with it are: the species depletes water resources and competes with agricultural crops; it has an allelopathic effect, so that it cannot be used for agro-forestry purposes (Jagger and Pender 2000).

Even if, people deem that the species would not serve for agro forestry purpose, under rain fed conditions, 6x1 m spacing, *Eucalyptus* as agro forestry tree has given the best results (Mathur et al. 1984). When sweet potato was inter-cropped in 208.7 ha of *Eucalyptus* plantations in China it gave good results, and brought an income of 1,286 RMB/ha (Zeng 1992). In India, Nepal, and Thailand, agricultural and horticultural crops growing with *Eucalyptus,* and no adverse effects were noted (White 1988). The use of some *Eucalyptus* trees in agro-forestry is also common in Nigeria and Thailand (Igboanugo et al. 1990). In Srilanka *E. grandis* forms an interesting agro-forestry combination with cardamom (Stocking 1993).

Moreover, under certain conditions tropical farmers use very fast growing and presumably competitive trees in tree crop associations. In some parts of Costa Rica, the use of *Eucalyptus deglipta* as coffee shade is common, and no evidence of negative effects of the trees on coffee growth, yield, and mineral nutrition was found despite the fast tree growth (Schaller et al. 2003). Generally, not all *Eucalyptus* species may have equal negative effects on different species growing with it. Their effect may vary within different geographical areas, rainfall regimes and within species. The overall objective of this study was to evaluate the effect of *E. grandis* over story tree in its underneath naturally regenerated *C. arabica* and on its quality. The hypotheses of the study were a) *Eucalyptus grandis* as an over story tree does not affect the natural regeneration of *C. arabica* as compared to its adjacent natural forest b) *Eucalyptus grandis* as a shade tree has a negative effect on the cup quality and green quality of coffee.

Materials and Methods

Site description

The study was conducted in Belete state forest (7^0 31' N, 36^0 33' E) in the south-western part of Ethiopia (Figure 1). The study area has an altitudinal range of 1978 - 2113 m above sea level. The physical feature is characterized by a rugged topography, dominated by gentle slopes and a localized steep slopes ranging from 4 – 45%. The *E. grandis* plantation was established in 1975 for the purpose of provenance trial and planted in 2.5 m x 2.5 m spacing. The mean height and mean diameter at breast height (DBH) of *E. grandis*, in the year 2006, were 19.5 m and 30.9 cm, respectively.

The study area has a uni-modal type of rainfall pattern with the highest rain occurring between January and April. The mean annual rain fall for the years 1968-2004 was 1547 $\pm$ 324.5 mm year $^{-1}$, with large inter annual variability. The mean annual temperature for the years 1980 - 2004 was 19.3 ^{0}C, with a mean minimum of 13.3 ^{0}C to mean maximum of 23.3 ^{0}C. The hottest months occur from September to November (maximum 27.8 ^{0}C). While coldness, occur from June to August (minimum 12.8 ^{0}C). The rocks in the study area consist of Precambrian rocks, and it has a Drystic Nitosols soil type, that has good potential for agriculture, good physical properties, stable structure, deep rooting volume, and high moisture storage volume (EMA 1988).

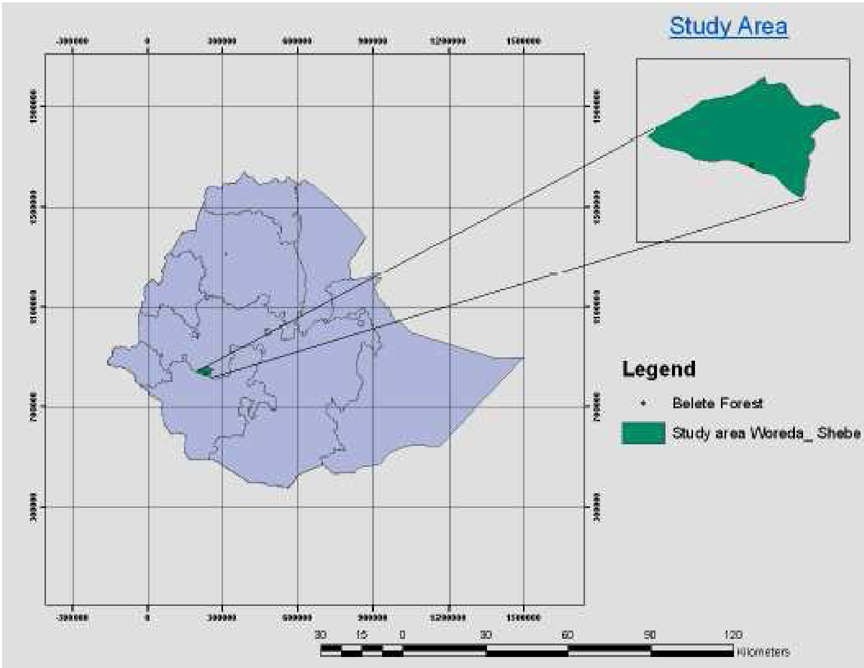

Figure 1. Study area (Belete State Forest)

Sampling and data collection

A systematic sampling design was used to collect data on coffee vegetation and environmental variables. A nested quadrant plot design was used to collect data. The plots were laid out along line transects. The distance between consecutive plots with in transect was 100 m, and the spacing between two adjacent transect lines was also 100 m. Inside each major plot (20 x 20 m), five subplots (2 x 2 m) established. Among these subplots, four of them were laid at the corners of the major plots, and the other at the centre. A total of 40 major sample plots, each having an area of 400 m^2 was laid out. Among these plots, 20 of them were in the natural forest and the remaining was in the *E. grandis* plantation. Hence, 100 subplots, each were placed in the plantation and natural forest. Within the major plot, the diameters of *C. arabica* individuals were taken at 30 cm above the ground. The total heights of individual stems of *C. arabica* were measured using a marked rod. Each subplot was used to collect data on numbers of coffee seedling (height < 25 cm).

Ripe coffee berries from both forest categories (Natural forest and *E. grandis* plantation) were collected in November 2005, and kept separately. Unripe, overripe, damaged berries, dirt, soil, and twig were sorted and removed from the harvested berries manually. Drying method, were used to prepare the coffee beans. Finally, the coffee beans were thoroughly mixed, and 1 kg sample from each forest category was taken. Coffee green quality, cup quality, and grading were done in the Laboratory of Coffee and Tea Quality Control and Liquoring Center of Ethiopia.

Data analysis

Density and structure of Coffee

Coffee data collected from each major plot and in each forest category were used for structural analysis. One-way ANOVA and Least Significant Difference (LSD) test was used to compare the mean diameter and total height of coffee plants (Mean diameter and total height values of each plot of the plantation and the natural forest were considered as a replication). Paired t-test was used to compare the density of coffee stems per plot that were enumerated in the natural forest and *E. grandis* plantation (Mean values of individual plots of the plantation and natural forest considered as a replication). The statistical test at 5% level of probability was analyzed using statistical SAS (9.1) software program (SAS 2003). The seedling data of coffee was also analyzed in a hectare base. Density and basal area of coffee in the two forest categories were calculated (Kent and Coker, 1994).

Coffee quality analysis

Coffee quality analysis were done and graded based on the Ethiopian Coffee Classification Standard. The samples were assessed, characterized and graded by appearance (bean size, uniformity, colour); number of defective beans per sample; cup quality, which includes acidity, flavour and body. Hundred point cupping system was used to score coffee characteristics. The overall coffee quality is analyzed as a sum of raw quality (Defect + Odour) and Cup quality (Acidity + Body + Flavour). Grading of coffee beans collected from the two forest categories were made after determining the overall quality [Cup quality (60 %) + raw quality (40 %)]. A coffee sample, which scored an overall quality of 81-100, 63-80, 50-62, 31-49, and 15-30 were classified as exportable standard coffee of grade 1, 2, 3, 4 and 5, respectively.

For the cup quality analysis, the coffee beans were roasted and the silver skins were removed before the coffee was crushed. Six standard sized cups (200 ml) were filled with 11 grams of grounded coffee. Boiled water was poured into the cups to half-full. The cups were then, stirred thoroughly. This procedure was repeated after 5 minutes. The floating silver skin and other waste substances were removed. Cup testing was performed after 20 minutes, when the cup reached the right temperature by three qualified and experienced cup testers, independently. The moisture percent of the coffee beans measured using Dickey-Jones Devices. Defect point was determined by taking 300-gram coffee beans from the sample.

Then, sorting out poor quality beans from good quality beans, percentages were noted. Bean size was determined using standardized screeners.

Results

Density of coffee and its growth

The density of coffee in the *E. grandis* plantation was 1022 stems/ha while it was 1042 stems/ha in the natural forest. The t- test statistics ($t_{0.025(38)} = 2.025$, t cal =0.0398) result revealed, no significant difference in the number of individuals of coffee in the natural forest and the Eucalypt plantation. The number of coffee seedlings in the Eucalypt plantation was 3,350 seedlings/ha, while it was 7000 seedlings/ha in the natural forest. On the other hand, the one-way ANOVA result (Table 1) revealed significance difference ($p < 0.05$) between the mean total height and diameter of coffee plants found in the plantation and the adjacent natural forest.

Table 1. Results of one-way ANOVA for mean diameter and total height of coffee grown in the natural forest and *E. grandis* plantation

Forest categories	Diameter (cm)	Total height (m)
Natural forest coffee	4.11A	3.89A
Eucalypt plantation coffee	3.29B	2.84B
P in ANOVA	0.0096	<0.0001

Means with the same letters are not significantly different at P=0.05

Coffee population structure

The diameter class distribution indicated that 81.9 % of coffee plants found in the Eucalypt plantation and 64.11% of coffee plants in the natural forest had a diameter of less than 4 cm (Fig. 2). The total height class distribution showed that 69.25 % of natural forest coffee and 72.3 % of Eucalypt plantation coffee fall in the height classes of 3, 4 and 5 (Figure 3). Coffee found in the plantation had a basal area of 18.76 % and 4.92 in the natural forest.

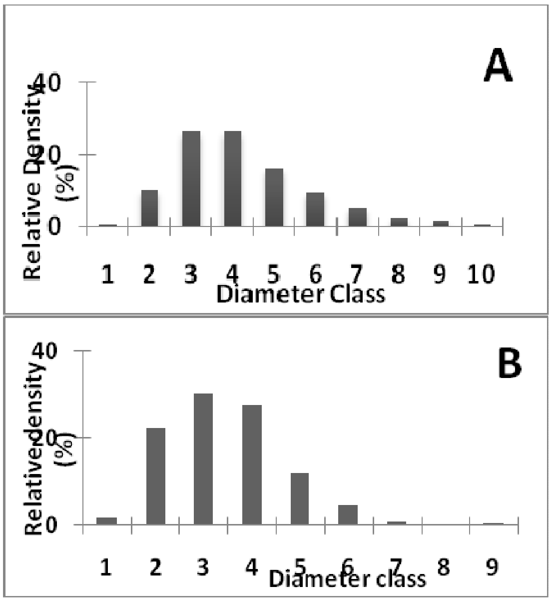

Figure 2. Diameter class distribution versus relative density of Coffee plants found in the natural forest (A) and *E. grandis* plantation (B).

1=0.1-1 cm., 2 = 1.1-2 cm, 3 = 2.1-3 cm, 4 = 3.1-4 cm, 5 = 4.1-5 cm, 6 = 5.1-6 cm, 7 = 6.1-7 cm, 8 =7.1-8 cm, 9 = 8.1-9 cm, 10 = ≥9.1cm

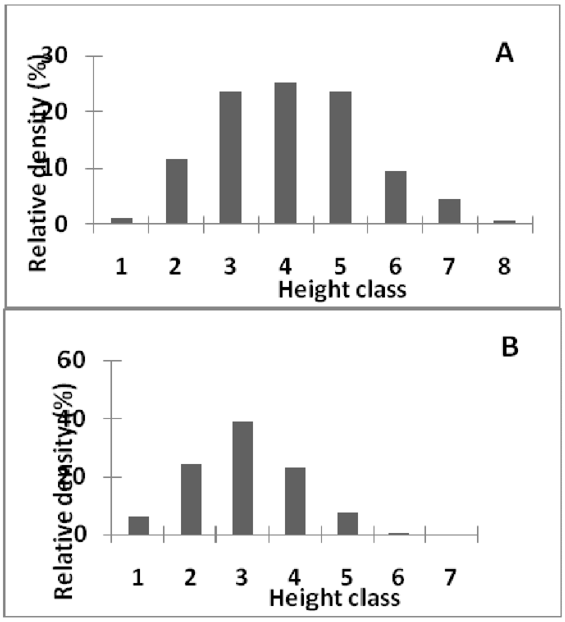

Figure 3. Total height class distribution versus relative density of Coffee plants in the natural forest (A) and *E. grandis* plantation (B)

1 = 0.1-1 m, 2 = 1.1-2 m, 3 = 2.1-3 m, 4 = 3.1-4 m, 5 = 4.1-5 m, 6 = 5.1-6 m, 7 = 6.1-7 m, 8 = 7.1-8 m

Coffee quality

The coffee quality (Green quality + Cup quality) inspection result indicated that 97 % of coffee beans collected in the Eucalypt plantation and natural forest were above screen 14 (Table 2). The total amount of defects of natural forest coffee was 79, while it was 90 in the plantation (Table 2). The cup quality (Acidity + Body + flavour) of coffee from natural forest and *E. grandis* plantation was the same (Table 2). Finally, the plantation coffee (green quality (33%, table 2) + cup quality (45%, table 3) =78 %) and the natural forest (green quality (35%, table 2) + cup quality (45%, table 3) =80 %) coffee has a grade two exportable standard Ethiopian coffee.

Table 2. Green quality analysis results of coffee beans collected in the natural forest and *E. grandis* plantation

Forest type	Moisture content (%)	Quantity above screen 14 (%)	Defect point (%)	Total score (%)
Natural forest	10	97	79	35
Eucalyptus grandis	9.8	97	90	33

Table 3. Cup quality analysis of coffee beans collected in the natural forest and *E. grandis* plantation

Forest type	Acidity	Body	Flavour	Total score (%)
Natural forest	15	15	15	45
Eucalyptus grandis	15	15	15	45

Discussion

Population structure, density, and growth

The ANOVA result revealed that, Coffee plants found in the natural forest were more vigorous than the plantation coffee. Though information on the history of the natural forest coffee is not available, this difference might be attributed to the age of coffee plants. The coffee plants in the plantation forest might be younger than natural forest.

The density of coffee plants decreased as the diameter class increased in both natural forest and the plantation. On the other hand, *C. arabica* had higher basal area in the plantation than the natural forest, suggesting that it is more abundant in the plantation than the natural forest. These results may indicate that *E. grandis* is one of the appropriate species, among others, where shade tree for *C. arabica* is desirable. Schaller et al. (2003) reported that the root system of coffee plants is competitive, and in areas where there is high availability of soil resources, coffee is compatible with very fast growing shade trees like *E.degelipta*. Density of coffee seedlings in the natural forest is much higher than that of the plantation. This may be associated due to collection of coffee beans by humans, since the coffee of Eucalypt plantation is more accessible than natural forest coffee. Therefore, few seeds were left in the ground to germinate in the plantation than the natural forest. Moreover, some farmers stated that seedlings under the *E. grandis* plantation uprooted and transplanted in the coffee farms by local communities. Studies made on the natural regeneration status of some species on exotic plantations in Ethiopia (*Grevillea robusta*), result revealed that in 55 % of the plots *C. arabica* were found naturally regenerating (Eshetu 2002). All this results can show that, some fast growing trees like *E. grandis* and *G. robusta* can catalyze the natural regeneration of *C. arabica*. Generally, these results may suggest that *E. grandis* favours the recruitment and growth of *C. arabica* and might not have a negative effect on coffee plants if used as shade tree.

Coffee quality

The quality of the coffee product is arguably the most important aspect of any production system and must be included in any discussion of shade. The result revealed that when *E. grandis* is used as shade tree, it has similar effect on the cup quality of coffee to the natural forest. Some studies showed that coffee bean size might increase or decrease slightly with shade (Andrea and Nair 2004). From, this study *E. grandis* as coffee shade tree does not have a different impact on the bean size of coffee from that of the natural forest. The total amount of defects was less under the natural forest than plantation coffee. This result may be attributed to insect attack of coffee beans during fruiting period in the Eucalypt plantation. Since, coffees in the plantation have open crowns, much more heat reaches and create favourable condition to insect breeding and attack than the natural forest coffee, which had dense crowns. Finally, as an over story tree *E. grandis* had no effect on the coffee quality. Natural forest and plantation coffee bean were assigned in grade two exportable standard coffees.

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References

Andrea A, PK Nair. 2004. Farmer perspectives on the role of shade trees in coffee production systems: An assessment from the Nicoya peninsula, Costa Rica. Journal of Human Ecology 32, 443 – 463

Christian DP, W Hoffman, JM Hanowski, GJ Niemi, J Beyea.1998. Bird and Mammal diversity on woody biomass plantations in North America. Biomass and Bioenergy14, 395-402.

Ethiopian Mapping Authority (EMA). 1998. National atlas of Ethiopia. Addis Ababa, Ethiopia. Pp. 76

Engelmark O. 2001. Ecological effects and management aspects of an exotic tree species: the case of lodge pole pine in Sweden. Ecology and Managment 141, 3-13.

Eshetu Y. 2002. Restoration of the native woody species diversity using plantation species as foster trees in the degraded highlands of Ethiopia. Dissertation, University of Helsinki. Pp. 61.

Evans J. 1992. Plantation forestry in the tropics: 2nd Edition. Oxford University Press, New York. Pp 403.

Feyera S, T Demel, N Bertake. 2002. Native woody species regeneration in exotic tree plantations at Munessa-Shashemene forest, Southern Ethiopia. New Forests 24, 131-145.

Igboanugo AB, JE Omijeh, JO Adegebehin. 1990. Pasture floristic composition in different *Eucalyptus* species plantations in some parts of the Northern Guinea savanna zone of Nigeria. Agroforestry system 12, 257-68.

Jagger P, J Pender. 2000. The role of trees for sustainable management of less favored lands: the case of *Eucalyptus* in Ethiopia, discussion paper No. 65. International Food Research Institute, Washington. Pp. 81

Kent M, P Coker. 1994. Vegetation description and analysis: a practical approach. John Wiley and Sons, England. Pp. 363

Lugo AE, 1997. The apparent paradox of reestablishing species richness on degraded lands with tree monocultures. Forest Ecology and Managment 99, 9-19.

Mathur RS, KK Sharma, MY Ansari. 1984. Economics of Eucalypts plantations under agro forestry. Indian Forester 5, 10-17.

Mulugeta L, T Demel T, 2004. Restoration of native forest flora in the degraded high lands of Ethiopia: constraints and opportunities. Ethiopian Journal of Science 27, 75-90.

Mulugeta L, G Taye, T Demel. 2004. Effects of canopy cover and understory environment of tree plantations on species richness, density and sizes of colonizing woody species in Southern Ethiopia. Forest Ecology and Managment 194, 1-10.

Norton DA. 1998. Indigenous biodiversity conservation and plantation forestry: options for the future. New Zealand Journal of Forestry 43, 34-39.

Schaller M, G Schroth, J Beer, F Jimenez. 2003. Species and site characteristics that permit the association of fast growing trees with crops: the case of *Eucalyptus deglipta* as coffee shade in Costa Rica. Forest Ecology and Managment 175, 205-215

White KJ. 1988. Tree farming practices in the Bhabar Terai of central Nepal, Sagarnath: Manual No 2. Ministry of Forestry, Kathmandu

Yitebitu M. 1998. The role of exotic plantation forests in fostering regeneration of native trees in an afromontane forest area in Ethiopia. Thesis, Wageningen Agricultural University. Pp. 52

Zeng Q. 1992. An effective measure for controlling soil degradation in Eucalypts plantation. Chinese Scientific and Technical Publishing House, Beijing.

Community Opinion, Marketing and Current Debates on *Eucalyptus* in Huruta District, Arsi Zone of Oromia Region, Ethiopia

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Abstract

The fast growth rate of *Eucalyptus* to provide possible products for the livelihood consumption and for the market has over won the continuing planting of the species irrespective of the policy resistant from the policy makers in Ethiopia. Until the end of the 1990s, the main tree seedling produced in government nurseries was *Eucalyptus,* but starting from the early 2000s, production of *Eucalyptus* in government nurseries has been given up. On the contrary, *Eucalyptus* gives some attention for concern in the context of diversified plantations by smallholder farmers, because owing to its importance to the household livelihood strategy by providing income and wood products for household consumption. With a large proportion of the world population in general, and of developing countries such as Ethiopia in particular, depending on wood for cooking and heating, the economic importance of *Eucalyptus* is immense. *Eucalyptus* outputs have significant impacts of change on rural livelihoods. The objective of the study is to review existing literature on *Eucalyptus* from science, policy, and farmers' perspectives and to assess the local market value and commercialization of *Eucalyptus* by farmers. In this study it was found that *Eucalyptus* wood products contributes 78 % of the local market economy for firewood, 100 % each for construction poles and posts, 20 % for charcoal and 93 % for the four wood product types at Huruta town which amounts a total of birr 99,867 ($ 12,484) in two weeks in 2005 markets and which is $15,189 when discounted at 4 % interest rate at the current market. Farmers have remarked that planting fast growing trees like *Eucalyptus* is the best alternative strategy to minimize the existing firewood scarcity in the locality rather than the use of cow dung and crop residues. The three extensive benefits farmers can obtain if they choose to grow *Eucalyptus* as a commercial tree on their land are (i) diversifying their farm income by growing it as a crop; (ii) increasing the productivity of their existing farm endeavour; and (iii) improving the sustainability of their current farming system.

Key words: *Eucalyptus,* market, livelihood, commercialization, controversy, wood source scarcity

Introduction

Wood shortage for firewood and construction in the highlands of Ethiopia was as old as 19th century. Intrigued by wood products scarcity and tree-less landscape surrounding the then newly established capital, Addis Ababa, Minilik II was forced to introduce a rather fast growing species of *Eucalyptus* in 1895. Since then, the species has expanded into all corners of the country. It also pioneered in the plantation development of the country. Currently, it is common to observe at least few eucalypt trees at the homesteads of most farmers and urban communities in Ethiopia (FAO 2009, Mekonnen *et a*l. 2007, Turnbull 1999). It has supplemented woods from natural forests that do not provide the desired quantity and quality of woods (Zobel 1987). The indigenous tree species of Ethiopia such as *Juniperus procera, Podocarpus afrocarpus, Cordia africana, Hagenia abyssinica,* and *Olea europhea* had become endangered due to the overexploitation of these species for various services and products. Recently *Eucalyptus* has been replacing the commercial values of wood products from other tree species. The fast growth rate of *Eucalyptus* to provide possible products for consumption and market has over won the continuing planting of the species irrespective of the resistance from the policy makers and environmentalists. Eucalypts planting on degraded lands at proper density and management improves the wood product scarcity for household consumption as well as for market and keep the balance of the environment (Liu *and Li* 2010, Mekonnen *et al*. 2007). The study by Mekonnen *et al*. (2007) has found that planting of *Eucalyptus* by poor households could contribute about 28 % of household's income and more than 90 % of wood source for household consumption in the Huruta district. In another study (Selamyihun 2004) it was also reported that *Eucalyptus* has the potential to satisfy the ever increasing fuel wood demand in Ethiopia without inducing a major land use shift.

The objectives of the study were to review and examine available literature, to assess claims from both the supporters and opponents of *Eucalyptus.* Here, the examination of the history and divergence of *Eucalyptus* in Ethiopia would be considered, wider criticisms would be explored in reference to some scientific evidences from Ethiopia and around the world. The role *Eucalyptus* can play in bridging the gap between demand - supply for energy and construction; divided views on the role of *Eucalyptus* were assessed from literature and from field study. The potential for increasing income for the farmers and commercializing it by them and market value assessments were undertaken.

The Study Area

The study area of Huruta district is about 175 km southeast of Addis Ababa. The rainfall in the study area is bimodal. The longer rainy season extends from June to September, which supports the major crop production. The shorter rainy season comes in March and April, and allows minor crop production. Main livelihood system is mixed agriculture with the main smallholder subsistence livestock are cattle, Shewats, and donkey; crops are wheat, barley, and bean; and the principal smallholder cash crop is onion.

The physiographic characteristics of the study area include altitude 1800–2500 m, annual rainfall 800–1000 mm, mean annual temperature 19 ºC, mean maximum annual temperature 27 ºC and mean minimum annual temperature 10 ºC. According to information from the Woreda Office of Agriculture (2005), much of the land in the Woreda is used for crop production (70.9%). Rangelands, forestlands, and others (including settlements) account for 16.9%, 4.5% and 7.7%, respectively. About 84.9% of the forest area is natural woodlands with acacias as the main species, and the remaining part is plantation forest, in which *Eucalyptus* contributes more than 85%. According to the same source, the wereda's agro-ecological configuration consists of lowland (7%), middle altitude (58%), and highland (35%).

Information Collection

A detailed review and survey has been conducted using different published literatures and web-based websites. Here both the negative and positive opinions were assessed from different perspectives. During field assessment 65 randomly selected farmers, who have *Eucalyptus* trees, were interviewed to know their opinion why they plant *Eucalyptus* and the strategy they took in case for wood shortage in the locality, especially for fuel wood and the income generation potential of *Eucalyptus* wood products. A market assessment was made to recognize the current and potential market condition of *Eucalyptus* wood products by asking 30 end-use buyers and sellers. Inflow registration of different wood products to town was made at four main entrances to be acquainted with the market economies from eucalypt and other species to the local market. The data collected was analyzed qualitatively by interpreting it being from the spot with group discussion and quantitatively by using SPSS-V 10 and Microsoft excel.

Findings

History and divergence of *Eucalyptus* in Ethiopia

Intrigued by wood products scarcity and tree-less landscape surrounding the then newly established capital, Addis Ababa, Minilik II was forced to introduce a rather fast growing species of *Eucalyptus* in 1895. *Eucalyptus* is increasing in importance globally**,** because many species of eucalypts have the ability to improve conditions in treeless areas. In Ethiopia, its divergence had increased in 1980s and then slows down (Fig.1). In many places, eucalypt*s* have helped to raise people's living standard by providing several end uses. In addition, the growing of eucalypts was financially more profitable, with a considerable positive net present value, compared to the alternative agricultural crops (Tesfaye 1997, Daba 1998, Asaye 2002, Demamu 2002, Zerihun 2002). Willingly, people grow and cut eucalypts to meet the needs of their families, without having to import goods from elsewhere. *Eucalyptus* gives some attention for concern in the context of diversified plantations, because owing to its importance to the household livelihood strategy by providing income and wood for household consumption.

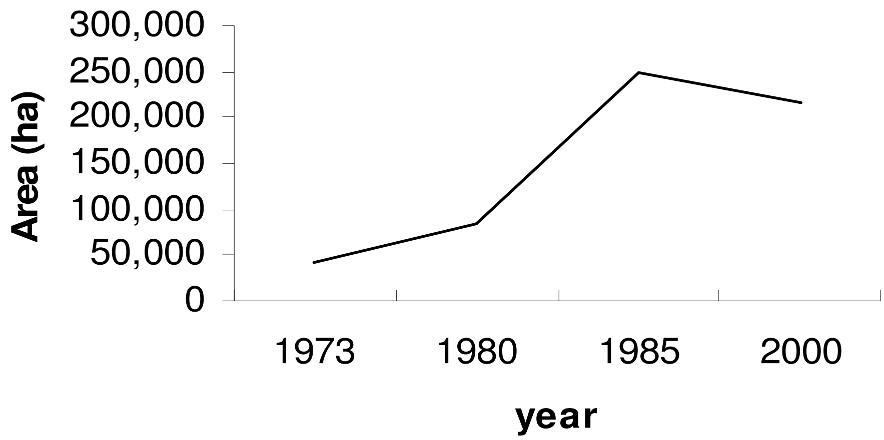

Figure 1: The trend of *Eucalyptus* plantation in Ethiopia (Adapted from FAO 1979, 1988, 1996, Davidson 1989 and Eldridge *et al.* 1997)

Eucalyptus from science and policy perspectives

Eucalyptus plantation has offered both negative and positive opinions from around the world in general and in Ethiopia too. It has negative impacts when it is planted on wrong sites, done by replacement of existing natural forests coupled with poor management and silviculture. However, it would have positive impacts, which outweigh the negative ones when it is planted on the right sites that are marginal and degraded with good management planning and proper tending. In this case it could help to fulfil the need of wood for energy, construction, income and farm implements plus an enhancing effect on environment (Amanuel 1996, Daba 1998, FAO 1988, Solomon 1999, Jagger and Pender 2000) – *Table 1 and 2*. The gap between supporters and opponents of *Eucalyptus* can be considered as driver, because the opposition between the various competing interests directly structures the social and policy discussion that is needed to find solutions (Buttoud 2009).

Table 1: Negative arguments on *Eucalyptus*

Negative arguments	Sources
• *Eucalyptus* trees compete for water and other nutrients with crops in their vicinity, and deprive of healthy growth of crops • *Eucalyptus spp* need plenty of water, and drain away sub-soil water and cause water scarcity • *Eucalyptus* trees suppress undergrowth and cause degradation of land • *Eucalyptus* trees do not support wildlife • "*Eucalyptus* is nothing less than ecological fascism, which can be described as a species that destroys the hydrological balance, impoverishes the soil of its nutrients, and reduces biodiversity." • "*Eucalyptus* is not only a soil degrader but also a crop destroyer, a depriver of fodder, flattener of natural forests, destroyer of security, creator of poverty and dependence, and killer of knowledge of future generations about how to live on one hand and livelihood and environment on the other."	Shiva and Bandyopadhyay 1985; Poore and Fries 1985; FAO 1988, 1992, 1996; IUCN 1992; Evans 1992; Lisanework 2000; El-Khawas and Sheheta 2005; Lohmann (1990) cited in Turnbull (1999)

Table 2: Positive arguments on *Eucalyptus*

Aspects	Positive arguments	Sources
Water loss	Transpiration rates from *Eucalyptus* species are similar to other tree species	Lima 2004; ARACRUZ 2004
	The intercepted water loss from *Eucalyptus* is relatively lower than that for other tree species	Amanuel 1996; ARACRUZ 2004
	In India and China, eucalypts consumed less water per unit of biomass produced than other species.	FAO 1988; Evans 1992; Davidson 1989; Bai 1996
Biodiversity impact	*Eucalyptus* acts as one of the best "nurse trees" for fostering native plants regeneration in Ethiopia and elsewhere	Feyera *et al.* 2002; Eshetu 2002; Mulugeta 2004
	In Malaysia, border plantation of eucalypts has increased wildlife diversity by providing additional habitat types not found in the natural forest.	Sawyer (1993)
	In India, the number of animals in Rannibennur Blackbuck Sanctuary was increased by planting eucalypts.	FAO 1988; Soni and Vasistha 1991
	Light, moisture and minerals under the canopy of *Eucalyptus* are adequate to support other growth	Davidson 1989; Amanuel 1996
	In Ethiopia, several indigenous species including *Juniperus procera*, *Podocarpus afrocarpus, and Hagenia abyssinica* grow in *Eucalyptus* plantations.	Amanuel 1996; Kidane 1998; Pukkala and Pohjonen 1987; Feyera 1998; Eshetu 2002
	In China and Brazil, species diversity of birds, animals and insects was found to increase in *Eucalyptus* plantations	Bai 1996; Poore and Fries 1985; ARACRUZ 2004
	Eucalyptus might be used to reduce eutrophication	Poores and Fries 1985

Effect on Soil nutrients	*Eucalyptus* was found to have beneficial effects on soil structure and to improve soil fertility on treeless site.	FAO 1988; Daping *et al* 1997; Zerfu 2002; Cossalter *and Pye-Smith* 2003
	In China and Ethiopia, soil organic matter content increased in *Eucalyptus* plantations where there was no gathering of dead leaves and branches by people.	Bai 1996; Zerfu 2002
	Eucalyptus is a species with low nutrient demands	Amanuel (1996)
Yield and allelopathy	In India and Ethiopia, farmers plant eucalypts along farm boundaries, because the elongated crowns and vertical roots do not noticeably reduce crop yields.	FAO 1988; Selamyihun 2004; Mekonnen *et al.*2007
	Sorghum and millet crops are found to grow well beneath *Eucalyptus* plantation in Senegal	Baumer (1990)
	In Thailand and Bangladesh, the use of *Eucalyptus camaldulensis* in agroforestry is fairly common.	Evans 1992; Poore and Fries 1985; Ahmed *et al.* 2007
	The effects of *Eucalyptus* on the microclimate are similar to those of other evergreen plantation species	FAO (1988)
Calorific value and timber quality	*Eucalyptus* is found to have a comparable calorific value with that of other species	Eckholm *et al.* 1984; Mulugeta and Tsegaye 2005
	In Ethiopia, *Eucalyptus* has been identified to be used as sawn boards and proved to have high quality timber.	Tsegaye (1996)
	E. globulus wood burns freely, leaving little ash, and carbonizes easily, making good charcoal.	Duke 1983; Mekonnen *et a*l. 2007

Role of *Eucalyptus*

With a large proportion of the world population in general, and of developing countries such as Ethiopia in particular, depending on wood for cooking and heating, the economic importance of *Eucalyptus* is immense. Even if it is difficult to obtain year-to-year cash income from tree cultivation in general, the average cash income from *Eucalyptus* over the rotation period is greater than that from other agricultural crops (Niskane and Saastamoinen 1996, Daba 1998) Table (3). Moreover, farmers' willingness to grow trees on their farms is a function of their attitudes towards the advantages and disadvantages of growing trees, their perception of the opinions of salient referents and factors that encourage and discourage farm level tree planting (Zubair and Garforth 2006).

Table 3: Comparative analysis of profitability of *Eucalyptus* plantation and cassava cultivation in Thailand

Management options (15 years period)	Profitability per year per hectare (US Dollars)			
	Economic	Socio-economic	Environmental economic	Financial
Industrial plantation	1062	1103	1529	931
Community-based plantation	718	915	1026	410
Agro-forestry	819	956	901	106
Cassava cultivation	56	186	-219	-511

Source: Niskane and Saastamoinen 1996

In Ethiopia, Daba (1998) in his study on the financial return of small-scale *Eucalyptus globulus* plantation against other agricultural production options at discount rate of 10%, found that NPV ha^{-1} yr^{-1} from agricultural options ranged from Birr 97 to 7,579, whereas that from *Eucalyptus* plantations ranged from Birr 16,151 to 74,966. A study made in Tigray (Ethiopia) had come with the conclusion that a woodlot of average-sized *Eucalyptus* trees would be worth more than 80,000 Ethiopian Birr/ha, or $ 10,000, and much more in places where trees are scarce. With more than 70 ha of woodlots per *tabia*[6], this represents a substantial contribution to the wealth of communities in Tigray (Gebremedhin *et al*. 2000). Similarly, in India, it was found that an investment of intercropping *Eucalyptus* and cotton that cost $ 1,700 ha^{-1} in the first year had gained a total return of $ 5,900 ha^{-1} after five years (FAO 1996).

Eucalyptus from policy perspective

As Janz and Persoon (2002) expressed, there are serious shortcomings in the supply and use of information needed for policy-making in the forestry sectors, particularly those of developing countries. It should be underlined that, for a successful forest policy process, it is often necessary to know, among several other things, more about plantations and their role for rural communities. There is a general prejudice against forestry, particularly against fast-growing trees plantation, as compared to agriculture. To support this, for example, the conversion to forestry plantations of natural forests in the tropics, which accounts for 6–7% of the loss of natural forests in the tropics**,** has been more criticized than conversion to agriculture and industrial development, which account for 93–94% of that loss (Cossalter and Pye-Smith 2003). The current policy issue regarding *Eucalyptus* planting in Ethiopia supports the issues specified under table 1. There is no encouraging concern in the country to raise *Eucalyptus* seedlings from government nurseries and distribute them for smallholder farmers. Moreover, the previously established plantations around Addis Ababa have been given to floriculture investors and being uprooted. The views of policy makers are largely less favourable to *Eucalyptus.* Farmers are aware of the negative impacts of *Eucalyptus.* They attempt to manage it through proper planting site selection and tree/stand management. Most farmers raise seedlings from their own nurseries and commercializing it to the local market for wood products. Sale of *Eucalyptus* wood provides sole income for the poor households. Owning to this importance, the policy practice of discouraging and in some cases banning planting of *Eucalyptus* by farmers need rethinking from the side of the policy makers. Taking into account the dwindling natural forests in Ethiopia, of which the area *per capita* is less than one-tenth of a hectare (FAO 2005); it would be necessary to pass legislation to require that almost all charcoal, poles and firewood be derived from plantations of fast-growing species such as *Eucalyptus,* to prevent further loss of natural forests (Turnbull 1999).

Eucalyptus species have been accepted as suitable for shelterbelts and for admixture with agricultural crops in Columbia, Tunisia, Senegal, Nigeria, Cameroon, Pakistan, India, China, Sri Lanka, and Bangladesh (Sunder 1993, Ahmed *et al*. 2007). The effects of eucalypt on the associated crop are not different from those of any other kind of trees when planted in shelterbelts and agroforestry

[6] *The lowest administrative division in the region which is equivalent to mean kebele in other regions of Ethiopia*

(Poore and Fries 1985). There is a need for care when comparing policy and actual practice, because stated intentions in policy documents sometimes bear no relation with how policies are interpreted and applied (Sithole 2002). In another concern, interventions to support market prices for the products of tree growing and to ensure producers' access to markets may be as effective as or more effective than subsidies. Agricultural policies should be complementary to tree growing. Subsidies for credit, price supports and incentives, including measures affecting land and tree tenure, should be seen in parallel to both agricultural crops and tree growing like eucalypts by farmers in order to avoid policy measures that likely to distort decisions against one at the expense of the other (FAO 1991).

Farmers' opinion and market assessments

Farmers in the Huruta district are planting *Eucalyptus* trees, perhaps not the species that the government would prefer. Farmers have suggested what trees they want, and have *Eucalyptus* trees within their farming systems for specific purposes (marketing poles or other products). In the field assessment from the sixty-five interviewed farmers in the district, about 80 % of them have planted *Eucalyptus* while only 15 % of the farmers have planted other species. Farmers select tree species for planting according to their service and product functions (Table 4).

Table 4: Farmers' priority to plant a tree based on the function it provides

What a tree could provide?	Weight of farmers' priority to plant
Fodder	3
Windbreak	1
Building materials and farm implements	5
Income generation	6
Live fence	3
Soil improvement and protection	2
Fuel wood and charcoal	4
Food/ fruit	6
Shade	2
Timber products	3
Non-timber products	2
Combination of two or more of the above	6

Note: 6 indicate six times more weight than 1, and functions with equal weight means equal importance to farmers

Eucalyptus wood products contribute 78% of the local market economy for firewood, 100 % each for construction poles and posts, 20 % for charcoal and 93 % for the four wood product types which amounts a total of birr 99,867 in two weeks in 2005 markets and which is $15,189 when discounted at 4 % interest rate at the current market (2010) (Table 5). With 52 weeks per *year*, this represents a sizeable input to the affluence of smallholder farmers in Huruta district. It was also reported that *Eucalyptus* contribute 92 %, 74 %, 85 %, 40 %, 83 % and 91 % of construction poles, timber, firewood, charcoal, posts and farm implements wood sources for rural livelihoods (Mekonnen *et al*. 2007). Farmers pointed out that during the Dergue regime (pre-1991) having *Eucalyptus* plantation was considered as 'live bank account', because farmers sell it during high-income needs or had been guaranteed as collateral to take loan from bank.

Table 5: Wood products inflow rates to Huruta town for two weeks and estimation of their market value (2005)

Inflow type	Unit	Amount by source		Unit price per source		Total price per source	
		eucalypt	others	eucalypt	others	eucalypt	others
Firewood	Kg	51,912	17,941	0.26	0.215	13,497	3,857
Construction poles	M^3	314.8	0	250	-	78,700	-
Splitted posts	M^3	34.35	0	200	-	6,870	-
Charcoal	Kg	3,200	12,200	0.25	0.30	800	3,660
					Total	**99,867**	**7,517**

Note: the unit for the price is Birr (8 birr = 1 USD In 2005)

The market value assessment for *Eucalyptus* end uses had shown a high market value in the local market. This is also true for the national market since there is a high potential and the market condition is unstable and unsaturated (Tables 6 and 7). However, some factors influence income and profitability of *Eucalyptus* tree commercialization by farmers. Those factors are technical, financial and awareness support; market mechanism; cash flow gains (wood price) and non-income gains (environmental).

Table 6: Market value assessment for *Eucalyptus* end-uses at Huruta town (2005)

End use type	Market value	
	During the assessment year	Potential to the consecutive years
Firewood	High	High
Construction poles	High	High
Posts	High	High
Timber	Medium	High
Essential oils	Low	Medium
Charcoal	Medium	high

If farmers choose to grow *Eucalyptus* as a commercial tree on their land, they can get the following benefits:

- diversifying their farm income by growing it as a crop;
- increasing the productivity of their existing farm endeavour; and
- Improving the sustainability of their current farming system

Table 7: Market survey results for *Eucalyptus* end-uses at Huruta town (2005)

End use type	Market conditions			
	Supply	Demand	Stability	Saturation
Firewood	Medium	High	Medium	Low
Construction poles	Low	High	Low	Low
Posts	Medium	Medium	Medium	Medium
Timber	Low	High	Very low	Very low
Essential oils	Nil	Nil	Nil	Nil
Charcoal	Low	High	Very low	Very low

Farmers have expressed that the more accessible and available sources of trees and forest products in the nearby areas, the least interest have been developed in planting trees in the farming systems. Farmers at the other corner of the availability extreme in contrast have emphasized as they have the highest interest in tree planting in order to close the gap between wood demand and supply. In addition, the farmers have remarked that planting fast growing trees like *Eucalyptus* is the best alternative strategy to minimize the existing firewood scarcity in the locality rather than the use of cow dung and crop residues. Fuel wood scarcity reduces the quality of the diet if women have to cook for less time; in some instances, the food may be undercooked, in others the consumption of reheated foods may increase, by which undercooking and reheating leftovers can have a serious impact on disease incidence. In this study, it was understood that *Eucalyptus* can play a paramount role in supplying fuel wood to smallholder households in both rural and urban communities.

From the market assessment, study it was found that price of poles and posts for construction is higher in the dry season (high demand) as there are more house and fence construction, while the price of fuel wood is higher during the wet season. The market chain that was found from the market assessment for construction pole product began with the collection of poles through farmers who collect pole from own farms and woodlots, and sell their products to regular purchasers of residential and commercial consumers or individual retailers. And the commercial consumers purchase poles directly from farmers and local market and sold it to other commercial consumers of bigger towns such as Asella, Nazareth, and Addis Ababa (Figure 2 and table 8).

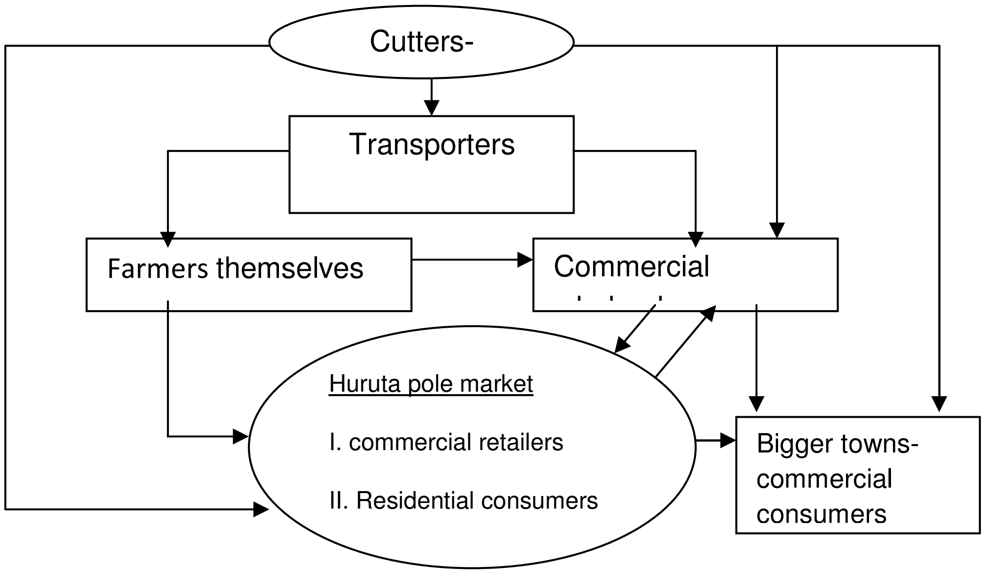

Figure 2: Market chain flow diagram for poles at Huruta.

Table 8: The marketing margin for a single *Eucalyptus* pole of size 5 to 8 cm in diameter and a height of about 7 m in the supply chain from Huruta to Addis Ababa (2005)

Farm gate	Cost (Birr)	Benefit (Birr)	Margin (Birr)
▪ Labour cost	1.50		
▪ Management cost	1.00		
▪ Total cost	2.50		
▪ Selling price		4.00	
Margin			1.50
Huruta town			
▪ Purchase	4.00		
▪ Transport and labour cost	0.50		
▪ Total cost	4.50		
▪ Selling price		6.00	1.50
Margin			
Nazareth city			
▪ Purchase	6.00		
▪ Transport and labour cost	1.50		
▪ Total cost	7.50		
▪ Selling price		10.00	
Margin			2.50
Addis Ababa city			
▪ Purchase	10.00		
▪ Transport and labour cost	2.00		
▪ Total cost	12.00		
▪ Selling price		15.00	
Margin			3.00
Total marketing margin			**8.50**

Conclusion and Recommendation

Eucalyptus is seen as an opportunity by its advocators, and a threat by environmentalists and policy makers. It is advocated as it grows well on poor soils and provides economic benefit to the farmers within a short period. On the other hand, it is criticized because of its detrimental effect on biodiversity and negative effect on water and soil nutrient. This could obscure the role the genus plays in the present day rural reality of wood scarcity in Ethiopia. Despite a drive for development and modernization, Ethiopia still maintains a largely biomass dependent society. Because of a growing population, and increased degradation of natural forest from agricultural and grazing land demands, it is imperative that local biomass needs are met from the existing natural forests. The policy practice of discouraging and in some cases banning planting of *Eucalyptus* by farmers need rethinking from the side of the policy makers. It was learnt that farmers have commercializing *Eucalyptus* wood products such as construction poles, posts, and fuel wood at the local market besides their own consumption. By doing this, the species helped in farmers' livelihood improvement. To this end, therefore, farmers should be certified for its planting in the way that is friendly to the environment and commercialize it to the local market in the short term and to the national market in the end.

To make concrete policy and management decision with regard to *Eucalyptus,* basic information is needed on the following areas:

- the importance of growing eucalypt to fulfil the growing demand for wood products;
- Socio- economic dimensions of growing and marketing *Eucalyptus*;
- In depth understanding about the positive and negative environmental effects of *Eucalyptus*;
- Information on the opportunities, limitations and acceptance of mixed planting of *Eucalyptus* with other native species;
- Information on the growth characteristics of different species of *Eucalyptus*;
- Information on nutrient distribution, nutrient cycling and water condition in *Eucalyptus* plantation;
- Information on the site factors that affects the conditions of *Eucalyptus*; and
- Information to establish whether much of the negative effects are due to species or human management errors.

References

Ahmed R, M Redowan, MS Uddin, MK Hossain. 2007. *Eucalyptus* as agroforestry component in the homestead and agricultural field of Sitakunda, Bangladesh, In: *Sustainable Agricultural Technology* 3(**3**): 46-51.

Amanuel M. 1996. Establishing fuel wood plantation and firewood tree crop performance on the Highlands of Ethiopia: the case of *Eucalyptus* globulus Labill. Spp. globulus. SLU, Sweden.

Aracruz Celulose SA. 2004. Sustainability annual Report. http://www.aracruz.com.br/ra2004/en/rsa_apresentacao.html Jan. 2005.

Asaye A. 2002. Growth performance and economics of growing *Eucalyptus camaldulensis* by smallholder farmers of Amhara Region: the case of Gonder Zuria District, North Gonder, Ethiopia. MSc Thesis. SLU, Sweden.

Bai J. 1996. *Eucalyptus* tree species grown in China. The Research Institute of Tropical Forestry, The Chinse Academy of Forestry, Longdong, China.

Baumer M. 1990. Agroforestry and Desertification: the potential role of agroforestry in combating desertification and environmental degradation with special reference to Africa, CTA, The Netherlands.

Buttoud J. 2009. Drivers and Barriers to Change to Governance in Small-Scale Forestry. Small-scale Forestry **8**:133–141.

Cossalter C, Charlie Pye-Smith. 2003. Fast-wood Forestry: Myths and Realities. CIFOR, Jakarta, Indonesia.

Daba W. 1998. The economics of growing *Eucalyptus globulus* (Labill.) on the Highlands of Oromia, Ethiopia; with special reference to Intoto and Chancho areas. MSc. Thesis. SLU, Sweden.

Davdson J. 1989. Ecological Aspects of *Eucalyptus* Plantations http://www.fao.org/documents/show_cdr.asp?url_file=/docrep/005/ac777e/ac777e02.htm Dec. 2005

Daping X, H Qixuan, Y Zengiang. 1997. Above-ground biomass production and nutrient cycling of *Eucalyptus grandis* X *E. urophylla* plantation in Tropical Areas of Southern China. Research Institute of Tropical Forestry, Chinese Academy of Forestry, Longdong, China.

Demamu M. 2002. Economic analysis of *Eucalyptus* globulus plantation in the former Dessie Fuel wood Project, South Wollo, Ethiopia. MSc. Thesis. SLU, Sweden.

Duke J, 1983. *Handbook of Energy Crops.* http://www.hort.purdue.edu/newcrop/duke_energy/Eucalyptus_ globulus.html, May, 2006

Eckholm E, G Foley, G Barnard, L Timberlake.1984. Fuel wood: the energy crisis that won't go away. An Earthscan Paperback, International Institute for Environment and Development, London and Washington, DC.

El-Khawas SA, M Shehata. 2005. The Allelopathic Potentialities of *Acacia nilotica* and *Eucalyptus rostrata* on Monocot (*Zea mays* L.) and Dicot (*Phaseolus vulgaris* L.) Plants. *Biotechnology*, 4 (**1**): 23-34.

Eldridge K, J Davidson, C Hardwood, G Wyk. 1997. *Eucalyptus* domestication and breeding. Oxford Science Publication, Claredon Press, Oxford.

Eshetu Y. 2002. Restoration of the native woody species diversity using plantation species as foster trees in the degraded highlands of Ethiopia. PhD thesis, University of Helsinki, Helsinki.

Evans J. 1992. Plantation forestry in the tropics: Tree planting for industrial, social, environmental, and agroforestry purposes. 2[ed] ed., Oxford Science Publications, Clarendon Press, Oxford, New York.

FAO. 1979. Eucalypts for planting. FAO Forestry series No. 11,679pp. Rome, Italy.

FAO. 1988. The Eucalypts Dilemma. 26pp. Rome, Italy.

FAO. 1991. Household food security and forestry- an analysis of socio-economic issues, community Forestry note 1. Rome, Italy.

FAO. 1992. Mixed and pure forest plantations in the tropics and subtropics. FAO Forestry Paper 103. Rome, Italy.

FAO. 1996. Proceedings of the Regional expert consultation on *Eucalyptus.* Volume II, 4-8 October 1993, FAO Regional Office for Asia and the Pacific (RAP) Bangkok, Thailand, December 1996. http://www.fao.org/DOCREP/005/AC772E/ac772e08.htm Feb. 2006

FAO. 2005. State of the World's Forests. http://www.fao.org/docrep/007/y5574e/y5574e00.htm Feb.2006

FAO. 2009.*Eucalyptus* in East Africa: The socio-economic and Environmental issues. Regional report. Addis Ababa, Ethiopia.

Feyera S. 1998. Native woody species regeneration under the canopies of tree plantations at Munessa-Shashemene Forest Project Areas, Southern Oromia.Ethiopia. MSc. Thesis. SLU. Skinnskatteberg, Sweden.

Feyera S, E Beck, U Luttge. 2002. Exotic trees as nurse-trees for the regeneration of natural tropical forests. *Trees* **16**: 245-249.

Gebremedhin B, J Pender, G Tesfaye G. 2000. Community natural resource management: the case of woodlots in northern Ethiopia. IFPRI, Washington. EPTD Discussion paper no. 60.

IUCN. 1992. Tropical deforestation and species extinction. Chapman and Hall, London.

Janz K, R Persson. 2002. How to know more about forests? Supply and use of information for forest policy. CIFOR occasional paper, No. 36, Jakarta, Indonesia.

Jagger P, J Pender. 2000. The role of trees for sustainable management of less-favored lands: The case of *Eucalyptus* in Ethiopia. EPTD Discussion paper No. 65. International Food Policy Research Institute, Washington, D. C. USA.

Kidane W. 1998. Natural Regeneration of Juniperus procera (Hocht.) in *Eucalyptus globulus* (Labill.) plantation: at Entoto Mountain, *Central Ethiopia*. MSc. Thesis, SLU, Sewden.

Lima P. 2004**.** *The Eucalyptus* Myth. http://www.bracelpa.org.br/en/estudantes/eucalipto/mito.htm Jan. 2005.

Lisanework N. 2000. Ecological Impacts of *Eucalyptus* plantations in Ethiopia. Paper presented at the workshop on "The *Eucalyptus* dilemma" 15 November 2000, Ghion Hotel, Addis Ababa, Ethiopia.

Liu H, J Li. 2010. The Study of the Ecological Problems of *Eucalyptus* Plantation and Sustainable Development in Maoming Xiaoliang, Journal of Sustainable development **3**(**1**):197 – 201.

Mekonnen Z, K Habtemariam, L Mulugeta, B Campbell. 2007. The role and management of *Eucalyptus* in Lode Hetosa District, Central Ethiopia. Forests, Trees and Livelihoods 17 (**4**):309-323.

Mulugeta L. 2004. Comparison of soil attributes under *Cupressus lustanica* and *Eucalyptus saligna* established on abandoned farmlands with continuously cropped farmlands and natural forests in Ethiopia. Effects of landuse changes on soil quality and Native Flora Degradation and Restoration in the Highlands of Ethiopia: implication for sustainable land management. PhD Thesis. SLU, Uppsala, Sweden.

Mulugeta L, B Tsegaye. 2005. Effects of age on calorific value and some mechanical properties of three *Eucalyptus* species grown in Ethiopia.Cycle11: LRG Workshop Proceedings. April 2005, Addis Ababa. Sand T popularization Department, Ethiopian Science and Technology Commission.

Niskanen A, O. Saastamoinen. 1996. Tree Plantations in the Philippines and Thailand: Economic, social and environmental Education. Research for Action 30. UNU/WIDER, Helsinki, Finland.

Poore MED, C Fries. 1985. The ecological effects of *Eucalyptus.* FAO Forestry Paper 59. Rome, Italy.

Pukkala and Pohjonen. 1987. Management planning system for *Eucalyptus globulus* plantations in Ethiopia. Addis Ababa.

Sawyer J. 1993. Plantation in the tropics: environmental concerns. IUCN/ UNEP/ WWF, Gland, Switzerland and Cambridge, UK.

Selamyihun K. 2004. Using *Eucalyptus* for soil and water conservation on the Highland Vertisols of Ethiopia. PhD Thesis, Wageningen University, The Netherlands.

Shiva V. and Bandyopadhyay J. 1985. *Ecological Audit of Eucalyptus Cultivation*. The English Book Depot, Dehradun. www.ganesha.co.uk/Articles/Eucalyptus.htm Feb. 2006

Sithole B. 2002. Where the power lies: multiple stakeholder politics over natural resources. A participatory methods guide. CIFOR, Jakarta, Indonesia.

Solomon T. 1999. Above- ground biomass functions for *Eucalyptus globulus*. *A* case study in Finfine Fuel wood Plantations, Oromia, Ethiopia. MSc Thesis. SLU, Sweden.

Soni P, HB Vasistha. 1991. Understorey vegetation in *Eucalyptus* plantation-A review. Environmental Research Station, Forest Research Institute, Dehradun. Journal of Tropical Forestry 7(**1**):15-26.

Sunder SS. 1993. The Ecological, Economic and Social Effects of *Eucalyptus.* http://www.fao.org/docrep/005/ac777e/ ac777e0c.htm Nov.2005

Tesfaye T. 1997. Problems and prospects of tree growing by smallholder farmers: A case study in Feleghe-Hiwot locality, eastern Tigray, Ethiopia. MSc. Thesis. SLU, Sweden.

Tsegaye B. 1996. Utilization of sawn boards from young *Eucalyptus* plantation timber grown in Ethiopia. PhD thesis. SLU, Uppsala, Sweden.

Turnbull J. W. 1999. *Eucalyptus* plantations. *New Forests **17***:37-52.

Zerfu H. 2002. Ecological impact evaluation of *Eucalyptus* plantations in comparison with agricultural and grazing landuse types in the Highlands of Ethiopia. PhD thesis. Institute of Forest Ecology, Vienna University of Agricultural Sciences, Vienna.

Zerihun K. 2002. Profitability and household income contribution of growing *Eucalyptus* globulus (Labill.) to smallholder farmers: the case of the Central Highlands of Oromia, Ethiopia. MSC Thesis. SLU, Sweden.

Zobel BJ.1987. Growing exotic forests. A Wiley-Interscience Publication. John Wiley and Sons, New York, Chichester, Brisbane, Toronto, Singapore.

Zubair M, C Garforth C. 2006. Farm level tree planting in Pakistan: the role of farmers' perceptions and attitudes. Agroforestry Systems, 66:217–229.

Mismatches between Farmers and Experts on *Eucalyptus* in Meskan Woreda, Ethiopia

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Abstract

Despite ceasing the growing of *Eucalyptus* seedlings in community nurseries, farmers continue planting this tree. This research aimed at gaining insight into the divergent interests of (governmental) experts and farmers on *Eucalyptus* expansion. It provides an analysis of the importance that experts and farmers adhere to different criteria taken into account during tree selection, as well as the corresponding weights for tree selection. For this purpose, the research compared *Eucalyptus camaldulensis* with eight other main tree species using 14 criteria for tree selection. Data were collected from farmers in four kebeles of Meskan Woreda, and from experts at the Office of Agriculture and Rural Development. A multi-criteria analysis procedure was used to analyses the data. The criteria were weighted using pair-wise ranking and the trees were scored with a scale of 1 to 5 based on each criterion. The overall weighted scores were obtained using the Simple Additive Weighting Model. The results indicate significant differences between farmers and experts concerning the relative importance of these criteria. Farmers assigned highest relative weights to adaptability (0.13), coppicing ability (0.11), pole quality (0.10), and market demand (0.10) of trees. Based on the overall weighted scores, farmers prefer *Eucalyptus camaldulensis* followed by *Podocarpus falcatus,* and *Juniperus procera*. However, experts' show preference for *Podocarpus falcatus* followed by *Cordia Africana* and *Acacia abyssinica*. *Eucalyptus camaldulensis* is the 6th important tree species based on experts' evaluation criteria. The conclusion from both analyses is that there is indeed a mismatch between farmers' and experts' interests and perspectives concerning tree species – and *Eucalyptus* in particular – in the study area. Farmers assign highest value to – short-term – economic benefits of trees, while experts are mainly concerned in environmental issues, resulting in discouraging the expansion of *Eucalyptus* species. This paper argues that it is difficult to stop *Eucalyptus* expansion as long as farmers' economic concerns are not accounted for or more seriously taken into account by governmental (rural development) programs. Therefore, there is a need to strengthen participatory planning with farmers and develop best future alternatives; e.g. by finding niches for *Eucalyptus* plantations within the current farming system. This underlines the crucial importance of considering farmers' interests in land-use planning activities in Ethiopia.

Keywords: *Eucalyptus,* Multi-criteria Analysis, Experts, farmers, Ethiopia

Introduction

The genus *Eucalyptus* comprises 500 to 600 species (Friis 1995; Turnbull 1999). *Eucalyptus,* or 'Bahir Zaf' as it is locally known in Amharic (meaning tree behind the ocean) is the most widely planted tree in Ethiopia. Planting of *Eucalyptus* has a long history dating back to as early as 1890s. When Addis Ababa was founded in 1890, the large concentration of people in the capital city let to a high demand for fuel wood and construction (Pohjonen and Pukkala 1988). Lumber and wood for fuel were being extracted from areas over 20 kilometres distance. This situation was so serious that there was even a fear that the capital would have to be moved to a new location close to a supply of wood. Emperor Menelik II (1868-1907) recognized the problem and decided to start afforestation and reforestation activities. It was in this critical period that the first *Eucalyptus* trees were introduced to Ethiopia. Yet, some doubt still exists about who brought the first tree. It is generally agreed that Europeans introduced the first tree in 1895 during the reign of Emperor Menelik II (Breitenbach 1961). Since then, *Eucalyptus* has expanded over large parts of Ethiopia, becoming an integral part of most of the Ethiopian farming system and one of the Ethiopian most important tree resources (Pohjonen and Pukkala 1988; Pohjonen and Pukkala 1990).

Recently, however, experts and policy makers at various levels have started discouraging farmers to plant *Eucalyptus* because of its presumed negative environmental impact. The main debates are focused on its aggressive extraction of water resource, impoverishment of soil fertility under *Eucalyptus,* and finally its allelopathic property, which excludes and restricts germination and growth of other species. It has been argued that *Eucalyptus* takes up a great amount of water from the soil and ground water, and when grown in plantations it lowers the ground-water level more than other trees and crops (Prabhakar 1998).

Research result on boundary planting of *Eucalyptus* globulus in Ethiopian Nitosols showed a significant reduction of wheat yield in the first 8 to 12m across the tree-crop interface (Kidanu *et al*. 2004). It has been reported that *Eucalyptus* leaves have phenolic acids, tannins, and flavonoids and that these chemicals inhibit the growth of crops and trees (Babu and Kandasamy 1997; Zhang and Fu 2009). Similarly, other studies suggested that *Eucalyptus* released toxic allelochemicals into the soil system mainly through litter decomposition products (May and Ash, 1990; Lisanework and Michelson 1993) and reduced germination and radical growth of chickpea, field pea, maize, and tef (Lisanework and Michelson 1993). It was also reported that *Eucalyptus globulus* depleted soil nutrients in the central highlands of Ethiopia (Michelsen *et al*. 1993; Kindu *et al*. 2006).

On the contrary, other studies showed that *Eucalyptus* had greater water use efficiency than other crops. For example, a study in India showed that most *Eucalyptus* species had higher water use efficiency than several annual crops such as sunflower, field pea, cowpea, soya bean, potato, sorghum, and maize (Davidson 1989). Under both moisture and nutrient stress *E. globulus* and *camaldulensis* also showed to grow better as compared to deciduous tree species in Ethiopia (Gindaba

2003; Gindaba *et a*l. 2005a; Gindaba *et al*. 2005b; Gindaba 2006). Another study in Ethiopia showed that land-use change from agriculture to an *E. globulus* and *camaldulensis* plantation had no adverse impact on exchangeable potassium, total soil nitrogen, phosphorus, and sulphur at least up to the age of 14.5 years (Hailu 2002). A study on a *E. globulus* plantation in the central highlands of Ethiopia proved that this species encourages natural regeneration of indigenous woody tree species (Yirdaw and Luukkanen 2003) and restored degraded lands through increasing the soil carbon by 37g m^{-2} yr^{-1} (Lemenih 2006). Evidence from literature also suggests the potential of *Eucalyptus* to reduce soil erosion (Grewal et al. 1992; Kidanu 2004).

The pro and contras of *Eucalyptus* are mainly debated among scientists and experts; the main stakeholders, farmers, are hardly involved. Moreover, scientific literature on the environmental impact of *Eucalyptus* trees shows complex, inconsistent, and site-specific results. Conclusions about the environmental impact of *Eucalyptus* should be treated with caution, as could lead to more controversy in the debate. Nevertheless, Ethiopian Governmental experts and politicians discourage the expansion of *Eucalyptus* and this has led to cease growing of its seedlings in community nurseries – which are funded by the Government. Despite being discouraged, farmers have expanded *Eucalyptus* plantations, even up to the extent of replacing productive farmlands. *Eucalyptus camaldulensis* Dehnh, commonly known as river red gum, is one of the widely grown species in Ethiopia (Gindaba 2006). It is known that the species is replacing vast areas of agricultural land in Meskan Woreda. Why do farmers still prefer *Eucalyptus* to other tree species and agricultural land use, even while governmental experts are not? This research aimed at gaining insight into the divergent interests of farmers and (governmental) experts on the pro and contras of *Eucalyptus* in Ethiopia.

Materials and Methods

Research Site

The study was conducted in Meskan Woreda of the Southern Nations, Nationalities, and People (SNNP) Regional state in Ethiopia. It is located about 135 km to the south of Addis Ababa and covers 50,117 hectare with a population of 202,206 (CSA 2008). The dominant agricultural activity is subsistence farming, where intensive multiple crop production is integrated with livestock production. The Woreda is composed of two farming systems: e*nset* based and cereal based. The enset based faming system is the most complex one, and consists of a large number of crop components such as cereals, root crops, fruits and vegetables in intimate association with enset[7] (*Ensete ventricosum*). Cereals, particularly maize and sorghum, are dominant and the main staple food crops in the cereal based farming system.

Data collection

The study was conducted in four kebeles[8] . First, all kebeles (n=40) were stratified into cereal-based (n=24) and enset-based (n=16) farming system. Second, two kebeles from each farming system were randomly selected. Two important actors were identified for data collection: small-scale farmers from the four kebeles and (Government) experts working in the Meskan Woreda. Data were collected using focus group discussions and household interviews. Twelve farmers of different age and sex compositions were selected from each kebele for focus group discussions. A total of 162 farm households were selected using systematic random sampling for household survey.

During the household surveys and focus group discussions, farmers were asked to mention different tree species that are used for different purposes and the criteria they use for selecting these species. The different tree species and criteria mentioned by farmers during interviews and focus groups discussions were compiled and presented for discussion at farmers and experts' meetings at Woreda level. At farmers' level, four focus group discussions were conducted: one in each kebele (with n=12). At experts' level, one focus group was formed (n=8) composed of experts with different disciplines such as plant sciences, forestry, animal sciences, agricultural economics, soil and water conservation and agricultural extension. The different tree species were ranked by both farmers' and experts using selected criteria and the criteria were weighed using pair-wise ranking technique. Multi-criteria analysis was used for data analysis as discussed in section 2.3.

Multi-criteria analysis

Multi-Criteria Analysis (MCA) is an evaluation framework that ranks the performances of decision options[9] against multiple objectives/criteria. Typically, the criteria[10] are weighted by decision makers to reflect their relative importance. MCA is a systematic way of making choices according to criteria and available options. It does not rely on monetary values and can use both qualitative and quantitative measurements. Therefore, MCA offers a great potential to address the shortcomings of other tree evaluation methods such as cost benefit analysis. In this research, the following major MCA procedures were employed.

Establishing the decision context/determination of objectives

The first step is always to establish a shared understanding of the decision context. It is crucial to have a clear understanding of objectives. To establish objectives (and criteria), there is a need to involve both the decision-makers and people who may be affected by the decision. In this research, farmers and experts were identified as decision makers in tree planting. Through focus group discussions and household survey, farmers were requested about their objectives regarding planting different tree species.

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[8] *Kebele is the lowest administrative unit in Ethiopia*

[9] *Options are defined as alternatives being chosen, ranked, or scored by the decision maker.*

[10] *Criteria are attributes or indicators used to measure performance against decision makers' objectives.*

Identifying options/alternatives

Having established the decision context, the next step is to list the set of options to be considered. The different tree species (both exotic and indigenous) were alternatives to meet objectives of tree planting in the area. Accordingly, nine alternative tree species were identified by farmers.

Identifying criteria

The criteria are the measures of performance by which the options/alternatives will be judged. A large proportion of the 'value-added' by a MCA process derives from establishing a soundly based set of criteria against which to judge the alternatives. These criteria serve as the performance measures for the MCA. A measurement or a judgment needs to specify how well each option meets the objectives expressed by the criteria. A total of 14 criteria were identified by farmers and approved by experts in the study area.

Determining the effects

Farmers and experts prioritize different trees by giving scores based on each criterion from the scale of 1 for not good to 5 for the best. The scores for farmers were average scores of the different focus groups.

Standardizing the effects

This step aims at eliminating the effect of inconsistent scoring of alternatives. After farmers and experts had given scores to the alternatives based on the criteria, the scores were standardized using the following equation (eq.1) (Hajkowicz S 2008).

$$v'_{ji} = (v_{ji} - Minv_j)/(Maxv_j - Minv_j) \quad \text{(eq.1)}$$

Where v' = standardized score, i = alternative i, j = criterion j, v = unstandardized score, Maxvj= highest score of criterion j, Minvj = lowest score of criterion j

Ranking the criteria

Using the interviews and discussions, the list of criteria from the farmers' perspective were developed. A pair-wise ranking matrix approach (Pretty 1995) was used for weighing these criteria. This ranking method systematically compares each criterion with each other criteria to understand their relative importance and it avoids confusion as well as subjective nature of absolute (direct) ranking method. The list of criteria was written both on the top and on the left side of the matrix. The criteria were weighted in pairs each at a time and the dominant ones were written in the matrix. Groups of farmers and experts were asked to make comparative judgments on the relative importance of each pair of criteria. If there was no consensus, group members voted by raising their hands. This was repeated for each pair until the entire matrix was completed. These judgments were used to assign relative weights to the criteria. The results of ranking were expressed as weight (eq.2), which is the ratio of the total scores for individual criteria to the overall scores for all criteria (Howard 1991; Zanakis *et al.* 1998). Similar to scoring of alternatives, the relative importance of criteria for farmers' was obtained by averaging the weights of all focus group.

$$W_j = S_t /(\sum_{j-1}^{n} S_a) \text{ ......(eq.2)}$$

Where *St* is total score for individual criteria, *Sa* is the overall scores for all criteria and *Wj* is the weight for criteria j

Aggregating results and ranking alternatives

The Simple Additive Weighting (SAW) model (Howard 1991; Joubert et al. 1997; Zanakis *et al.* 1998) was used to obtain the overall weighted scores for each alternative (tree species). This was done by multiplying the value of score on each criterion by the weight of that criterion, and then adding all those weighted scores together (eq.3). The alternative with the highest total weighted score is considered as the most preferred tree species.

$$P_i = \sum_{j=1}^{J} w_j \cdot \mathrm{v'}_{ji} \text{ ......(eq.3)}$$

Where Pi is overall weighted score of alternative I, wj is weight to criterion j, v'ji is standardized score of criterion j for alternative i

Results and Discussions

Farmers' opinion on the expansion of *Eucalyptus* species

According to farmers, it was difficult to plant trees before the 1974 land reform, as tenants had no land. Even after tenants owned land in 1974, farmers said that there was low plantation of trees during the Derg regime (1974-1991) because trees were considered as common properties. Farmers perceived that there has been a rapid expansion of *Eucalyptus* plantations in Meskan Woreda since Ethiopian People Revolutionary Democratic Front (EPRDF) took power in 1991. Farmers give several reasons for this expansion. First, the profitability of the tree is very high due to its fast growth rate, high coppicing ability, low production cost and high market demand. Second, the tree has wide adaptability, including degraded lands unsuitable for agriculture. Third, *Eucalyptus* is considered a security crop to avoid income risks associated with crop failure as a result of drought and pests. Fourth, trees have become private property since 1991.

Household survey showed that about 26% (n=139) of plots[11] which were operated by 70% (n=114) of the sample households had a *Eucalyptus* plantation (table 1).

[11] *Plot is any piece of land which is entirely part of one or more cadastral units or fields adjacent to each other*

On average, 272 trees per household were found in the study area in 2008 with some variations among the households.

Table 1. Percentages of households having *Eucalyptus* trees and plots covered by *Eucalyptus* and number of *Eucalyptus* stands per sample households in Meskan Woreda

	Percentage/number
Percentage of households with *Eucalyptus* trees (n=162)	70.37
Percentage of plots covered by *Eucalyptus* trees (n=542)	25.65
Number of *Eucalyptus* trees per sample household	272.32

Source: own survey, 2009

In order to characterize the temporal variability of *Eucalyptus* expansion over the years, cumulative number of *Eucalyptus* trees is plotted against years (figure 1). The number of trees in this figure was obtained through household survey of 162 households. The figure shows a steady trend, although with less growth during the Derg regime (1974-1991). A rapid increment of *Eucalyptus* plantation per year is observed after change in government (1991). Moreover, the number of *Eucalyptus* trees planted over the last 5 years (2004-2008) is extremely higher than the previous years; the figure shows a very steep slope. Generally, this result supports farmers' opinion on *Eucalyptus* expansion in the area over years since 1991.

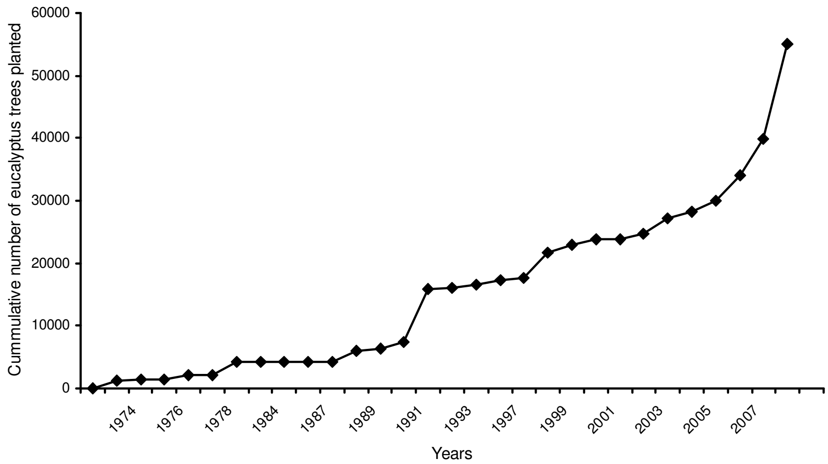

Figure 3. Trends of *Eucalyptus* trees planted over years (source: own survey, 2009)

Farmers' tree selection criteria

Farmers aim at multiple objectives with tree planting, such as cash generation, construction, fuel wood, and field demarcation/boundary and soil fertility maintenance. The majority of the farmers planted *Eucalyptus* mainly for cash generation. Of the interviewed households, 48% of them planted *Eucalyptus* mainly for cash generation, 15% mainly for fuel wood, 21% mainly for construction, and 2% mainly for boundary demarcation. Farmers were asked to list criteria they consider in tree planting. Fourteen criteria were defined after interviews and discussions. These criteria were adaptability, growth rate, resistance to browsing, fuel wood quality, coppicing ability, seedling availability, crop compatibility (including allelopathic effect and competition for water), compatibility for boundary planting, timber and pole quality, shade provision, fodder quality, market demand and soil fertility improvement. These criteria reflect the advantages and disadvantages based on which the trees were judged. Experts at district level mentioned several criteria. Farmers' criteria were also presented to experts at Woreda level to identify similarities and differences of criteria by farmers' and experts. However, farmers and experts' criteria were the same except explaining in different words. For example, allelopathic effect was mentioned by experts who were interpreted as crop compatibility by farmers. Therefore, the experts accepted all the criteria listed by farmers.

Scoring and ranking of trees

Both farmers and experts scored and ranked tree species based on the selected criteria. The values reflect the perceived degree of importance of each tree species based on these criteria. Farmers gave the highest total score for *Eucalyptus camaldulensis*, which was associated with highest scores for its adaptability, growth rate, coppicing ability, seedling availability, and resistance to browsing (table 2). Whereas experts gave the highest total score for *Podocarpus, falcatus, which* was associated with highest scores for most of the criteria (table 3). This shows the divergence of interests between farmers and experts in which farmers are interested in short-term economic benefits while experts are concerned in long-term environmental issues.

Table 2. Farmers' average scores[12] of different tree species[13] based on evaluation criteria

Criteria	*Ec*	*Ca*	*Aa*	*Jp*	*Cl*	*Pf*	*Cm*	*Sm*	*Gr*
Adaptatbility	5	4	5	4	4	3.75	3.75	4	3.5
Growth rate	5	3.75	4	2.75	4.25	4	3	3	3.75
Resistance to browsing	5	3.25	1.5	4	4	3.25	4.25	4.5	4
Fuel wood quality	4.25	4.5	3.75	5	3.25	3.5	2.5	3	4
Coppicing ability	5	3.75	3.25	4	3.25	3.25	3.25	3	1
Seedling availability	5	3	1.75	2.75	3.75	3.25	2.25	3.5	3.75
Crop compatibility	3.25	3	4.75	4.75	2.5	4.25	4.25	2.75	2.75
Boundary planting	4	3.5	3.75	3	3.75	3.75	2.5	3	4.25
Timber quality	3.75	4	2.5	3.75	4.5	4.5	1	2.25	4.5
Pole quality	4.25	3.25	2.75	3.75	3.5	3.5	2	2.25	3.75
Shade provision	2	3.5	4.5	2.5	2	3.75	3.5	2.5	2.75
Fodder quality	1.5	3.25	4.75	1.5	1.75	2.5	3	2.25	2.75
Market demand	5	4	1.25	5	3.5	4.5	2.75	1.75	3.25
Soil fertility improvement	1	4.25	4.5	3.75	1.5	3.75	5	2.75	2.5
Overall score	54	51	48	50.5	45.5	51.5	43	40.5	46.5

[12] Scores; 5=*Best, 4= Very good,* 3 = *Good,* 2 = *Average,* 1 = *Not good*
[13] Ec=*Eucalyptus camaldulensis*,, Ca= *Cordia africana*, Aa=*Accacia abyssinica*, Jp=*Juniperus procera*, Cl=*Cupressus lusitanica*, Pf=*Podocarpus falcatus*, Cm= *Croton macrostachyus*, Sm= *Schinus molle*, Gr= *Grevillea robusta*

Table 3. Experts' scores of different tree species based on evaluation criteria

Criteria	*EC*	*Ca*	*Aa*	*Jp*	*Cl*	*Pf*	*Cm*	*Sm*	*Gr*
Adaptatbility	5	4	5	4	5	5	3	3	5
Growth rate	5	4	3	4	5	5	3	3	4
Resistant to browsing	5	5	4	5	5	5	2	3	3
Fuel wood quality	3	5	5	5	2	5	2	2	3
Coppicing ability	5	4	3	4	2	5	3	3	4
Seedling availability	4	4	4	5	5	5	4	4	3
Crop compatibility	1	5	5	4	2	5	2	3	5
Boundary planting	1	5	2	5	2	5	3	3	4
Timber quality	4	5	3	5	3	4	1	2	3
Pole quality	5	4	3	4	4	2	3	3	4
Shade provision	2	2	4	2	2	3	3	4	3
Fodder quality	1	2	4	1	1	2	4	2	2
Market demand	4	5	4	4	4	4	4	3	5
Soil fertility improvement	1	4	5	3	3	4	4	2	4
Overall score	46	58	54	55	45	59	41	40	52

Although farmers and experts had different scores for different tree species (table 2 and 3), they had similar perception on the growth rate of *E. camaldulensis* as compared to other species. Both of them believed that E. camaldulensis is superior in growth rate. This perception is supported by empirical evidences. For example, a nursery experiment in Ethiopia showed that *E. camaldulensis* had higher plant height as compared to *C. africana* and *C. macrostachyus* (Gindaba 2004). Similarly, field research in the central highlands of Ethiopia showed that the height and dry biomass of *E. camaldulensis* was higher than *G. robusta* (Kindu 2006).

Criteria weights for tree selection

The relative weights of criteria are shown in table 4. The pair-wise ranking shows that farmers assigned highest relative weight for adaptability (0.13), coppicing ability (0.11), pole quality (0.11) and market demand (0.11). Whereas experts assigned highest weights for crop compatibility (0.13), soil fertility improvement (0.12), adaptability (0.11) and market demand (0.10) of tree species. Similar to scoring of tree species, farmers and experts have different opinions concerning the importance (weights) of the different criteria to be taken into account during tree selection. For example, farmers gave lowest value (0.04) for soil fertility improvement while experts gave a high value (0.12) to the same criterion.

Standardizing the scores

Generally, the standardized scores are between 0 and 1. Criteria with the highest unstandardised scores (5) have the standardized score of one and criteria with the lowest unstandardised scores (1) have standardized score of zero (Tables 5 and 6). The distribution of standardized scores (Tables 5 and 6) follows the distribution of unstandardised scores (Tables 2 and 3).

Table 4. Relative weights of criteria given by farmers and experts using pair-wise ranking

Criteria	Relative weights	
	Farmers	Experts
Adaptability	0.13	0.11
Growth rate	0.10	0.05
Resistance to browsing	0.03	0.02
Fueld wood quality	0.03	0.02
Coppicing ability	0.11	0.09
Seedling availability	0.06	0.05
Crop compatibility	0.10	0.13
Boundary planting	0.05	0.07
Timber quality	0.10	0.09
Pole quality	0.11	0.07
Shade provision	0.01	0.01
Fodder quality	0.03	0.08
Market demand	0.11	0.10
Soil fertility improvement	0.04	0.12

Table 5. Standardized scores of farmers

Criteria	*Ec*	*Ca*	*Aa*	*Jp*	*Cl*	*Pf*	*Cm*	*Sm*	*Gr*
Adaptatbility	1.00	0.33	1.00	0.33	0.33	0.17	0.17	0.33	0.00
Growth rate	1.00	0.44	0.56	0.00	0.67	0.56	0.11	0.11	0.44
Resistance to browsing	1.00	0.50	0.00	0.71	0.71	0.50	0.79	0.86	0.71
Fuel wood quality	0.70	0.80	0.50	1.00	0.30	0.40	0.00	0.20	0.60
Coppicing ability	1.00	0.69	0.56	0.75	0.56	0.56	0.56	0.50	0.00
Seedling availability	1.00	0.38	0.00	0.31	0.62	0.46	0.15	0.54	0.62
Crop compatibility	0.33	0.22	1.00	1.00	0.00	0.78	0.78	0.11	0.11
Boundary planting	0.86	0.57	0.71	0.29	0.71	0.71	0.00	0.29	1.00
Timber quality	0.79	0.86	0.43	0.79	1.00	1.00	0.00	0.36	1.00
Pole quality	1.00	0.56	0.33	0.78	0.67	0.67	0.00	0.11	0.78
Shade provision	0.00	0.60	1.00	0.20	0.00	0.70	0.60	0.20	0.30
Fodder quality	0.00	0.54	1.00	0.00	0.08	0.31	0.46	0.23	0.38
Market demand	1.00	0.73	0.00	1.00	0.60	0.87	0.40	0.13	0.53
Soil fertility improvement	0.00	0.81	0.88	0.69	0.13	0.69	1.00	0.44	0.38

Table 6. Standardized scores of experts

Criteria	*Ec*	*Ca*	*Aa*	*Jp*	*Cl*	*Pf*	*Cm*	*Sm*	*Gr*
Adaptatbility	1.00	0.50	1.00	0.50	1.00	1.00	0.00	0.00	1.00
Growth rate	1.00	0.50	0.00	0.50	1.00	1.00	0.00	0.00	0.50
Resistance to browsing	1.00	1.00	0.67	1.00	1.00	1.00	0.00	0.33	0.33
Fuel wood quality	0.33	1.00	1.00	1.00	0.00	1.00	0.00	0.00	0.33
Coppicing ability	1.00	0.67	0.33	0.67	0.00	1.00	0.33	0.33	0.67
Seedling availability	0.50	0.50	0.50	1.00	1.00	1.00	0.50	0.50	0.00
Crop compatibility	0.00	1.00	1.00	0.75	0.25	1.00	0.25	0.50	1.00
Boundary planting	0.00	1.00	0.25	1.00	0.25	1.00	0.50	0.50	0.75
Timber quality	0.75	1.00	0.50	1.00	0.50	0.75	0.00	0.25	0.50
Pole quality	1.00	0.67	0.33	0.67	0.67	0.00	0.33	0.33	0.67
Shade provision	0.00	0.00	1.00	0.00	0.00	0.50	0.50	1.00	0.50
Fodder quality	0.00	0.33	1.00	0.00	0.00	0.33	1.00	0.33	0.33
Market demand	0.50	1.00	0.50	0.50	0.50	0.50	0.50	0.00	1.00
Soil fertility improvement	0.00	0.75	1.00	0.50	0.50	0.75	0.75	0.25	0.75

Aggregating the results and ranking alternatives

In this research, the results were aggregated using the Simple Additive Weighting technique of MCA. Accordingly, the result of the MCA shows that farmers' rank *E. camaldulensis* the 1st preferred tree species followed by *Podocarpus falcatus* and *Juniperus procera* in the area (table 7). However, experts' show preference for *P. falcatus* followed by *C. africana* and *A. abyssinica* (table 8). Experts place *E. camaldulensis* in the 6th position. Experts criticized *Eucalyptus* due to their environmental concern such as competition with crops for water, depletion of ground water and its allelopathic effects. A previous study showed that farmers rank *Eucalyptus* as the most preferred in the central highlands of Ethiopia (Kidanu 2004). Farmers mentioned that high economic return resulted from its fast growth, coppicing ability and high market demand makes *Eucalyptus* the most preferred species. The result showed that there are mismatches between farmers and experts on *Eucalyptus.* This is because there are differences between farmers and experts in the weighing of criteria and scoring of tree species.

Table 7. MCA ranking (standardized) of the different tree species by farmers in Meskan Woreda

Criteria	*Ec*	*Ca*	*Aa*	*Jp*	*Cl*	*Pf*	*Cm*	*Sm*	*Gr*
Adaptatbility	0.130	0.043	0.130	0.043	0.043	0.022	0.022	0.043	0.000
Growth rate	0.100	0.044	0.056	0.000	0.067	0.056	0.011	0.011	0.044
Resistant to browsing	0.030	0.015	0.000	0.021	0.021	0.015	0.024	0.026	0.021
Fuel wood quality	0.021	0.024	0.015	0.030	0.009	0.012	0.000	0.006	0.018
Coppicing ability	0.110	0.076	0.062	0.083	0.062	0.062	0.062	0.055	0.000
Seedling availability	0.060	0.023	0.000	0.018	0.037	0.028	0.009	0.032	0.037
Crop compatibility	0.033	0.022	0.100	0.100	0.000	0.078	0.078	0.011	0.011
Boundary planting	0.043	0.029	0.036	0.014	0.036	0.036	0.000	0.014	0.050
Timber quality	0.079	0.086	0.043	0.079	0.100	0.100	0.000	0.036	0.100
Pole quality	0.110	0.061	0.037	0.086	0.073	0.073	0.000	0.012	0.086
Shade	0.000	0.006	0.010	0.002	0.000	0.007	0.006	0.002	0.003
Fodder quality	0.000	0.016	0.030	0.000	0.002	0.009	0.014	0.007	0.012
Market demand	0.110	0.081	0.000	0.110	0.066	0.095	0.044	0.015	0.059
Soil fertility improvement	0.000	0.033	0.035	0.028	0.005	0.028	0.040	0.018	0.015
Overall scores (Pi)	0.826	0.558	0.553	0.614	0.522	0.620	0.309	0.288	0.456
Farmers' rank of alternatives based on overall scores: ***EC>Pf> Jp > Ca>Aa> Cl> Gr> Sm >Cm***									

Table 8. MCA ranking (standerdized) of the different tree species by experts in Meskan Woreda

Criteria	*EC*	*Ca*	*Aa*	*Jp*	*Cl*	*Pf*	*CM*	*SM*	*Gr*
Adaptatbility	0.110	0.055	0.110	0.055	0.110	0.110	0.000	0.000	0.110
Growth rate	0.050	0.025	0.000	0.025	0.050	0.050	0.000	0.000	0.025
Resistant to browsing	0.020	0.020	0.013	0.020	0.020	0.020	0.000	0.007	0.007
Wood quality	0.007	0.020	0.020	0.020	0.000	0.020	0.000	0.000	0.007
Coppicing ability	0.090	0.060	0.030	0.060	0.000	0.090	0.030	0.030	0.060
Seedling availability	0.025	0.025	0.025	0.050	0.050	0.050	0.025	0.025	0.000
Crop compatibility	0.000	0.130	0.130	0.098	0.033	0.130	0.033	0.065	0.130
Boundary planting	0.000	0.070	0.018	0.070	0.018	0.070	0.035	0.035	0.053
Timber quality	0.068	0.090	0.045	0.090	0.045	0.068	0.000	0.023	0.045
Pole quality	0.070	0.047	0.023	0.047	0.047	0.000	0.023	0.023	0.047
Shade	0.000	0.000	0.010	0.000	0.000	0.005	0.005	0.010	0.005
Fodder quality	0.000	0.027	0.080	0.000	0.000	0.027	0.080	0.027	0.027
Market demand	0.005	0.010	0.005	0.005	0.005	0.005	0.005	0.000	0.010
Soil fertility improvement	0.000	0.090	0.120	0.060	0.060	0.090	0.090	0.030	0.090
Overall scores (Pi)	0.444	0.668	0.629	0.599	0.437	0.734	0.326	0.274	0.614
Experts' rank of alternatives based on overall scores: ***Pf>Ca>Aa>Gr>Jp >Ec >Cl>Cm>Sm***									

Conclusions and Recommendations

The research shows that there are divergent interests between experts and farmers on tree selection, *Eucalyptus* in particular. Farmers are interested to expand *Eucalyptus* due to its high economic return while experts discourage its expansion mainly due to their concerns in environmental issues.

In a country like Ethiopia where the community has little energy alternatives, low-income, low wood biomass for fuel and construction purpose, it is hardly possible to stop *Eucalyptus* expansion. However, its further expansion to productive farmlands might be threatening. Two consequences might be hypothesized in this regard. Firstly, there will be a reduction in productive farmland for crops, resulting in shortage of food crops. Secondly, there is little information about future market demand for *Eucalyptus* tree products and there might be a fall in the price of wood and wood products, which in turn reduces the economic return from the tree. Therefore, the plantation of *Eucalyptus* should be managed appropriately in such a way that its benefits can be maximized and its risks be kept minimal. Management includes spatial planning by searching for a compatible niche to ensure that sensitive habitats such as productive farmlands and water bodies are conserved. It is important to expand *Eucalyptus* plantation in degraded niches such as bare hillsides, gullies, and waterways.

Besides its economic benefits, the availability of fuel wood from *Eucalyptus* may have also indirect benefits such as soil fertility improvement by reducing the demand for crop residues and animal manure, which might have otherwise been used as fuel wood. Therefore, integrated development plans are needed that would spell out benefits as well as risks of *Eucalyptus,* and that take into account the needs of communities.

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References

Babu RC, OS Kandasamy. 1997. Allelopathic effects of *Eucalyptus globulus* Labill on Cyperus Rotundus L. and Cynodol dactaylon L. Pers. Journal of Agronomy and Crop Science 179, 123-126.

Central Statistical Authority (CSA). 2008. Statistical abstract of Ethiopia, Central Statistical Authority, Addis Ababa, Ethiopia.

Davidson J. 1989. The *Eucalyptus* Dilemma, Arguments for and against Eucalypt planting in Ethiopia. Seminar Note Series No. 1. Forestry Research Center, Addis Ababa.

Breitenbach F, 1961. Exotic forest trees in Ethiopia, Addis Ababa, Ethiopian Forestry Association, Ethiopian Forest Review 2, 19-39.

Friis I. 1995. Myrtaceae. In Edwards S, Mesfin T, Hedberg I, (eds.). Flora of Ethiopia and Eritrea, Vol. 2 (2). Addis Ababa University, Addis Ababa and Uppsala University, Uppsala, pp. 71-106.

Gindaba J. 2003. Water and Nutrient Relations of Selected Tree Species of Ethiopia. PhD Dissertation. Department of Forest Science, Stellenbosch University, South Africa.

Gindaba J, A Rozanov, L Negash. 2004. Response of seedlings of two *Eucalyptus* and three deciduous tree species from Ethiopia to severe water stress. Forest Ecology and Management 201,119–129

Gindaba J, A Rozanov, L Negash. 2005a. Trees on farms and their contribution to soil fertility parameters in Badessa, eastern Ethiopia. Biology and Fertility of Soils 42, 66-71.

Gindaba J, A Rozanov, L Negash. 2005b. Photosynthetic gas exchange, growth and biomass allocation of two *Eucalyptus* and three indigenous tree species of Ethiopia under moisture deficit. Forest Ecology and Management 205, 127–138.

Gindaba J. 2006. Overview of water and nutrient relations of *Eucalyptus* and deciduous tree species and implications for their use in land rehabilitation. Journal of the Drylands 1(1), 15-25.

Grewal SS, SP Mittal, S Dyal, Y Agnihotri. 1992. Agroforestry systems for soil and water conservation and sustainable production from foothill areas of north India. Agroforestry Systems 17, 183–191.

Hajkowicz S. 2008. Rethinking the economists' evaluation toolkit in light of sustainability policy. Sustainability: science, practice and policy 4(1), 17-24

Howard A. 1991. A critical look at multiple criteria decision making techniques with reference to forestry applications. Canadian Journal of forest research 21(4),1649-1659.

Joubert AR, A Leiman, HM de Clerk, S Katua, JC Aggenbach. 1997. Fynbos (fine bush) vegetation and the supply of water: a comparison of multi-criteria decision analysis and cost-benefit analysis. Ecological economics 22,123-140.

Kidanu S, T Mamo, L Stroosnijder. 2004. *Eucalyptus*–wheat interaction on Ethiopian Nitosols. Agricultural Systems 80, 151–170.

Kidanu S. 2004. Using *Eucalyptus* for Soil and Water Conservation on the highland Vertisols of Ethiopia. Tropical Resource Management Papers No. 52, Wageningen University and Research Center, The Netherlands.

Kindu M, G Glatzel, Y Tadesse, A Yosef. 2006. Tree species screened on Nitosols of Central Ethiopia: biomass production, nutrient contents and effect on soil nitrogen. *Journal of Tropical Forest Science* 18(3), 173–180.

Lemenih M. 2006. Expediting ecological restoration with the help of foster tree plantations in Ethiopia. Journal of the Drylands 1(1), 72-84.

Lisanework N, A Michelsen. 1993. Allelopathy in agroforestry systems: the effect of leaf extracts of *Cupressus lustanica* and three *Eucalyptus* spps. on four Ethiopian crops. Agroforestry Systems 21, 63-74.

May F, A Ash. 1990. An assessment of the allelopathic potential of *Eucalyptus.* Australian Journal of Botany 38, 245–254.

Michelsen A, N Lisanework, I Friis. 1993. Impacts of tree plantation in the Ethiopian highland on soil fertility, shoot and root growth, nutrient utilization and mycorrhizal colonization. Forest Ecology and Management 61, 299–324.

Pohjonen V, T Pukkala. 1988. Profitability of establishing *Eucalyptus globulus* plantation in the Central Highlands of Ethiopia. Silva Fennica 22 (4), 307-321.

Pohjonen V, T Pukkala. 1990. *Eucalyptus globulus* in Ethiopian forestry. Forest Ecology and Management 36, 19-31.

Prabhakar VK. 1998. Social and Community Forestry. Satish Garg, New Delhi, 316p.

Pretty JN, 1995. Participatory learning for sustainable agriculture. World Development 23 (8), 1247–1263.

Turnbull JW. 1999. Eucalypt Plantations. New Forests 17, 37-52.

Yirdaw E, O Luukkanen. 2003. Indigenous woody species diversity in *Eucalyptus globulus* Labill. ssp. *globulus* plantations in the Ethiopian highlands. Biodiversity and Conservation 12, 567–582.

Zhang C, S Fu. 2009. Allelopathic effects of *Eucalyptus* and the establishment of mixed stands of *Eucalyptus* and native species. Forest Ecology and Management 258, 1391–1396.

Zanakis S, A Solomon, N Wishart, S Dubish. 1998. Multiattribute decision Making: a simulation comparison of selected methods. European journal of operational research 107 (3), 507-529.

Is *Eucalyptus* Farming Blessing or Curse in the Central Highlands of Ethiopia? Analysis from Farmers' Perspective

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Abstract

It is more than a century since eucalypts has been introduced into Ethiopian landscapes. During this period, eucalypts has reached all corners of the country; and being prized by the larger segments of the society for its wood values. In order to evaluate the socio-economic importance of eucalypts farming, a household survey was conducted in Sululta District, in the central highlands of Ethiopia. In the study area, eucalypts are apparently the widely planted species for household consumption as well as for commercial use. The results show that eucalypts are playing an important role in poverty reduction being a source of income through selling construction materials and fuel woods. Moreover, it is an important source of construction materials, farm tools, fuel wood, and charcoal for household's own use. The leaves of the plant are also used as a medicine and the flower is serving as honeybee flora. The plant has also important social values such as providing shade for various social events. It has also reduced the possible deforestation that may occur in the fragmented patches of natural forest in central high lands. This is mainly by supporting the wood demand of local households and Addis Ababa city. Despite these importance, the farmers in the study area are also complained its effect on environment-specifically its effect on water and nutrients. It was argued that crops productivity is very much reduced when crops are planted close to eucalypts stands. In addition, eucalypts is perceived to dry up stream and wetlands in the area. In a net shell, eucalypts is becoming an important cash crop of the area; farmers are less concerned about the ecological or environmental blames of eucalypts.

Key words: eucalypt, highlands, landscapes, poverty reduction, Ethiopia

Introduction

Eucalyptus is one of the diverse genus of flowering plants in the world. The genus has now been recognized to comprise about 800 species, mostly native to Australia, and a very small number are found in adjacent parts of New Guinea and Indonesia (Brooker, 2002). The genus has many favourable characteristics including fast growth rates, wide adaptability to soils and climate, ease of management through coppicing and valuable wood properties. Because of these reasons, they are among the most widely cultivated of all plants, particularly in tropical and subtropical parts of the world (Davidson, 1993). In the tropics alone, there were over 10 million ha of eucalypt plantations at the end of 1990 (FAO, 1993). In China, for example, over 200 species have been introduced but fewer than ten are now cultivated on a significant scale (Turnbull and Booth, 2002). This is holds true for Ethiopia where over 60 species have been introduced but only four species, *E. camaldulensis*, *E. globulus*, *E. grandis* and *E. saligna*, dominate the Ethiopian landscapes.

Globally, eucalypts are cultivated for different purposes such as source of wood, its oil can be used for cleaning and functions as a natural insecticide, and it is sometimes used to drain swamps and thereby reduce the risk of malaria (Luzar, 2007). In particular, population growth in the developing world has led to a greater demand for fuel wood, poles, and other wood products. In these countries, natural forests are being heavily exploited; hence, the scale of wood shortages in these countries cannot be satisfied without planting fast growing species like eucalypts.

Outside their natural ranges, eucalypts are both acclaimed for their economic benefits to poor populations and derided for being aggressive of nutrient and water leading to controversy over their total impact. According to various studies (e.g., Lugo, 1992; Senbeta, 1998; Senbeta *et al.*, 2002a, b; Calder, 2002) establishing exotic forest plantation like eucalypts species has been under big debate over the last three decades regarding the advantages and disadvantages of growing eucalypts. Some of the commonly mentioned advantages include quick provision of benefits associated with fast growth, short rotation plantations for production of fuel wood and timber. Under proper management they are good source of forage for bees (honey production), can produce fiber for pulp and paper industries under relatively short rotation, can grow adequately in a wide range of ecological conditions and sites among others (Jagger and Pender, 2000; Brooker, 2002; Calder, 2002). On the contrary, despite these benefits, eucalypts have been said to have their disadvantages (FAO, 1988; Jagger and Pender, 2000). These disadvantages include consumption of much ground water associated with its high growth rate. They may not provide good soil protection against erosion and may not provide good habitats and supports biodiversity.

Apparently, in recent years, planting of eucalypts has been faced controversies and critiques based on ecological and socio-economic arguments in Ethiopia and elsewhere (Jagger and Pender, 2000). The major argument has been that eucalypts removes too much water from underground reserves and inhibit the growth of other vegetation. Its leaf litter has adverse effects on soil humus. Trade-offs between potential socio-economic benefits and the environmental impacts associated with eucalypts trees, therefore, need to be thoroughly assessed.

In Ethiopia, such critiques have led to develop an opinion differences among academia and policy makers. *Eucalyptus* impacts and responses at different sites are complex and may require substantial research and adequate information before conclusive arguments can be made. Given these scenarios, conclusive decisions on eucalypts will likely be a major debate in the years to come. This study try to analysis farmers' viewpoint about the controversial issue of *Eucalyptus* tree planting regarding the socio-economic and ecological aspects of eucalypt farming in Sululta district in the central highlands of Ethiopia.

Eucalyptus was introduced to Ethiopia as early as 1890s; and it was introduced because of the massive deforestation around the city for firewood. Apparently, blocks of plantations of eucalypts were established around Addis Ababa and later expanded to other areas to supply fuel wood for urban populations (Bristow, 1995). At beginning only few species, like *Eucalyptus globulus* and *E. camaldulensis* were the two species probably introduced. Later on species like *E. saligna, E. tereticornis, E.citriodora, E. grandis, E. maculata, E. cladocalyx, E. urophylla* and others were introduced*;* although about five species dominate the landscapes of the country today.

The great advantage of the eucalypts was that they were fast growing, required little attention, and when cut down grew up again from the coppice; it could be harvested every five to ten years. The tree proved successful from the onset of introduction. In the 1970s, *Eucalyptus* plantations covered approximately 91,000 hectares around Addis Ababa and the surrounding highland (Pohjonen and Pakulla 1990). With a change of government in 1974, along with the shift in government policy, large-scale forest plantation and rehabilitation of degraded forestland became an important millstone of the country. For this, *Eucalyptus* species became the centre of endeavour throughout large-scale plantation schemes in the country. Moreover, through 1984 and 1988, the international support for rural afforestation with *Eucalyptus* was provided by the Sudano-Sahelian Office of the UN (UNSO) to Ethiopia, which initiated a fuel wood program that established over 9000 ha of fuel wood plantations. Added together with farmers' individual initiatives, Ethiopia currently has 477,000 ha of *Eucalyptus* plantation (WAC, 2006).

Research Methodology

The study area

This study is conducted in Sululta district of central highlands of Ethiopia. Sululta district is located about 40 km north of Addis Ababa. The total area of the district is about 109, 269 ha. It encompasses 23 rural kebeles and 2 town kebeles. Topographically, the district covers flat plains, sloppy and mountainous areas. About 56% of the area is flat land while 12% are gentle slope. The remaining considerably large areas of the district, which is about 32%, are mountainous area not suitable for cultivation of annual crops. Agro-ecologically, most parts of the district (about 71%) are located on a highland while about 25% falls under mid-altitude. In terms of land use types, agricultural land makes about 36% of the total area followed by grazing land (makes about 28%) of the area. The forestland is about 14% of the total district area. While the remaining share of the area is allocated to other land uses; and degraded areas makes a considerable portion (about 4.5 %) of the district (SARDO, 2009).

A total of 16,422 households are living in the district of which about 82% are male headed households and the rest 18% are female headed households. The population density of the area is about 98 persons per km^2 (SARDO, 2009). Most farmers are engaged in farming and livestock rearing as the main economic activities to make living. Most income of the households, i.e., about 51% comes from farming (*Eucalyptus* farming is also included) while the livestock contributes 39% of household income (Ibid). The remaining 10 percent of income of household comes from other activities such as off-farm employment, petty-trade, and handcrafts. As compared to other parts of the country, the area has good access to market and other services. Moreover, with the current growing economic activities and establishment of new industries in the area, the area is becoming a destination for many people, which is expected to increase population density and demand for natural resources (including fuel wood) in the area.

Data collection and analysis

The study was based on both primary and secondary data sources. The primary qualitative and quantitative data on socio-economic important and side effect of eucalypts were collected using focus groups discussion and sampled household survey. The semi-structured questionnaires were prepared for face-to-face interview. The semi-structured questionnaires was designed to collect data related to reasons underlying for the expansion of eucalypts farming in the area, it ecological implication and socio-economic contributions. A total 60 household heads were randomly picked from the study area for the interviews. The focus groups discussion is meant to generate in-depth information while transect walk and field observations were mainly to cross check data generated through interviews. Two focus group discussions each having 5-7 members, with men and women groups including both elderly and youths drawn purposively were organized to generate information that support the survey results.. Secondary data was collected from the district Agricultural and Rural Development office. Regarding data analysis, descriptive method of analysis is used to meet each objectives of this study.

Results and Discussion

Why farmers grow eucalypts?

All respondents including focus group discussions members grow eucalypts tree in the study area. Largely, the farmers grow eucalypts to produce wood and leaves for fuel wood, poles, or posts for house building and other farm uses, and large poles and timber for sale. Tree planting for shade, shelter and the marking of farm boundaries is also important for some farmers. According to 50% of the respondents, the use of trees as a living bank account, to be harvested when there is a need for cash, is widespread. About 70% of the respondents claimed that the leaves of the plant are also used as a medicine and the flower is serving as honeybee flora. In the study area, on the average a household own about 0.5 ha of eucalypts woodlots. Most growers produce eucalypts as woodlots. Those farmers who have insufficient land for woodlots often grow few trees wherever possible close to their homestead.

In terms of income generation, the eucalypts growers in the study area claimed that a household can get on average between 500 -15,000 BIRR every 4-5 years depending on the size of the stand a households own. Because of this income, almost all respondents are courageous to expanding their eucalypts stands if they get land for planting.

All respondents' farmers' in the study area mainly grow *E. globulus.* The main reason for most farmers choosing to plant *E. globulus* in study area is the quick cash return that they can get from harvesting and selling poles. Farmers select species that best provides profit and meets their immediate needs. This is a critical first step in the decision-making process. Farmers also prefer fast growing and easily managed species as those species provide an early return on the capital invested and do not divert the farmers from other activities. *E. globulus* meet these criteria and are popular with farmers in the study area. Various studies elsewhere in Ethiopia (e.g., Breitenbach, 1961; Davidson, 1989, 1995; Jagger and Pender, 2000) have reported that tree growers are usually governed by fast growth of the species and easy manageability. Many people in Ethiopia are mainly dependent on eucalypts as a source of fuel and house building materials. The introduction of *Eucalyptus* in Ethiopia was a great success (Henry, 1973) and is undeniable fact that *Eucalyptus* plantations have played and will play a tremendous role in alleviating the fuel and construction material problems of the community in Ethiopia (Tesfaye, 2007). This is highly prevalent in highlands of Ethiopia where agricultural expansion and settlements have already destroyed the natural vegetation and the people have few options other than eucalypts for energy and house construction. In similar way in Tanzania, eucalypts are among the major species grown under smallholder forestry and contributes significant source of building material (poles) and fuel wood. Today eucalypts from smallholder farms contribute a significant proportion in the timber market and large-scale trade in transmission poles in Tanzania (Munishi *et al*., 2004).

Gender dimensions of eucalypts farming

To understand the gender dimensions of eucalypts farming and management in the study area, the respondents were asked whether man, women, or both are involved in planting, harvesting and selling of eucalypts. Accordingly, about 43% of the respondents said that male play major role in planting; whereas 57% says both men and women are involved in planning and management of eucalypts stands. Most respondents also responded that the large share of harvesting responsibility goes to the male; however, selling activities said to be the role of both male and female in most cases. According to these findings, eucalypts planting and management is mainly done by men and women involvement in the study area. In the study area, gender is not any more a barrier rather it is a means through which the households members usually share responsibilities regardless of the sex. Most women respondents also supported the ideas and they do not feel they are ignored or underrepresented in eucalypts farming and management. The women socioeconomic role in the family and community underwent alterations and several of women in the study area are being involved in activities that used to be of only men.

Status of eucalypts trees expansion

The landscapes in the study area are mainly covered by eucalypts woodlots as observed during transect walk. About 95% of the respondents also claimed that eucalypts woodlots are increasing in the study area in the recent years. As a major barrier toward the expansion of woodlots, however, scarcity of land was noted by many respondents. This is also supported by the forestry expert of the district. Although the forestry department of the district is discouraging the local farmers not to plant eucalypts, most farmers refused to plant non-eucalypts species and continuously demand eucalypt seedlings. About 20% of the respondents stated that they have started producing their own eucalypts seedlings because of inadequate supply of seedlings by the district forestry department. This finding is line with the reports of the Agricultural and Rural Development Office of the district. The forest cover of the district is 14, 970 ha, of which more than 90% is eucalypts plantation. *Eucalyptus globulus* is the dominant species in the plantations.

Ecological aspects of eucalypts

Figure 1 shows, farmers' views about the effects of eucalypts on environment, mainly on biodiversity, water, soil and microclimate. In collective terms, the respondents are asked whether eucalypts has negative environmental effects and around 56% of the respondents supported negative effect of eucalypts.

Effects of eucalypts on water sources

The farmers in the study area were asked to share their perception about the effects of eucalypts stand on water resources. About 79% of the respondents said eucalypts has negative effect on water resources while 14% of the respondents stated that it has no effect on the water sources. The remaining 7% responded as if *Eucalyptus* increases the water availability through better microclimate (Figure 2). Those who said eucalypts has negative impacts on water they stated that eucalypt reduce water yield and can change springs and wetlands when planted close to these sources. As justification, they said they are planting eucalypts in or close to wetlands in order to dry-up wetlands systems so that they can use for other purposes.

The effect of eucalypts on water budget has been claimed by many scholars elsewhere although the level is not yet agreed. Many scholars claim that the effects of eucalypts on the water budgets will depend on the species in question, climate of the areas, surface soil conditions, slope gradient and length, tree growth stage and tree density and the like (Davidson, 1989; Jagger and Pender, 2000; Teshome, 2007).

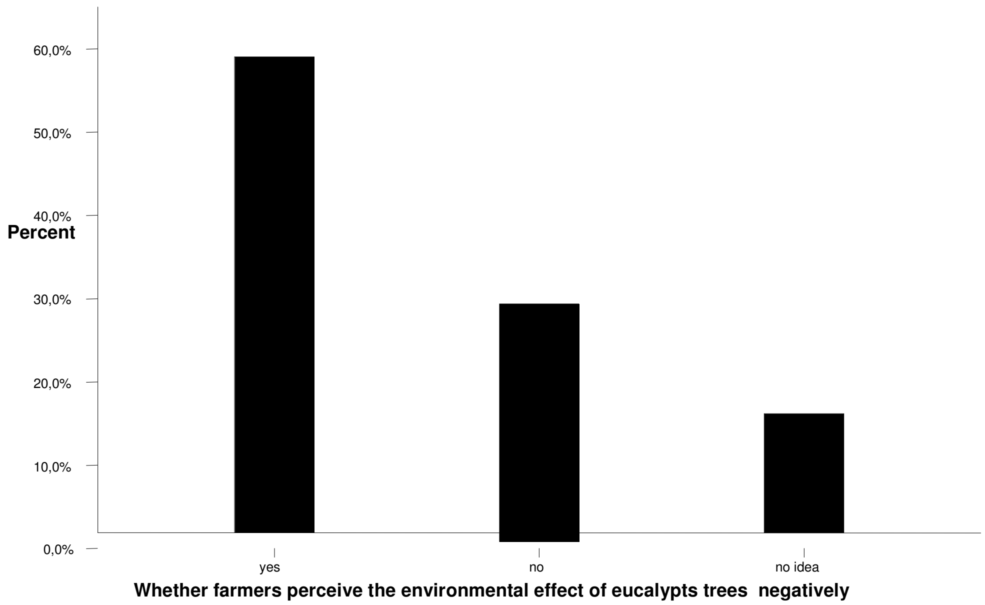

Figure 1. Local farmers' perception towards environmental effect of eucalypts tree

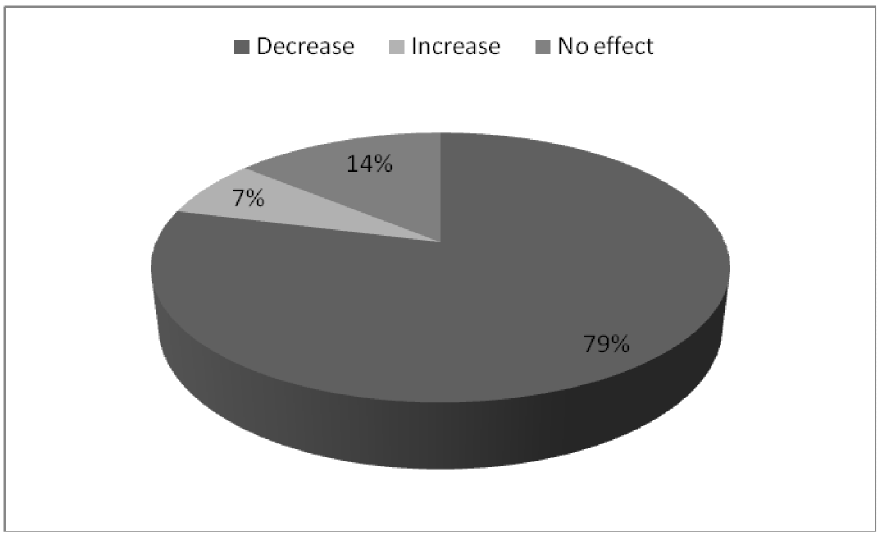

Figure 2. How local households perceive effect of Eucalypts tree on water availability

Although the farmers perceive the negative effects of eucalypts on water budget but they are not ready to stop or minimize planting eucalypts. The farmers claim that they do not have alternative fast growing and multipurpose species that can be planted and used for various services and products.

Effects of eucalypts on soil and on nutrients

About 50% of the respondents perceived the negative effects of eucalypts on soil and nutrient. But significant proportion of the respondents claimed that eucalypts has less effect on soil and nutrients. According to those who claimed the negative effect of eucalypts, accelerated run off and soil erosion due to lack of undergrowth beneath the eucalypts canopy is mentioned as major reasons. The respondents who claimed to support the negative effects of eucalypts on soil and nutrients they underlined its impact on agricultural crops when planted close. They stated that eucalypts has the capacity to compete and reduce productivity of the crop significant. Although this negative claim have been supported by several studies elsewhere (e.g., FAO, 1988; Davidson, 1989; Lima, 1990; El-Amin *et al*. 2001; Calder, 2002; Brooker, 2002); but the level and extent of eucalypts effects seems to be arguable among researchers.

Most of the concerns related to soil effects deal with depletion of nutrients and allelopathy caused by the litter, which is said to exert an antibiotic effect on soil microorganisms. Eucalypt plantations are sometimes accused of not providing adequate soil protection. This lack of protection can lead to less water infiltration and greater runoff, resulting in soil erosion and watershed sedimentation (Couto and Betters, 1995). On the contrary, study in Sudan showed little nutrient depletion and changes in soil properties were observed under eucalypts plantation as compared to fallow and cultivated land use practices (El-Amin *et al*., 2001). These authors argued that the change depends on the species and soil type under any particular environment and the biological complex influencing the rate of change, which is usually slow. Others argued that properly managed eucalypt plantations could provide soil protection (Lima, 1990; Couto and Betters, 1995). As always, sensitive sites need to be treated carefully to avoid adverse effects on soils.

Effects eucalypts on biodiversity

One of the major criticisms that have been debated over years among the scholars concerning eucalypts is its impact on flora and fauna of the area. In this regard, the farmers in the study area were asked to express their observation about the effects of eucalypts on biodiversity of the area. Accordingly, about 79 % of respondents uttered the negative effect of eucalypts on biodiversity. Most of their observation shows that eucalypts suppress undergrowth and does not allow other indigenous plant species to grow in its vicinity, specifically under its canopies. Yet, two indigenous tree species, namely *Juniperus excelsa* Bieb and *Olea europaea* L. ssp. cuspidata (Wall. ex G. Don) Cif., are identified by farmers as tolerant to eucalypts trees and can grow close to eucalypts tree. About 87% of the respondents also clearly stipulated eucalypts impact on herbs and other undergrowth because of its aggressiveness it terms of competing for water and nutrients. This is in accordance with a number of study reports in different parts of the world (e.g., FAO, 1988; Calder, 2002; Coppen, 2002). According to these authors, eucalypts species can compete vigorously for water and nutrients where these resources are scarce. Eucalypts are tall plants. Because of their faster growth, will tend to shade out native vegetation of the same age regenerating beneath them. Nearby crops can also be affected in this way, resulting in reduced yields. However, not all eucalypts cast shade, which is heavy enough to discourage ground vegetation or understory shrubs, and shading can be adjusted by varying the density of the trees. There are complex interactions between light and water requirements of different trees that generalize difficult.

Similarly, 85% of the respondents reported that eucalypts plantation support less fauna diversity as compared to natural forest. Since the eucalypts stands usually have low undergrowth and shrubs, the stands are very open because of these the animals cannot get hiding place from their enemy. Apparently, planted stands of any tree type generally will contain lower numbers of animal species than more diverse natural forests. Introduced species of trees will not have a local fauna adapted to them. Replacing indigenous vegetation with plantations of Eucalyptus species is almost certain to have an effect on native fauna. But the results are often difficult to predict, and varies from species to species and with the size of plots and compartments and with kind of native vegetation that is found adjacent to the planted stands (Senbeta, 1998; Senbeta *et al*., 2002a, b; Munishi *et al*., 2004).

Effects on Climate and Microclimate

Under this section, the farmers were asked whether they have noticed or recognized any climate or microclimate related impacts of eucalypts plantations. Accordingly, most respondents (92%) said they do not know whether eucalypts plantations have positive or negative effects on microclimate of the area. It is very difficult for them to distinguish; in particular, the eucalypts from plantations of any other tree or from different types of native forests in their effects on regional rainfall or on other regional climate parameters. However, about 8% of the respondents said that eucalypts stands are positively influencing the microclimate in the last couple of years. They said eucalypts attract rainfall and regulate microclimatic conditions of the area. They noticed effects of eucalypts on microclimate at the local level.

Conclusion and Policy Implications

The present study shows that eucalypts plantations are expanding at alarming rate in the study area. Eucalypts is an important cash crop of the area that can play an important role in the poverty reduction efforts. The unprecedented uptake of eucalypts amongst farmers led to a flood of poles and post materials on the local market and central market (Addis Ababa). Farmers had also anticipated greater gains and smaller costs from cultivating this exotic tree species. Many of the scientific claims made by different scholars against the plant are partly shared by farmers. From farmers' perspective, the ecological or environmental blames of the species are not big concern, as the majority of the farmers are more interested in its immediate social and economic benefits. Farmers found eucalypts as important cash crop that can be produced with small initial capital and labour. On the other hand, the district Agricultural and Rural Development office is very much concerned about the expansion of eucalypts and unwillingness of the farmers to be engaged in planting indigenous species. The forest department of the district is advising farmers not to expand *Eucalyptus* because of its environmental and ecological impacts. However, the outcomes of interventions undertaken to stop expansion are so far unsatisfactory.

Given the economic benefits of eucalypts and its environmental implications, this study recommends that the areas suitable for eucalypts plantation need to be identified through detailed land use planning. Planting eucalypts in appropriate niches may enhance its role in poverty reduction and reducing possible natural forest deforestation.

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References

Breitenbach F. 1961. Exotic forest trees in Ethiopia. Addis Ababa. Ethiopian Forestry Association, Ethiopian Forestry Review 2:19 - 39.

Bristow S. 1995. *Agroforestry* and community-based forestry in Eritrea. Working Paper No.2. Washington, D.C.: World Bank.

Brooker I. 2002. Botany of the eucalypts**.** *In*: Coppen JW (ed). *Eucalyptus:* The Genus *Eucalyptus.* Taylor and Francis, London, pp. 3-35.

Calder IR. 2002. *Eucalyptus,* water and the environment. In: Coppen J.W. (Ed.), *Eucalyptus:* The Genus *Eucalyptus.* Taylor and Francis, London, pp. 36-52.

Coppen JJ. 2002. *Eucalyptus*: The Genus *Eucalyptus.* Taylor and Francis, London.

Couto L, DR Betters. 1995. Short-rotation eucalypt plantations in Brazil: social and environmental issues. OAK RIDGE NATIONAL LABOURATORY, Tennessee. http://bioenergy.ornl.gov/reports/euc-braz/toc.html; accessed 17/8/2010.

Davidson J. 1989. The *Eucalyptus* dilemma. Arguments for and against *Eucalyptus* planting in Ethiopia. The Forestry Research Centre Seminar Note Series No. 1. Addis Ababa.

Davidson J. 1993. Ecological Aspects of *Eucalyptus* Plantations. In: Proceeding of the Regional Expert Consultation on *Eucalyptus,* 4-8 October 1993, Volume 1, FAO Regional Office for Asia and the Pacific, Bangkok. http://www.fao.org/docrep/005/ac777e/ac777e04.htm#bm04.1;accssed-16/07/2010.

El-Amin E A, IE Diab, SI Ibrahim. 2001. Influence of *Eucalyptus* cover on some physical and chemical properties of a soil in Sudan. COMMUN. SOIL SCI. PLANT ANAL., 32(13/14): 2267–2278.

FAO. 1993. Forest Resources Assessment. http://www.fao.org/docrep/007/t0830e/t0830e00.htm; accessed -16/07/2010.

FAO.1988. The *Eucalyptus* Dilemma. FAO, Rome. 26 pp.

Henery PW. 1973. Notes on maps of the *Eucalyptus* plantations around Addis Ababa and the Menagesha State Forest, Ethiopia. ODA. London. Misc. Report. 150:1-10.

Jagger P, J Pender. 2000. The role of trees for sustainable management of less favored lands: the case of *Eucalyptus* in Ethiopia. International Food Policy Research Institute, EPTD Discussion Paper NO. 65.

Lima W. P. 1990. Overland flow and soil nutrient losses from *Eucalyptus* plantations. IPEF International 1:35-44.

Luzar J. 2007. The Political Ecology of a "Forest Transition": *Eucalyptus* forestry in the Southern Peruvian. Ethnobotany Research and Applications, 5:085-093.

Munishi PKT, A O'Kting'ati, GC Monela, SP Kingazi. 2004. Small holder forestry for employment, income generation, and rural development in Tanzania. Journal of Tanzania Association of Foresters 10: 49-63.

Sululta Agricultural and Rural Development Office. 2009. Annual Report. Chancho.

Senbeta F. 1998. Native woody species regeneration under the canopies of Tree Plantations at Munessa-Shashemene Forest Project Area, Southern Oromia, Ethiopia. Report No. 1998: 38.

Senbeta F, E Beck, U Lüttge. 2002b. Exotic trees as nurse-trees for the regeneration of natural tropical forests. *TREES*: Structure and Function, 16:245-249.

Senbeta F, D Teketay, N Naslund. 2002a. Native woody species regeneration in exotic tree plantations at Munessa-Shashemene Forest, southern Ethiopia. New Forests 24: 131-145.

Teshome T. 2007. Is *Eucalyptus* Ecologically Hazardous Tree Species? Ethiopian Tree Fund Foundation. http://etff.org/Articles/ Eucalyptus.html; accessed -15/05/2010.

Turnbull JW, TH Booth. 2002. Eucalypts in cultivation: an overview. *In:* Coppen JW (ed.), *Eucalyptus:* The Genus *Eucalyptus.* Taylor and Francis, London, pp. 52-74.

World Agroforestry Center. 2006. Rising preference for *Eucalyptus* poses dilemma in eastern Africa. Eastern and Central African Policy Brief, World Agroforestry Centre, Nairobi, Kenya /http://www.relma.org/pdfs/Eucalyptus_policy_brief.pdf/; accessed-15/05/2010**.**

Community Needs, Management and the Environment Pertinent to *Eucalyptus*

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Abstract

Based on their concrete selection criteria, *Eucalyptus* species have been highly preferred and appreciated by Ethiopian farmers over indigenous or other exotic tree species. In the warm lowland areas, *E. camaldulensis* is their first choice and in the cold highland areas *E. globulus* is mostly planted at homesteads private woodlots and in farmland areas. However, expansion of *Eucalyptus* plantations has been the focus of debate concerning the environmental impact of the species. This research was conducted to quantify and evaluate nutrient output with aboveground biomass harvest from a sustainability point of view, and to contribute to the knowledge of proper management of *Eucalyptus* plantation management for the benefit of the society. The study was conducted in the Central Highlands of Ethiopia where *Eucalyptus* species mainly *E. globulus* is progressively integrated in the farming systems. The research site called *Weldeab Ager* is found in *Basonaworana Woreda* of North Shea administrative zone and has an area of 6.2 ha. It is found north of *Debre Berhan* town at a distance of about 30 km. The paper focuses on how management influences the removal of macronutrient from a plantation site and proposes appropriate harvesting measures to be taken. The level of phosphorus removal can be reduced to unavoidable levels by different management options. Supposed the management option is to remove only stem wood from the site, and then the level of phosphorus removal will be as low as 66.4%. However, the level of percentage removal of phosphorus with stem wood is higher than for nitrogen removal. Supposed the management option for this plantation is to harvest only stem wood then the amount of potassium removal will be as low as 43.4%, which is an avoidable. From the total calcium, calculated 25.9% is contained in stem wood and branch-biomass. However, 78.9% of the biomass, which is the stem wood, contained only 12.7% of calcium. On the other hand, 10.8% of the biomass that is the stem bark contains 59.2%. Hence, removing stem bark from the site will have a very serious consequence on sustainable site potential. The current culture of whole tree harvest and plantation site brushing for litter collection and marketing should be avoided and should be in the focus of the forestry extension system. Overall, macronutrient removals from plantation sites were found to be dependent on intensity of biomass removals rather than on species. To reduce the removal of nutrients from plantations management should get special attention from sustainability viewpoint. Altogether, the facts in this study lead to the conclusion of encouraging *Eucalyptus* plantations in the Ethiopian highlands.

Key words: *Eucalyptus globulus*, Farming systems, Nutrient removals

Introduction

Eucalyptus species have been highly preferred and appreciated by the farmers over indigenous or other exotic tree species. In a research conducted in two districts in Ethiopia Kahurananga et al. (1993) report from farmers' species preference that in the warm lowland areas *E. camaldulensis* is their first choice, whereas in the cold highland areas *E. globulus* is their first choice to plant as homestead plantation, private woodlots and in farmland areas. Similarly, Kinfe (2000, unpublished) reports that people in the highland areas have higher consideration for *Eucalyptus* than for any indigenous species.

Accordingly, farmers are engaged in expanding of woodlots by planting *Eucalyptus* on their agricultural and grazing land and bit-by-bit converting agricultural land into *Eucalyptus* plantations. The ongoing expansion of *Eucalyptus* plantations by farmers has been the focus of a debate concerning the environmental impact of the species centred on forecasted soil acidification, nutrient depletion, allelopathic effect, and excessive water utilization of the species. Other arguments focuses on the importance of the species because of its fast growth and biomass production as well as browsing resistance, so the country is desperately in need of it at large. Agricultural and forestry extension services have largely stopped to encourage farmers to plant *Eucalyptus* because of environmental concerns. However, these environmental concern arguments are not quantified and evaluated from sustainable resource utilization point of view based on the specific Ethiopian site conditions. Therefore, there is an urgent need to investigate environmental issues related to *Eucalyptus* under Ethiopian ecological and socio-economical conditions. Hence, this research is designed to address the following hypotheses and information needs:

- How much is the magnitude of nutrient removal with aboveground biomass harvest in *Eucalyptus* plantations? and
- Are there management scenarios that minimise nutrient removal from *Eucalyptus* plantations sites?

It was necessary to look for areas where conventional block plantations of sufficient size have been established. Therefore, site selection criteria were established before the site selection fieldwork was conducted. After a thorough discussion made in the Institute of Forest Ecology at the University of Natural resources and Life Science (BOKU), the site was selected in line with established site selection criteria.

This study is aimed at to quantify and evaluate nutrient output fluxes with aboveground biomass harvest from sustainability point of view, suggest proper management scenarios to reduce nutrient fluxes to avoid site depletion, and contribute to the knowledge of proper management of *Eucalyptus* plantations for the benefit of the society.

Materials and Methods

Description of research site

The research site called *Weldeab Ager* is found in *Basonaworana Woreda* of North Shea administrative zone, north of *Debreberhan* town at a distance of about 30 km. Its global location is 39^{0} 40´49´´–39^{0} 41´04´´ Longitude and 9^{0} 46´44´´–9^{0} 46´54´´ Latitude. It is inclined from Southeast to Northwest with a slope of 10% and has an area of 6.2 ha.

The agro-ecological zone of the research site was identified by determining the length of growing period, thermal zone and the physiographic units of the site. Accordingly, the research site is found in the cool moist mountain sub-agroecological zone. Topography of this subzone is mountainous with altitude ranging from 2,500 to 3200 m and its mean annual temperature varies from 11^{0} C to 16^{0} C. Mean annual rainfall varies from 1800 mm to 2600 mm.

The major soil units occurring in the site are Phaeozems, Luvisols, and Leptosols. Currently these soils are under agricultural cultivation and *E. globulus* plantation. Luvic Phaeozems occur on strongly sloping and moderately steep landforms. It is characterised as very deep, well drained, and slightly eroded. Vertic Luvisols found on strongly sloping land units and characterized as moderately deep, well drained and slightly eroded. Lithic Leptosols are found on western part of the research site.

Establishment of *E. globulus* plantations in the research site

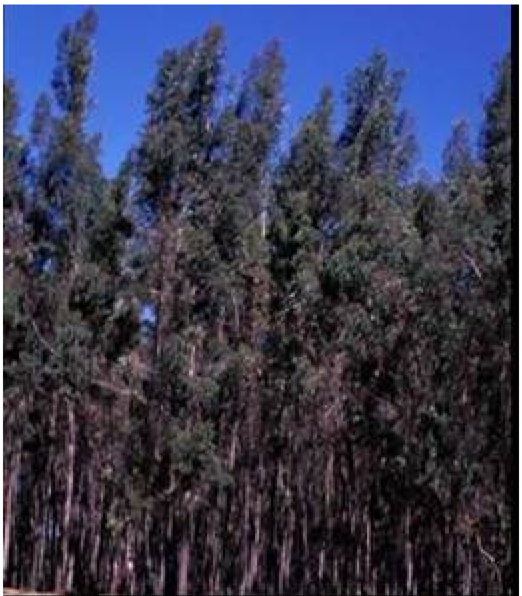


Figure 1. 14.5 years old plantation

In the research site *E. globulus* plantation has been established in 1985 by the then Debre Birhan fuel wood project. Before the establishment of the plantations, the land had been used mainly for agricultural crop production and to some extent for grazing. Prior to the planting of seedlings, spot holes with a size of 40 cm wide and 30 cm deep at 2 m interval, 2500 per ha, have been prepared. At the onset of the rainy season, 20–30 cm tall seedlings raised in open-ended plastic pots in tree nurseries were planted. As part of tending operation and insuring, a 50 cm radius from the edge of the planting hole has been weeded and cultivated two times at early stage of the plantation to reduce competition and to loosen the soil to give a good start for the planted seedlings. At the time of data collection the average number of trees was estimated to be about 1,121 per ha.

Farming systems in the area

The farming system in the research area is characterized by integrated crop-livestock production. Although there are very limited small-scale irrigation practices, rain-fed agriculture is the most dominant; rainfalls last from middle of June to middle of September. The cultivation method is oxen plough. The main crop types grown in the area according to their priority are barley, faba bean, field pea, lentils, and linseed. Crop rotation between cereal and legumes is a well-known practice in the area. Application of inorganic fertilizer is not a common.

Sheep and cattle are the dominant livestock reared in the area. Livestock manure is not used to fertilize the fields, but is effectively collected and used for domestic fuel and it is the main source of fuel in the area. It is also marketed to generate income, Crop residue is also effectively collected and used for livestock feed. Livestock are always returned to the compound at night. Thus, most of the dung produced by livestock is deposited in the compound and dung cakes are prepared out of it every morning by women. Dung droplets along roadsides and in grazing areas are effectively collected by children and transported to home yards. Tree planting is also becoming part of the farming system from time to time.

Sample collection procedures

Plantation inventory

To ascertain the total number of trees per ha and to classify the trees in different diameter classes, a systematic sample procedure was applied. By establishing a straight line with the help of compass traverse procedure, at every 50 m interval a circular sample plot with a radius of 5.64 m corresponding to an area of 100 m^2 was established. In each sample plot, all trees were counted and diameter at breast height (DBH) was measured in cm by a diameter tape. Trees at the boarder of the circular plot were left out when the largest part fell out-side the circle. Trees were classified in different diameter classes of 5 cm intervals. Thereafter, three sample trees were randomly selected from the three dominant diameter classes for destructive sampling to estimate above ground biomass per ha on dry mass basis. From each sample tree wood, bark, branches, and leaves were sampled for chemical analyses. Reproductive parts such as flowers, cones, and seeds were not considered separately in this procedure.

Sampling of discs and bark

Sample trees were felled at a height of 10 cm from the ground with a bow saw. This stump height was chosen in accordance to the stump height practiced in tree felling by the farming communities in the area. After felling, branches were removed from the trunk and the total height up to the tip of the leading shoot was measured. The first disc of 3 cm thick was taken from the very bottom of the stem. Thereafter at every 1 m interval along the length, discs were collected with the same disc width until the diameter over bark dropped below 2.5 cm. The top remaining part of the stem with over bark diameter less than 2.5 cm was included with the branch biomass.

After cross cutting of discs at an interval of 1 m, diameter over bark was measured in cm by a diameter tape. Then the bark was removed very carefully from the disc and diameter under bark was measured. Immediately after separation of the bark from the wood, fresh weight of bark and wood were measured separately on site using a digital balance. The samples were packed in plastic bags and transported to the local seasoning yard, dried in open air to avoid decay before transportation to the labouratory for oven dry weight determination and analytical work. From the 9 sample trees felled 174 disc/wood and 174 bark samples were collected for oven dry weight determination and chemical analysis.

Branches and leaf sampling

After separation of the branches from the stem all leaves were removed by hand from the branches, packed in a bag, and weighed using a spring balance to determine the total fresh weight of the leaves per sample tree in grams. After mixing the leaves properly, a sub sample of extract 200 gram was drawn. The samples were packed in plastic bags and transported to the local seasoning yard, dried in open air to avoid decay before transportation to the labouratory for oven dry weight determination and chemical analyses. Branches, including branch bark, were cut into smaller sizes, tied in a bundle, and weighed immediately after removal of leaves for total branch fresh weight determination per sample tree. Immediately sub sample of exactly 200 gram of branches per tree was drawn. The samples were packed in plastic bags and transported to local seasoning yard, dried in open air to avoid decay before being transported to the labouratory for oven dry weight determination and chemical analyses.

Labouratory procedures

All biomass samples were oven dried at 80 ^{0}C to constant weight. After cooling, oven dry weight was determined using a digital precision balance. If necessary, biomass samples were chipped mechanically and grinded with a cutting mill. For subsequent analytical work sub samples from all compartments were milled using a Cyclotec mill (TECATOR) with a sieve mesh of 0.5 mm samples were dried again and kept for further treatment in an exsiccator. Chemical parameters were determined by standard procedures. For GLP fitted certified samples (BCR) were treated in a similar way as the analytic samples. “Total” nitrogen was determined by semi-micro-Kjeldahl analysis. Automatic vapour distillation with saturated NaOH and titration of evolved NH_3 using a Kjeltec Auto 2300 (TECATOR) with automatic calculation device was used. The determination of all other respective elements was by extraction of oven dry samples with a mixture of HNO_3 and $HClO_4$ at 200 °C with reflux cooling. Determination of the relevant elements including P, S and heavy metals was carried out using a simultaneous ICP-OES with an axial plasma and SCD (Perkin Elmer, OPTIMA 3000 XL). The measurements were made after linear calibration (r^2 at least 0.999) with matrix adapted standard solutions.

Biomass samples calculations

To estimate stem wood and stem bark biomass a relationship between volume and density of substances was applied as it is presented in the formulas:

$$d_1 = \frac{m_1}{v_1}$$

d_1 = density of the 3 cm thick disc sample, m_1 = mass and v_1 = volume of the same disc.

$$D_2 = \frac{M_2}{V_2}$$

D_2 = density of 1.03 meter long wood, M_2 = mass and V_2 = volume of the same wood.

Assuming d_1 and D_2 to be equivalent, the mass of 1.03 meter long wood section was estimated as $M_2 = d_1 \cdot V_2$. The same procedure was applied to estimate stem bark biomass. To arrive at the final estimate of biomass, the following steps of calculations were followed. Biomass sub samples were oven dried at 80 ^{0}C in the labouratory. Conversion factors were derived to convert fresh weight measured in the field to oven dry weight measured in labouratory.

To calculate over bark and under bark volumes of each 1.03 m section of the stems, including the disc sample, the mean diameter in cm was calculated based on the bottom and top diameters of each section. Bark volume was calculated by subtracting volume under bark from volume over bark. Density of fresh wood was calculated by dividing the fresh weight of the disc by its respective volume. The fresh wood density was transformed into dry density by multiplying with the conversion factor calculated initially for each section based on the oven dry weight of the disc samples. The dry density of the disc was used to estimate the dry biomass of each 1.03 m section by multiplying with the calculated volume. The same procedure was used to estimate the dry biomass of the bark on the bole. Finally, the biomass of each section was summed up to estimate the dry biomass of stem wood and stem bark of each sample tree.

The dry biomass of leaves and branches were estimated by multiplying the total fresh weight measured in the field by the conversion factor determined using oven dry weight and fresh weight of the sub samples.

A non-linear allometric model, ($Y = aDBH^b$) was developed by regression analysis using DBH, (1.3 m above ground) as independent variable and dry biomass, (Y), as dependent variable for each component. Interring mean diameter of the diameter class into the equation, dry biomass per tree was estimated for each component for each diameter class. Then dry biomass for each diameter class was estimated by multiplying the estimated biomass per tree with the number of trees in each diameter class. Dry biomass per ha was estimated by summing up all values in each diameter class.

Result and Discussion

Calculated results of aboveground biomass production and macronutrient storage in *E. globulus* are presented in Table 1. The 14.5 years old *E. globulus* plantation with a stocking of 1,121 trees/ha produced 223.6 t/ha of aboveground biomass. Proportionally, 78.9%, 10.8%, 5.6%, and 4.7% was stem wood, stem bark, branches and leaf-biomass.

Total nitrogen contained in aboveground biomass of the plantation was 291.3 kg ha^{-1}. Proportionally, 67.5% was contained in stem bark, branches and leaves biomass and 32.5% in stem wood biomass. Total phosphorus contained in the 14.5 years old *E. globulus* plantation reached 72.6 kg ha^{-1}. Out of this, 66.4% were contained in stem wood biomass. Leaves, branches, and stem bark biomasses together contained only 33.6% of the total phosphorus. As per our calculation, total potassium was 469.3 kg ha^{-1}. In this plantation, 43.4% is contained in stem wood biomass whereas 56.6% is contained in the others three components. Total calcium contained in aboveground biomass of the plantation was calculated to be 1,163.3 kg ha^{-1}. Proportionally, 59.2% is contained in stem bark biomass and 12.7% is contained in stem wood biomass.

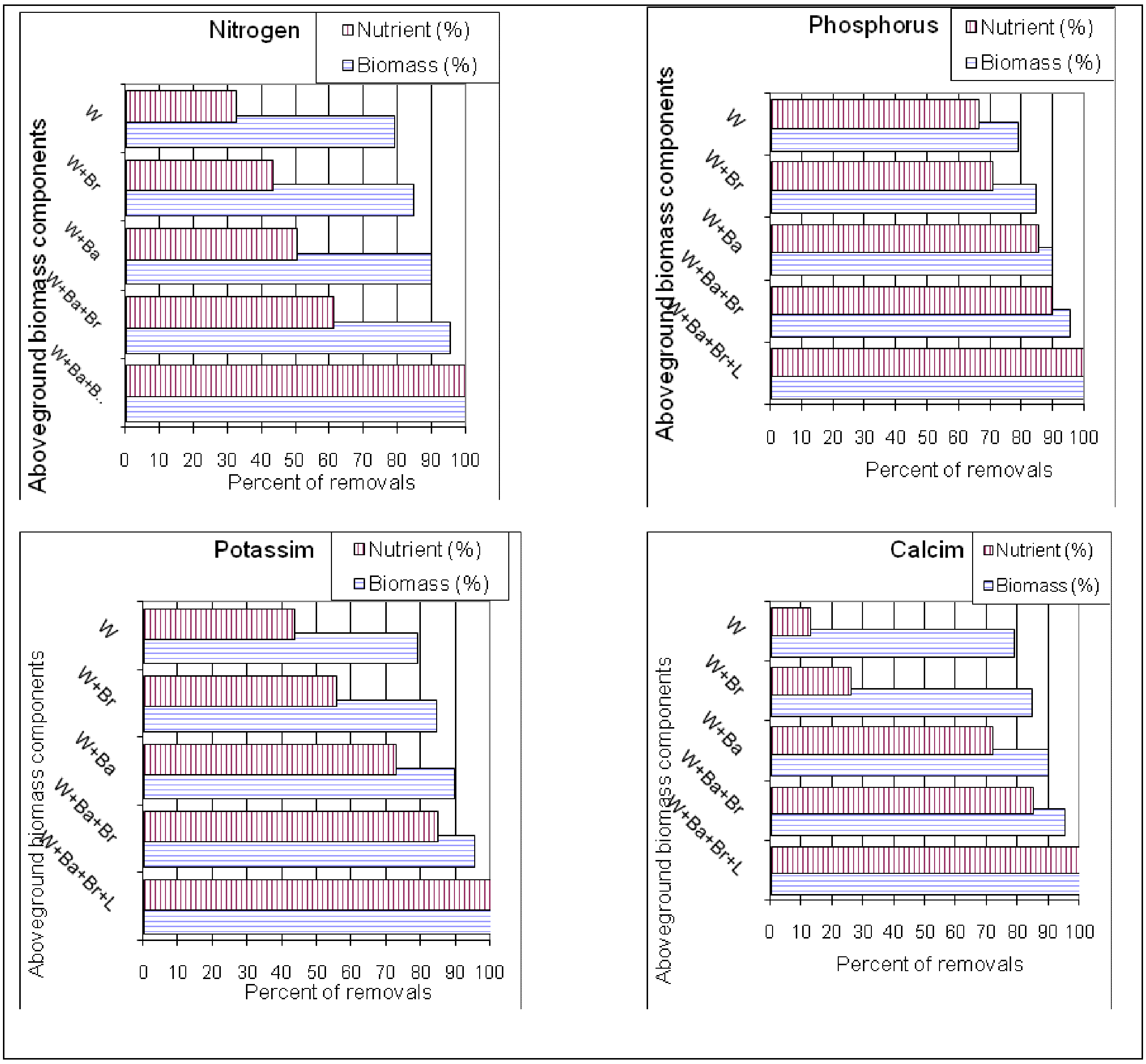
Table 1: Aboveground biomass (tonnes·ha^{-1}) and micronutrients (kg·ha^{-1}) in a 14.5 years *E. globulus* plantation

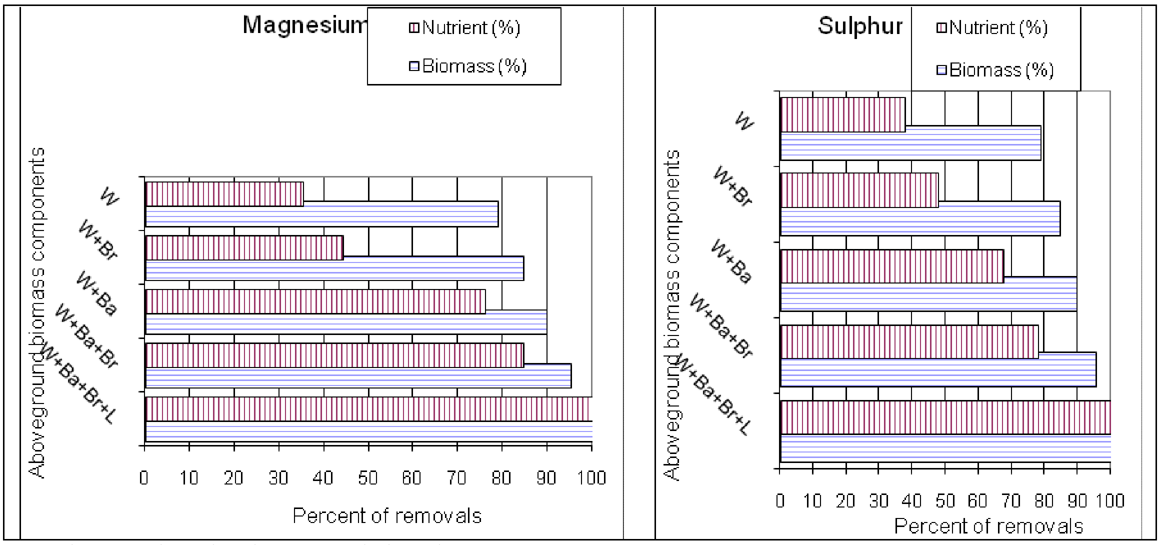
Trees/ha	Components	Biomass	N kg/ha	P kg/ha	K kg/ha	S kg/ha	Ca kg/ha	Mg kg/ha
1121	Leaves	10.4 *(4.7)*	113.3 *(38.9)*	7.5 *(10.3)*	71.6 *(15.3)*	10.2 *(22.1)*	174.4 *(15.0)*	14.6 *(15.3)*
	Branches	12.6 *(5.6)*	31.7 *(10.9)*	3.2 *(4.4)*	56.8 *(12.1)*	4.7 *(10.2)*	153.2 *(13.2)*	8.2 *(8.6)*
	Stem bark	24.1 *(10.8)*	51.5 *(17.7)*	13.7 *(18.9)*	137.2 *(29.2)*	13.8 *(29.9)*	688.5 *(59.2)*	38.8 *(40.6)*
	Stem wood	176.5 *(78.9)*	94.8 *(32.5)*	48.2 *(66.4)*	203.7 *(43.4)*	17.5 *(37.9)*	147.2 *(12.7)*	33.9 *(35.5)*
	Total	**233.6**	**291.3**	**72.6**	**469.3**	**46.2**	**1163.3**	**95.5**

Values in parenthesis are percent of the total

The following bar graph (fig. 2) visualizes the influence of different management strategies on the removal of macronutrients with aboveground biomass harvest. The amount of nutrients removed from a plantation site with aboveground biomass harvest depends on the content of nutrients within the various components of the biomass and the intensity of biomass removal. If the plantation forest floor litter is removed intensively and regularly, it leads to a substantial loss of nutrient from the site. Therefore, one has to know the distribution of nutrients in different aboveground components in order to decide which one and how much should be removed to avoid excessive nutrient losses from the plantation site. Proper plantation management is to retain biomass on the site as large as possible and to reduce the nutrient removal to unavoidable levels.

If the plantation was harvested at the age of 14.5 years and if stem wood and branch biomass was taken out from the site, with 84.5% of the biomass, 43.4% of total nitrogen could be removed from the site. However, it has to be noticed that leaving only 15.5% of the total biomass in the plantation site could retain 56.6% of the total nitrogen to be recycled in the plantation site. Reducing the amount of biomass removal to 78.9% that is harvesting only stem wood, leads as low as 32.5% removal of nitrogen from the plantation.





Legend: W = wood, Br = branches, Ba =stem bark, L = leaves

Fig. 2: Potential nutrient removal (%) with aboveground biomass

The potential removal of 43.4% of nitrogen with stem and branch biomass is low compared with results of other studies. Poggiani (1985) calculated that 65.9% of nitrogen removal with stem and branch biomass for a 11 years old *E. saligna* plantation. In another study, Poggiani (1985) calculated that 52.6% of the total nitrogen amount is located in stem wood and branch biomass of a 14 years old *Pinus caribaea* plantation. Frederick et al (1985) calculated 55.1% of nitrogen amount for a 17 years old *E. regnans* plantation. In another study, Frederick et al (1985) calculated that 52.8% of the nitrogen amount is in stem wood and branch biomass of 8 years old *Acacia dealbata* plantation. Wang et al (1995) calculated for a 95 years old *Populus tremuloides* stand that 73.2% of the nitrogen amount is located in stem wood and branch biomass.

The total phosphorus amount of the 14.5 years old *E. globulus* plantations reached 72.6 kg ha^{-1}. Out of this phosphorus amount, 70.8% was contained in stem wood and branch biomass. The level of phosphorus removal can be reduced to unavoidable level by different management options. Supposed the management option is to remove only stem wood from the site, the phosphorus removal will be as low as 66.4%. However, the percentage of phosphorous removal with stem wood is higher than for nitrogen removal. This needs a serious attention. In the studied plantation, calculated total potassium amount was 469.3 kg ha^{-1}. Out of this 55.5% was contained in stem wood and branch biomass. Supposed the management option for this plantation is to harvest only stem wood then the amount of potassium removal will be as low as 43.4%. The total calcium amount contained in aboveground biomass of the 14.5 years old *E. globulus* plantation was calculated to be 1,163.3 kg ha^{-1}. Proportionally 25.9% was contained in stem wood and branch biomass. However, 78.9% of the biomass, which is the stem wood, contained only 12.7% of calcium (Table 1). On the other hand, 10.8% of the biomass that is the stem bark contains 59.2% of this element. Total magnesium amount contained in aboveground biomass of the studied plantation was calculated to be 95.5 kg ha^{-1} and proportionally 44.1% was contained in stem wood and branch biomass. In this site, the share of stem wood was as low as 35.5%. Calculated amount of sulphur appeared to be 46.2 kg ha^{-1}. As the result indicates 48.1% was immobilized in stem wood and branch biomass, which shares 84.5% of the aboveground components. Once more reduction of the biomass removal to 78.9% reduces sulphur removal to 37.9%.

Conclusions and Recommendations

As presented and discussed above, whole tree harvesting system could cause nutrient depletion in plantation sites. This can be reduced to unavoidable level by taking out only the stem wood. The current culture of whole tree harvest and plantation site brushing for litter fall collection and marketing should be avoided.

The wood market is expanding very fast in Ethiopia. The farmers are very much comfortable with the plantation that they have using the *Eucalyptus* species. Their reasoning is clear; they are earning significant income from the sale of wood. Therefore, it contributes to diversify farmers' income by selling fuel wood and construction pole. Assets created in form of plantation are serving as a guarantee during years of reduced agricultural crops production due to draught and other reasons, which means food security is realized. In response to the market, demand and better income from the sale of wood farmers are expanding the plantation into agricultural lands. They have introduced light fire management to enhance decomposition of litter fall for fast availability of nutrients and early sprout of old stumps, figure 5. These practices of the farmers have to be supported with facts that should be generated with research.

Macronutrients removals were found to be dependent on intensity of biomass removals rather than species. The current *Eucalyptus* plantation management in the Highlands of Ethiopia is highly associated with far reaching negative consequences of future productivity and production. Therefore, it is an urgent need to create awareness on the serious negative consequences of whole tree harvest and letter fall raking on soil fertility. Farmers have to be advised to harvest only woody components from their plantation. This activity has to be included explicitly in the agricultural extension package without any delay. The facts revealed in this study lead to a recommendation of *Eucalyptus* plantation encouragement. Therefore, expansion of *Eucalyptus* plantation should continue in the highlands of Ethiopia.

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References

Attiwill PM, HB Guthrie, R Leuning. 1978. Nutrient cycling in a *Eucalyptus obliqua* (L'Heérit.) forest. Australian Jornal of Bot. (26) 79-91

Bennet LT. 1996. The effect of fertilizer on early growth and foliar nutrient concentrations of three plantation eucalypts on high quality sites in Gippsland, southeastern Australia. Journal of Forest Ecology and Management (89) 213-226.

Berthelot A, J Ranger, D Gelhaye. 2000. Nutrient uptake and immobilization in a short-rotation coppice stand of hybrid poplars in north-west France. Journal of Forest Ecology and Management (128) 167-179.

Binkley D, KA Dunkin, D DeBell, MG Ryan. 1992. Production and nutrient cycling in mixed plantation of *Eucalyptus* and *Albizia* in Hawaii. Forest Science (38) 393-408.

Chen H.1998. Biomass and nutrient distribution in a Chinese-fir plantation chronosequence in Southwest Hunan, China. Jornal of Forest Ecology and Management (105) 209-216.

Couto L, GR Betters.1995, Short – rotation Eucalypt plantations in Brazil: Social and Environmental issues, OKA Ridge national labouratory, Tennessee, USA.

Davidson J.1993. Ecological aspect of *Eucalyptus* plantation, pp 35-72. *In:* White K. et.al (eds.) Proceedings of the regional expert consultation on *Eucalyptus,* held between 4 – 8 October 1993, Bangkok.

Doughty RW. 2000. The *Eucalyptus.* The Johns Hopkins University Press, Baltimore and London, pp 237.

Ethiopian Forestry action plan 1994, The challenge for development, volume 2, Ministry of Natural Resources development and Environmental Protection, Addis Ababa, Ethiopia.

Evans J. 1992. Plantation forestry in the tropics. 2nd edn. Oxford University Press, Oxford, UK, 403 pp.

FAO. 1988. The Eucalypt dilemma, Rome, Italy.

Fernandez JQP. LE Dias,NE Barros,RF Novais, EJ Moraes. 2000. Productivity of *Eucalyptus camaldulensis* affected by rate and placement of two phosphorus fertilizers to Brazilian Oxisol. Forest Ecology and Management (127) 93-102.

Frederick DJ, HAI Madgwick, MF Jurgensen, GR Oliver. 1985. Dry matter, energy, and nutrient contents of 8 years old stands of *Eucalyptus regnans, Acacia dealbata,* and *Pinus radiat* in New Zealand*,* New Zealand Journal of forestry Science 15(2) 142-57

Frederick DJ, HAI Madgwick, MF Jurgensen, GR Oliver. 1985. Dry matter content and nutrient distribution in an age series of *Eucalyptus regnans* plantation in New Zealand, New Zealand Journal of forestry Science 15(2) 158-79

Frederick DJ, HAI Madgwick, GR Oliver, MF Jurgensen. 1985. Dry matter and nutrient content of 8 years old *E. saligna* growing at Taheke forest, New Zealand Journal of forestry Science 15(2) 251-4

Guo LB, REH Sims. 1999. Litter production and nutrient return in New Zealand eucalypt short-rotation forests: implication for land management. Agriculture, Ecosystems and Environment (73) 93-100

Guo LB, REH Sims.1999. Litter decomposition and nutrient release via litter decomposition in New Zealand eucalypt short-rotation forests. Agriculture, Ecosystems and Environment (75) 133-140

Guthrie HB, PM Attiwill, R Leuning. 1978. Nutrient cycling in a *Eucalyptus obliqua* (L`Herit.) forest. II A study in a small catchment. Australian jornal of botany (26) 189-201.

Harrison RB, GG Reis, MDGF Reis, AL Bernardo, DJ Firme. 2000. Effect of spacing and age on nitrogen and phosphorus distribution in biomass of *Eucalyptus camaldulensis, Eucalyptus pellita*, and *Eucalyptus urophylla* plantations in southeastern Brazil. Forest Ecology and Management (133) 167-177

Hingston FJ, GM Dimmock, AG Turton. 1980. Nutrient distribution in a Jarrah (*Eucalyptus marginata* Donn ex SM.) ecosystem in south-west Western Australia. Forest ecology and management (3) 183-207

Jordan CF. 1985. Nutrient cycling in tropical forest ecosystems, Jhon Wiley, New York, 190.

Kahurananga J, Y Alemayehu, S Tadesse, T Bekele, 1993. Informal survey to assess social forestry at Dibandiba and Aleta Wendo, Ethiopia. Agroforestry systems (24) 57-80.

Khanna PK. 1997. Comparison of growth and nutrition of young monoculture and mixed stand of *Eucalyptus globulus* and Acacia mearnsii. Journal of Forest Ecology and Management (94) 105-113.

Madeira M, MC Araujo, JS Pereira. 1995. Effect of water and nutrient supply on amount and on nutrient concentration of litterfall and forest floor litter in *Eucalyptus globulus* plantation. Plant and soil (168-169) 287-295.

Montagnini F. 2000. Accumulation in above-ground biomass and soil storage of mineral nutrients in pure and mixed plantations in humid tropical lowland. Journal of Forest Ecology and Management (134) 257-270

Poggiani F, HTZ Couto. 1983. Biomass and nutrient estimates in short rotation intensively cultured plantation of *Eucalyptus grandis*. IPEF, Piracicaba, (23) 37-42

Poggiani F. 1985. Nutrient cycling in *Eucalyptus* and *Pinus* plantations Ecosystems. Silicultural implications. IPEF, Piracicaba,31, Departamento de Silvicultura, Sao Paulo, Brazil.

Pohjonen V, T Pukkala. 1991. Which Eucalypt grows best in Ethiopian Highlands? Journal of biomass and bioenergy 1 (4) 193-195.

Pukkala T, V Pohjonen. 1989, Yield models for Ethiopian highland *Eucalyptus,* United Nations Sudano-Sahelian Office, Addis Ababa, Ethiopia 53 p.

Reed D, M Tome. 1998. Total aboveground biomass and net dry matter accumulation by plant component in young *Eucalyptus globulus* in response to irrigation. Journal of Forest Ecology and Management (103) 21-32.

Shumacher MV, F Poggiani, JW Simoes. 1994. Leaf-litterfall and nutrient translocation from the canopy to the soil in stands of *Eucalyptus camaldulensis*, *Eucalyptus grandis* and *Eucalyptus torelliana*. IPEF, Piracicaba (47) 56-61

Son Y, HW Kim. 1998. Above-ground biomass and nutrient distribution in a 15-year old Ginkgo *(Ginkgo biloba)* plantation in central Korea. Jornal of Bioresource Technology (63) 173-177.

Spangenberg A, U Girmm, JRS Da Silva, H Fölster. 1996. Nurtrient store and export rates of *Eucalyptus urograndis* plantations in eastern Amazonia (Jari). Forest ecology and management (80) 225-234

Stanley WG, F Montagnini. 1999. Biomass and nutrient accumulation in pure and mixed plantations of indigenous tree species grown on poor soils in the humid tropics of Costa Rica. Jornal of Forest Ecology and Management (113) 91-103.

Ste-Marie C, D Pare. 1999. Soil, pH and N availability effects on net nitrification in the forest floors of a range of boreal forest stands. Jornal of Soil Biology and Biochemistry (31) 1579-1589

Stoorvogel JJ, EMA Smaling, BH Janssen. 1993. Calculating soil nutrient balances in Africa at different scales. Ferilizer research. (35) 227-235

Sunder SS. 1993. The ecological, economic and social effects of *Eucalyptus,* pp 90-128: In White. K. etal (eds.) Proceedings of the regional expert consultation on *Eucalyptus,* held between 4 – 8 October 1993, Bangkok.

Turner J, MJ Lambert. 1996. Nutrient cycling and forest management. PP, 229-248. *In:* Attiwill PM, MA Adams (eds). Nutrition of *Eucalyptus,* 1996 CSIRO Australia.

UNSO. 1991. Reforestation, the Ethiopian experience, 1984 –1989, Technical Publication series No.4, Bucks, UK

Versfeld DB, DGM Donald. 1991. Litterfal and nutrient release in mature *pinus radiata* in the southwest Cape.South African Forestry Jornal No. 156

Wang JR,AL Zhong, P Comeau, M Tsze, JP Kimmins. 1995. Aboveground biomass and nutrient accumulation in an age sequence of aspen (*Populus tremuloides*) stands in the Boreal White and Black Spruce Zone, British Columbia. Jornal of Forest Ecology and Management (78) 127-138.

Williams J, JCZ Woinarski. 1997. *Eucalyptus* ecology: Individual to ecosystem, Cambridge University Press, UK, 430 pp.

Environmental and Socio-Economic Implications *of Eucalyptus* in Ethiopia

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Abstract

Eucalyptus is one of the exotic tree species in Ethiopia. It has been once associated with the Ethiopian environment and economy. It is one of the most successful trees; it adapts to a variety of environments. *Eucalyptus* is often considered to have undesirable ecological qualities such as depletion of soil water and nutrients, aggressive competition for resources with native flora, unsuitability for erosion control, production of allelopathic chemicals that suppress the growth of other plants and provision of inadequate food and shelter to wildlife. On the other hand, *Eucalyptus* provides multiple ecological and socio-economic benefits. It has been found to be useful for provision of various products particularly wood thereby reducing the pressure on the natural forests, conservation of soil and water, rehabilitation of degraded lands, fostering the regeneration of native woody species, provision of food and habitat for wildlife, drainage of swampy areas, control of climate change and provision of amenity. The benefits of *Eucalyptus* are far greater than the negative impacts. The negative impacts are mainly because of the poor management rather than its biological characteristics. *Eucalyptus* has been found to be efficient water user. As it is fast growing, it consumes more nutrients from the soil. Applying appropriate silviculture and management on *Eucalyptus* planting will enhance the utilization of this important tree for maintaining or restoring the environment and solving socio-economic problems in Ethiopia and elsewhere. It appears that there are no profound reasons not to continue *Eucalyptus* planting in Ethiopia.

Keywords: Ecological, Exotic, Socio-economic, *Eucalyptus,* Ethiopia

Introduction

Eucalyptus is native to Australia, but a very small number of species are found in New Guinea, Indonesia, and the Philippines. In their natural habitat, *Eucalyptus* species dominate most of the natural forests, growing in diverse climates and soil types ranging in altitude from sea level to 1,850 m (Pohjonen 1989). They play an important part in the closed forests of southern Australia, and typically, they form a transition stage between the older, fire-damaged natural forest and the closed rainforest. Acacias are also often a component in this type of forest. The open forests, on the other hand, are dominated by *Eucalyptus* species growing together with species of *Callitris*, *Casuarina*, *Melaleuca,* and *Acacia* (FAO 1988).

Eucalyptus is one of the most successful trees; it adapts to a variety of habitats. According to Davidson (1989), the evolutionary adaptive features of *Eucalyptus* include:

- Tolerance of severe periodic moisture stress: Xeromorphic leaves, stomata close when water potential deficit in the leaf is high, wax coating, hairy juvenile leaves (some species), volatile leaf oils, deciduous in dry season (few species);
- Tolerance of low soil fertility: Adapted to soils with low nitrogen and phosphorus contents, do not fix nitrogen but do have specialized nutrient uptake system of ecto- and endomycorrhizae that increase phosphorus uptake mainly, but also zinc, copper, molybdenum and in some cases ammonium;
- Tolerance of fire damage: Lignotubers (underground organs), thick barks, dormant bud system, indeterminate crown; and
- Tolerance of insect damage: Oils and phenolic compounds.

The superior performance of *Eucalyptus* species in relation to other exotic and native species has its origin in their greater ancestral diversity. There was a higher number of species in the ancestral moist forests in which *Eucalyptus* species evolved as environmental conditions changed severely in Australia. Flora of other continents do not have this genetic history. Because no two areas of the world are exactly similar, plants evolving in one place under fiercer competitive conditions involving a wider and better range of ancestors over a longer time must be at an advantage (Davidson 1989).

Eucalyptus species have many uses that have made them economically important tree species. Initially, *Eucalyptus* species were planted for curiosity in botanic gardens, arboreta (tree-collections), parks and for amenity. Later on, they were found to be useful for fuel wood, charcoal, timber, posts, poles, mine props, plywood, paper pulp, fibreboard, and tannin, production of *Eucalyptus* oil, shade and shelter, ornamental purposes and as a source of nectar in honey production (Pohjonen 1989; Friis 1995; Turnbull 1999).

History on *Eucalyptus* planting

Many species of *Eucalyptus* when planted outside their natural range have shown a high degree of tolerance to extremes of environmental conditions. This is in contrast to many plants, which cannot flourish when introduced to other areas. Outside their natural habitat, *Eucalyptus* species were probably first grown in Portugal 400 years ago, but the first major plantings were started in Brazil in 1904 (FAO 1988; Turnbull 1999). It was subsequently introduced to many parts of the world, notably California, Ecuador, Colombia, Chile, Spain, Ethiopia, Morocco, South Africa, Uganda and Israel. At present, *Eucalyptus* species are cultivated in North America, South America, Europe, Africa, and Asia. *Eucalyptus* has become the most planted genus of trees in the world; over 100 countries are growing *Eucalyptus* in plantations. A large number of *Eucalyptus* species have been planted throughout the tropical zone, of which the most common species are *E. camaldulensis, E. globulus, E. grandis, E. maculata, E. paniculata, E. robusta, E. saligna, E. urophylla,* and *E. viminalis.* In East Africa, over 100 species have been recorded from cultivation (Friis 1995).

Although reliable estimates of areas of *Eucalyptus* plantations are difficult to obtain, published reports suggest that there are at least 12 million ha of *Eucalyptus* plantations all over the world (Turnbull 1999). Area coverage of *Eucalyptus* plantations in some countries is given in Table 1. The major reasons that contributed to the widespread cultivation of Eucalyptus include availability and easy propagation of seeds, relative ease of plantation establishment, tolerance to wide environmental conditions, fast growth, efficient conversion of solar energy, wood of high specific gravity and calorific value, high coppicing ability, exceptional hardiness and other fine qualities of its timber, good economic returns, unpalatability or tolerance of most species to browsing and grazing animals, and relative tolerance to pests and diseases (von Breitenbach 1961; FAO 1988; Davidson 1989; Pohjonen 1989; Turnbull 1999).

Table 1. Area coverage of *Eucalyptus* plantations in some countries

Country	Area (ha)
Brazil	3,000,000
India	1,000,000
China	600,000
Portugal	550,000
South Africa	477,000
Spain	396,000
Ethiopia	250,000 *
Morocco	200,000
Chile	170,000
Australia	125,000
Thailand	100,000
Total	**6,618,000**

*Source: Tsegaye Bekele (1996), * only E. camaldulensis and E. globulus; Turnbull (1999)*

Introduction of *Eucalyptus* to Ethiopia

The natural forests of the country particularly the *Juniperus-Podocarpus-Olea* forests around Addis Ababa were depleted at a faster rate for fuel wood and construction material. The decimation of native tree species has led to the introduction of a large number of exotic tree species such as *Eucalyptus, Cupressus*, *Pinus*, *Acacia,* and *Grevillea.*

Eucalyptus was first introduced to Ethiopia during the reign of Emperor Menelik II (1868-1907) in 1895 (von Breitenbach 1961). His major aim was to solve the critical shortage of fuel wood and construction material in Addis Ababa and other towns in the country. He recognized the fact that town development and natural forest preservation in the absence of any other alternative measure could be contradicting to each other. He made various incentive mechanisms, including tax relief and the distribution of *Eucalyptus* seeds and seedlings free of charge, to encourage every landowner to plant more trees on his land for various uses. Had it not been the introduction of *Eucalyptus,* the natural forests of the country would have disappeared.

Discouraged by the slow growth of indigenous species, which could not keep pace with the demands, Menelik embarked in the introduction of fast growing exotic species in the plantation forestry exercises. He requested Mondon-Vidaillet, a French railway engineer and philologist (one of his expatriate advisors), to assist him in the introduction of exotic tree species. Accordingly, Mondon-Vidaillet ordered seeds of many *Eucalyptus* species (*E. amygdalina, E. largiflorens, E. camaldulensis, E. cladocalyx, E. cornuta, E. diversicolor, E. globulus, E. incrassata, E. leucoxylon, E. melliodora, E. patens, E. resinifera, E. rudis, E. salubris* and *E. tereticornis*) and *Acacia* species from Australia and *Pinus* species from Portugal, Italy and Greece. After the seeds had arrived, he laid out a nursery in the Imperial Palace and raised seedlings, which were planted afterwards in Addis Ababa. Only a few of the *Eucalyptus* species succeeded.

E. camaldulensis and *E. globulus*, locally known as “key baharzaf” and “nech baharzaf”, respectively, were preferred by the public on account of their fast growth and easy propagation. The other introduced species remained more or less neglected. With the beginning of the modern development and industrialization, however, the necessity of favouring other *Eucalyptus* species, which might yield better timber, particularly more suitable for building and industrial purposes, was recognized. Hence, *Eucalyptus* species unknown in Ethiopia up to that time (*E. grandis, E. mucronata, E. rubida, E. saligna, E. sideroxylon, and E. viminalis*) were introduced by E.H.F. Swain (Australian Forestry Advisor), H.L. Vernede (French Forestry Advisor), F. Mooney (British Forest Officer), and Wolde Michael Kelecha (Ethiopian Forester) (von Breitenbach 1961). Since then, quite a number of other *Eucalyptus* species have been introduced.

Currently, about 55 species of *Eucalyptus* are known to grow in Ethiopia, of which between five and ten are widely planted (Friis 1995). For the list of *Eucalyptus* species in Ethiopia, see Appendix. The most widespread species include *E. camaldulensis, E. citriodora, E. globulus, E. regnans, E. saligna, and E. tereticornis.* These are chiefly grown for fuel wood and construction material, both in large-scale plantations and small woodlots. However, it is also grown as shelterbelts in farmlands and as shady groves in and around villages, churches and other dwellings. They occur nearly everywhere in the country where the rainfall is above ca. 400 mm (Friis 1995). Many other species have been planted as ornamentals, in arboreta, trial plots or in pilot plantations on a comparatively small-scale. About 10 species of *Eucalyptus* are potentially able to cover a wide range of environments. They are generally superior to other exotic and native species in their field performance (Demel Teketay 2000).

Status of *Eucalyptus* in Ethiopia

The chances of a species being maladapted to the environment increase if it is exotic (Tewolde Berhan Gebre Egziabher 1986). Today, many species of *Cupressus* and *Pinus* are dying simply because they seem ill adapted (at least after a certain developmental stage) to much of Africa's environment (Legesse Negash 1999). This is due to the work of evolutionary principles that is central to all of biological systems. Africa's biodiversity is the result of millions of years of continuous evolution. Plantation of exotic tree species is more vulnerable to climatic changes, fire hazards, pests, and diseases (Feyisa Abate and Mebrate Mihretu 1994). The diebacks of *Cupressus*, *Pinus* and some other exotic tree species are a reflection of mal-adaptation to the local environment.

In contrast, *Eucalyptus* generally has become well adapted to the Ethiopian environment. During the socio-economic survey made by Haileab Zegeye (2009), a farmer at Addis Zemen stated, "*Eucalyptus* is the king of trees though it has some adverse impacts on crops". *Eucalyptus* planting is mostly by farmers, but also by state and private sectors. Survival and growth rate is good. The local communities have become increasingly dependent on *Eucalyptus* for fuel wood and construction material among other uses.

Controversy on *Eucalyptus* Planting

Despite the apparent benefits, there have been some adverse public reactions against *Eucalyptus* planting. The criticisms are based on a range of technical, ecological, and socio-economic arguments (FAO 1988). Most of the criticisms are unfair, biased, nationalistic or emotional (Davidson 1989). He noted that the criticisms could also be equally applied to other exotic tree species.

Replacing indigenous trees with exotic species has created environmental crises (Legesse Negash 1999). He pointed out that *Eucalyptus* has undesirable ecological qualities that include depletion of soil water and nutrients, aggressive competition for resources with other plants, production of allelopathic chemicals that suppress the growth of other vegetation, unsuitability for erosion control and incapability of providing adequate food and habitat for wildlife.

Ecological Effects of *Eucalyptus*

Some of the arguments on the ecological effects of *Eucalyptus* are presented below in order to have a better understanding and for making informed decision on *Eucalyptus* planting.

Soil water consumption

It has been argued that *Eucalyptus* species take up a great amount of water from the soil. To the extreme, it has been thought that *Eucalyptus* species consume a lot of water more than any other tree species and agricultural crops. However, this is not true. A number of research results revealed that *Eucalyptus* species are efficient water users (FAO 1988; Davidson 1989). They have greater water use efficiency, i.e., they consume less water per unit of biomass produced than most agricultural crops, conifers, acacias, and broad-leaved tree species (Table 2). To produce one unit of woody matter young trees require between 300 and 500 units of water, but as they get older their efficiency decreases and more water per unit of wood is needed (Demel Teketay 2000). In fact, use of water is proportional to the amount of biomass produced (wood, branches, twigs, leaves, flowers, fruits, etc.), and the relatively high water consumption is consistent with their high growth rate and biomass production. On the other hand, most of the water absorbed from the soil by the roots is lost through the leaves, and in *Eucalyptus* species, the rate of transpiration can reach between 20 and 40 litres per tree each day, depending on the size of the tree and the surface area of the leaves.

In arid regions, water is limited and plants with deep spreading roots take most water while plants with shallow roots may be stunted or unable to survive. Some *Eucalyptus* species such as *E. tereticornis* are able to grow in very dry climates and may take most of the available water in the soil. In low rainfall areas, *Eucalyptus* species may suppress other plants by competing for water, but this is unlikely to occur in an area of high rainfall.

If the planting is not well planned, it may reduce the groundwater level and thereby affect water supplies of the local people. In South Africa, *E. camaldulensis*, *E. cladocalyx*, *E. diversicolor*, *E. grandis* and *E. lehmannii* have become naturalized and are considered invasive, with their water-sucking capabilities threatening water supplies. Similarly, in Zimbabwe, *E. robusta,* and *E. tereticornis* have become naturalized.

Table 2. Water use efficiency or consumption of water per unit of biomass produced.

Plant	Litres of water/kg of biomass produced
Sorghum	250
Maize	250
Cow pea	500
Soybean	500
Eucalyptus (tree)	510
Albizia lebbek (tree)	580
Potato	600
Sunflower	600
Field pea	600
Horse bean	600
Paddy rice	600
Syzygium cuminii (tree)	610
Cotton/coffee/banana	800
Acacia auriculiformis (tree)	860
Dalbergia sissoo (tree)	890
Conifers	1,000
Pongamia pinnata (tree)	1,300

Source: FAO (1988), Davidson (1989)

Soil nutrients consumption

Recent investigations on the effects of uncropped *Eucalyptus* trees on soil quality, mostly from India and the Mediterranean, have showed that *Eucalyptus* species were found to have a beneficial effect on soil structure, and on treeless sites, they improved soil fertility through decayed litter. Very few comparative studies have been made in Ethiopia on soil nutrients among plantations of different species including *Eucalyptus* species and the adjacent natural forests (Michelsen *et al.* 1993; Lisanework Nigatu and Michelsen 1994; Michelsen *et al.* 1996; Betre Alemu 1998). These studies have shown that plantation stands of fast growing exotics such as *E. globulus, E. grandis, E. saligna, Cupressus lusitanica* and *P. patula* had lower nutrient contents than soils of the adjacent natural forest. This seems logical as they are fast growing, thereby drain, and consume more nutrients from the soil. *Eucalyptus* species have high demand for nutrients, but this is comparable with other tree species and much lower than agricultural crops. Tesfaye Teshome (2009) pointed out that the nutrient consumption of fast growing species like *Eucalyptus* species need to be well studied before wrong conclusion and recommendation is being made. On the other hand, the soil nutrient levels under *Eucalyptus* plantations can be improved by leaving litter uncollected, adjusting spacing and mixing *Eucalyptus species* with leguminous plants like *Acacia* and *Albizia* species. Mixing *Eucalyptus* species with *Acacia* species, e.g. *A. nilotica* that produces high amount of litter (8,000 kg ha^{-1} y^{-1}), increases the litterfall and thereby improves the soil nutrient bank (Tesfaye Teshome 2009).

However, there is an important difference between the nutrient status of a natural forest and that of cropped plantations, especially when these are grown on short rotations. In a natural forest with little disturbance nutrients are conserved and cycled between trees and soil. When a plantation is thinned or felled and the wood is extracted, the nutrient capital changes considerably because nutrients are removed from the site. *Eucalyptus* foliage and bark contain a large amount of nutrients, and the retention of foliage and debarking of logs at the felling site is therefore a good management practice in order to retain a sufficient amount of nutrients at the site. Fertilizer application and mulching are also alternative management practices to add nutrients to the soil, particularly for short rotations.

Allelopathic effects

Eucalyptus species release allelopathic chemicals into the surrounding soil that suppress the growth of other plants. In Ethiopia, two different results have been reported concerning the interaction or association of *Eucalyptus* with other plants, i.e. positive interactions (Mebrate Mihretu 1992; Michelsen *et al*. 1993; Michelsen *et al*. 1996; Feyera Senbeta 1998; Kidane Woldu 1998; Yitebitu Moges 1998) and negative interactions (Lisanework Nigatu and Michelsen 1993).

Eucalyptus species are frequently viewed as harmful for understory plants. However, the results from the study made by Michelsen *et al.* (1993) revealed that the number of forbs and grasses was high in the plantations of *E. globulus, C. lusitanica* and *J. procera* and the adjacent natural forest. Similarly, the investigation made by Michelsen *et al.* (1996) on 83 plantations and adjacent natural forests in the highlands of Ethiopia showed that the richness and biomass of herbaceous plant species in plantations of *Eucalyptus* and *P. patula* was as high as those of natural forests.

Eucalyptus species are not the only exotic tree species with allelopathic effects. For instance, *Grevillea robusta* has allelopathic effects on most agricultural crops (Tesfaye Teshome 2009). It is believed that *Eucalyptus* species can affect other plants directly through the inhibitory influences of leaf litter and root exudates or through the effect of litter on nutrient mineralization and soil micro flora. However, the allelopathic effects on the native flora are not detrimental. Allelopathic effects of *Eucalyptus* are more prominent in areas with annual rainfall of less than 400 mm. Allelopathy can be minimized, even in dry climates, by cultivation methods, fertilization and irrigation, and also by the selection of compatible crops.

Shading on crops

Since they are fast growing, plantations of exotics are usually taller than other plants of equal age, and their shade may affect nearby crops by reducing the sunlight needed for growth. Because of shading and competition for water, the yields from agricultural crops close to *Eucalyptus* plantations are sometimes not as good as they are further away from the edge (Demel Teketay 2000). However, some *Eucalyptus* species cast less shade than other broad-leaved trees because their leaves are held vertically downwards on the twigs and their crowns are often narrow. It is widely accepted that shelterbelts increase crop yields. On the other hand, the study made by Onyewotu *et al.* (1994) on the competitive effects between a *E. camaldulensis* shelterbelt and an adjacent millet (*Pennisetum typhoides*) crop indicated that the yield of the crop grown very close to the belt was reduced because of competition with the trees for light, soil moisture and nutrients, and shading. On the other hand, the results indicated that the yield of millet grown adjacent to the shelterbelt increased substantially by pruning the roots at a distance of 0.25 times the belt height (0.25H) from the trees. It is worthwhile to note that in *Eucalyptus* species the shade is characteristically patchy because the leaves usually hang downwards, indicating that shading is not a major problem.

Inadequate food and habitat for wildlife

Mammals, birds, and insects that live in the wild depend on natural vegetation for their food and shelter. Therefore, when a plantation of exotic species replaces their natural habitat, they are affected. Birds and browsing animals may find this plantation less palatable, and although some remain in their established feeding areas others move away to search for new territory. Usually the population is reduced than eliminated in an area. The unpalatability of most species to browsing and grazing animals (von Breitenbach 1961; FAO 1988; Davidson 1989; Pohjonen 1989; Turnbull 1999) and incapability of providing adequate food and habitat for wildlife (FAO 1988; Legesse Negash 1999; Demel Teketay 2000) can thus reduce wildlife in an area. However, this problem can be alleviated by establishing mosaics of plantations, natural forests, pastures, grasslands, and croplands. It is important to note that the biodiversity of a natural forest and that of a *Eucalyptus* plantation are not comparable. The natural ecosystems are very diverse, whilst the biodiversity of *Eucalyptus* plantations is limited.

Fire incidence

In dry climates, *Eucalyptus* stands tend to promote fire because of the volatile and highly combustible oils produced by the leaves, as well as the production of large amounts of litter which is high in phenolics, preventing its breakdown by fungi and thus accumulates as large amounts of dry, combustible fuel. *Eucalyptus* generally produces litter fall of about 1,800 kg ha/yr, but this is less compared, for example, with *A. lebbeck* that produces 5,000 kg ha^{-1} y^{-1} (Tesfaye Teshome 2009). Consequently, *Eucalyptus* forests become subject to catastrophic firestorms, as it is common in Australia. In Ethiopia, however, fire incidence in *Eucalyptus* plantations may not be a problem since most of the litter is collected for fuel.

Ecological importance

Control of soil erosion

The two main ways to conserve soil are physical conservation measures (e.g. terraces, check-dams) and biological conservation measures (e.g. tree planting). Thus, properly managed *Eucalyptus* plantations can control soil erosion, but their effect depends on such factors as intensity of rainfall, soil condition, slope and the presence of ground vegetation and litter cover. However, planting of any kind of tree species in the form of a monoculture should not be taken as the best solution to soil erosion, particularly sheet or surface erosion (Davidson 1989).

The litter, which accumulates under most *Eucalyptus* plantations, can help to form a protective barrier against erosion, but in many places, the litter is collected as fuel or removed to reduce fire hazard. For instance, the depth of the accumulated litter under *Eucalyptus* stands in Shashemene-Munesa Forest Project Area was found to be on average 20-30 cm (Tesfaye Teshome 2009). However, under *Eucalyptus* stands around Addis Ababa and very big towns, the accumulation of litter is very low because of human and animal disturbance. People take away most of the litter and cattle and foot traffic compact the soil. If the litter is left on the site uncollected, it would have been incorporated into the soil system to slow down runoff and improve infiltration, and substantial amount of nutrients may pass to the soil system thereby improving soil fertility. In fact, the presence of mycorrhizae is an advantage to most *Eucalyptus* species, which facilitates accumulation of nutrients even in poor soils (Tesfaye Teshome 2009). However, because of litter collection, the ground under the trees is left bare and the soil is exposed to erosion. The barren ground is attributed to removal of litter and not to allelopathy as often misquoted. Therefore, litter should be allowed to accumulate on the sites particularly on sites that are easily eroded.

A realistic assessment of each area to be planted is needed to decide whether erosion will be a serious problem, and if so, whether it can be controlled. Some places may not be suitable for plantation establishment.

Eucalyptus plantations on steep slopes can provide effective erosion control if careful techniques such as contour planting are used. This method has been successful in Nigeria where a humid climate favoured rapid site coverage and production of large volumes of wood from *E. hemiphloia* and *E. occidentalis* have been recommended for control of erosion in these conditions (Demel Teketay 2000).

Eucalyptus plantations established for catchment protection should be developed into uneven ones by selective cutting over a period of years. The root system of selected species influences the soil binding capacity because of which soil erosion is checked. *E. globulus*, for instance, has a strong taproot and good lateral root system that makes it very reputable species for catchment protection (Demel

Teketay 2000; Tesfaye Teshome 2009). It has been widely planted for this purpose in countries other than Ethiopia. Even more suitable may be mixed stands, particularly of *Eucalyptus* and *Acacia* (they have been shown to form associations in their natural habitat). Species of *Acacia* in symbiosis with bacteria and fungi fix atmospheric nitrogen, thereby improving soil fertility.

Eucalyptus species can be planted as windbreaks or shelterbelts to reduce the force of the wind. Wind erosion occurs on light soils when there are few tree roots or other vegetation to hold the topsoil. *Eucalyptus* species rapidly develop good roots even in dry sandy soils, so they are useful for starting wind barriers (FAO 1988).

Rehabilitation of degraded lands

When there is environmental deterioration in a given area, remedial actions are usually needed as quickly as possible. In many situations, exotic trees have proved to be faster growing than native trees and have been utilized for quick results. In the tropics and subtropics, *Eucalyptus* species are often judged to be faster growing than other species and the most likely to survive on difficult sites (FAO 1988). There are *Eucalyptus* species that can be grown in areas with low soil fertility and extremes of temperature and rainfall, thus presenting a potential for recovery of degraded ecosystems.

Fostering the regeneration of native woody species

Plantation stands of *Eucalyptus* and other tree species have been shown to foster or catalyze the regeneration of native woody species under their canopy if they are established close to seed sources and protected from human and animal disturbance, thereby enhancing biodiversity (Feyera Senbeta 1998; Yitebitu Moges 1998; Demel Teketay 2000). The establishment of plantation forests as foster crops is opportunities that could be utilized for rapid and productive restoration of the vast degraded ecosystems in the country (Mulugeta Lemenih and Demel Teketay 2004).

The studies made by Mebrate Mihretu (1992) and Kidane Woldu (1998) indicated that there is a good natural regeneration of *J. procera* under *E. globulus* plantations at Entoto Hills in Addis Ababa. The juniper has grown effectively on the eroded areas competing well with the *Eucalyptus* trees (Kidane Woldu 1998). Analysis of the distribution of height and diameter classes, density, and general structure of the juniper population indicates good recruitment and, thereof, good regeneration potential that can contribute to its future if the area is protected from grazing and human interference. Evidently, a dense juniper forest, probably mixed with other species such as *O. europaea* and *P. falcatus*, must have once covered the hills before it was deforested and replaced by *Eucalyptus* plantations. Apparently, the plantations might have created favourable conditions for the regeneration of juniper by allowing sufficient light through the canopy and protecting the seedlings and saplings from scorching light and desiccating winds. In addition, the presence of mature juniper trees as source of seeds for regeneration and protection of the plantations by the ex-landowners from trespassers and grazing has contributed to the natural regeneration of juniper (Mebrate Mihretu 1992).

Similarly, the studies made by Feyera Senbeta (1998) and Yitebitu Moges (1998) at Munesa-Shashemene Forest Project Area clearly showed that plantation stands of *E. globulus, E. saligna, C. lusitanica* and *P. patula* have been found to foster the natural regeneration of several native woody species like *P. falcatus, Prunus africana*, *Syzygium guineense* and *Croton macrostachyus*. The source of seeds for the naturally regenerated native woody species is the adjacent natural forest.

The species richness, density, diameter at breast height (DBH), and height of colonizing woody species under the canopies of different plantation species varied considerably (Mebrate Mihretu 1992; Feyera Senbeta 1998; Kidane Woldu 1998; Yitebitu Moges 1998; Mulugeta Lemenih *et al.* 2004). The major factors determining the variations have been investigated by Mulugeta Lemenih *et al.* (2004) in southern Ethiopia using the plantation stands of *Cordia africana*, *E. saligna*, *C. lusitanica* and *P. patula* and the adjacent natural forest. Their results suggest that stand canopy characteristics such as canopy closure percent and leaf area index determine the amount of canopy gaps available for solar radiation to penetrate through and influence the understory environmental conditions such as air and soil temperatures, and soil moisture, which in turn affect seed germination, seedling survival, and growth of colonizing woody species. The results also revealed that both indigenous and exotic species could be equally used to foster the regeneration of native woody species as long as the plantation species provides a reasonably open canopy that allows enough radiation to penetrate through the canopy. In fact, the moisture content, or humidity, of the air inside the plantation stands is often higher than the outside, and as there is less direct sunlight the average temperature is usually lower (Demel Teketay 2000).

Provision of food and habitat for wildlife

Eucalyptus species are often considered less palatable to wildlife. However, several marsupial herbivores, notably koalas and some possums, eat *Eucalyptus* leaves. The flowers produce a great abundance of nectar, providing food for many pollinators including insects (e.g. honeybees), birds, bats, and possums.

If they are properly managed, *Eucalyptus* plantations can be a habitat for certain species of wildlife. Mammals and birds that used to live in natural forests can be encouraged to return to a forest replanted with a mixture of exotic species by leaving open spaces occasionally, and allowing undergrowth to remain here and there. In plantations grown only for wood production, there are very few over matured and dead trees, which are essential in the life cycles of many insects and birds. It is technically possible to reintroduce wild boar, rabbits, grey jungle fowl, and partridge in areas where they used to live. Establishing plantations in treeless areas can provide shelter for wildlife. Plantations can be made more favourable for animals and plants by appropriate management practices that provide desired habitat. In general, plantations have a less diverse fauna than natural forests, and plantations composed of exotic tree species have a less diverse fauna than plantations of indigenous species.

In India, planting *Eucalyptus* species has increased the number of animals. Since 1958, grassland in the 119 km^2 game reserve has been progressively reforested with *E. tereticornis, thus,* resulted in a population increase of species that had almost disappeared. Strips of exotic trees planted along the roadsides have attracted partridge in large numbers.

Drainage of swampy areas

In swampy areas, the groundwater level is near or at the surface, and some species of *Eucalyptus* have been used to drain the water away by drawing it up through the roots (Demel Teketay 2000). *E. globulus* is useful for this purpose. Mosquito breeding areas can sometimes be controlled in this way. Drainage removes swamps that provide a habitat for mosquito larvae, thereby reducing the risk of malaria. This method has been used in Algeria, Lebanon, Europe, and California. However, drainage can also destroy ecologically productive areas.

In agroforestry systems

Agroforestry is an approach to land use based on integrating trees and shrubs into crop and livestock production systems. Agroforestry systems provide a wide range of environmental and socio-economic benefits. Thus, *Eucalyptus* species can be used in agroforestry systems, i.e. they can be planted in homesteads, farm boundaries, roadsides, and woodlots. *Eucalyptus* plantations can provide wood for various purposes, rehabilitate degraded lands, conserve soil and water, and provide amenities such as recreational areas. Although *Eucalyptus* species do not provide fodder or add nitrogen to the soil like some species of *Acacia* and *Leucaena*, they provide various benefits particularly fuel wood and construction material and thereby make an important contribution to improved rural living.

In India, farmers are now planting *Eucalyptus* along farm boundaries. This is because the elongated crowns and vertical roots of *Eucalyptus* do not noticeably reduce crop yields, and because the farmers can use or sell the produce from the trees. In Pakistan, intercropping with strips of *E. camaldulensis* increased the production of cotton under irrigation. This is because it can help to reduce salinity. In Colombia, single trees of *E. camaldulensis* are grown along field boundaries for the pulpwood market. On the highland Vertisols of Ethiopia, *E. globulus* trees are planted along farm boundaries for multiple purposes such as timber, fuel wood, as a cash crop, boundary demarcation, fencing, soil and water conservation, and increasing crop yield (Selamyihun Kidanu 2004).

Control of climate change

Increase in the concentration of carbon dioxide and other greenhouse gases in the atmosphere results in an increase in global temperature and a change in the global distribution of precipitation. Global climate change causes rise of sea level due to melting of ice and glaciers and thereby submergence of islands and inundation of coastal areas, redistribution of vegetation patterns and expansion of desertification. Climate change brings complex changes in species composition and interactions, and may result in a significant reduction in biodiversity (Mooney *et al*. 1995).

One of the main strategies to control climate change is tree planting. *Eucalyptus* species are one of the best tree species since they are fast growing and can fix more carbon dioxide by the process of photosynthesis, thereby serving as a carbon sink. *Eucalyptus* is an efficient biomass producer; it can produce more biomass than many other tree species. It is known that carbon sequestration is proportional to biomass production. In the Ethiopian highlands, the annual wood production rates for *E. globulus* range between 168 to 2,900 kg ha^{-1} y^{-1} depending on soil type, stand age and rotation cycle (Selamyihun Kidanu 2004), thus indicating more carbon sequestration in the biomass. On the other hand, recent studies have showed that inter-planting *Eucalyptus* species with nitrogen-fixing trees like *Acacia* and *Albizia* species can promote carbon sequestration. Therefore, *Eucalyptus* plantations can play an important role in generating additional revenues from carbon trade.

Socio-economic Importance

Eucalyptus species provide a variety of socio-economic benefits. They provide fuel wood, charcoal, construction, timber, posts, poles, paper pulp, and tannin, nectar for honey production, *Eucalyptus* oil, and shade and ornamentals purposes. Due to their fast growth, the foremost benefit of *Eucalyptus* species is their wood. In Brazil and Spain, the wood is highly appreciated by the paper industry. *Eucalyptus* oil, obtained by steam-distillation from the leaves, twigs and branches, is used in medicines, antiseptics, food supplements, pesticides, insect repellents, perfumes, soaps, and detergents. Some species such as *E. citriodora* have been widely used for oil production. Significant producers of *Eucalyptus* oil include South Africa, Portugal, Spain, Brazil, Australia, Chile and Swaziland. *Eucalyptus* species have also been used for production of gums and dyes. *Eucalyptus* species have become a cash crop for the poor in Africa and other parts of the world. *Eucalyptus* plantations help to increase job opportunities both in planting and in downstream industries.

Eucalyptus species are planted for fuel wood, construction material, charcoal, timber, poles, posts, farm implements, income generation from selling of wood, shade, ornamental purposes, and honey production. Many species such as *E.*

camaldulensis, *E. globulus*, *E. grandis,* and *E. tereticornis* are suitable for these purposes. *Eucalyptus* species can supply wood in good quantities within 4-5 years from comparatively small areas of land (Demel Teketay 2000). In most parts of the country, *Eucalyptus* species have become the mainstay of the community for additional income generation. Some species like *E. citriodora* have been used for perfume and oil production, e.g. Wondo Genet Essential Oil Factory. *Eucalyptus* has been found to be useful in honey production; for instance, *E. camaldulensis*, *E. globulus*), and thus has been recorded in the honeybee flora of Ethiopia (Fichtl and Admasu Adi 1994).

Silviculture and management

Planting of *Eucalyptus* species might fail because they have frequently been of the wrong species, site, or management. The blame then falls on *Eucalyptus* rather than on the real culprit, which is bad forestry practice (Poore and Fries 1985). Actually, the poor management should be blamed rather than *Eucalyptus*. All things are always changing; and our way of thinking should change with the rapidly changing conditions of our world.

Most species of *Eucalyptus* do not have to be replanted after felling because they can be regenerated by coppicing. The second crop matures more quickly than the original one because it has well developed roots left by the first crop. Coppicing is needed since water use efficiency decreases with increasing age. Coppicing also helps to obtain more boles/stems from a single crop, but this should be followed by thinning the new shoots and remaining about 2-3 sprouts for the next rotation. However, eventually replanting must take place.

The choice of *Eucalyptus* species for plantations should be based on many criteria such as maximum wood production, ecological sustainability, marketability of the planted species (commercial production of timber), and usefulness of the species to the local communities. All these criteria involve not only a choice of species planted but also a choice of plantation management methods from initial planting to final cutting of the trees.

The establishment of *Eucalyptus* plantations could take different forms, e.g. huge number of small woodlots, groups, belts, lines and single trees scattered throughout the rural as well as urban areas. *Eucalyptus* species can be planted in homesteads, farm boundaries, woodlots, roadsides, communal lands in rural areas, urban and peri-urban areas, compounds of institutions and schools, around churches and monasteries, etc.

In some areas *Eucalyptus* species will be very useful; in other areas *Eucalyptus* species will not be appropriate. As with other forestry and land use decisions, careful analysis of the needs of the local communities and potential productivity of the sites is the key to success. Whatever the tactics adopted, better quality planting material, species-site matching, establishment and aftercare, in short better silviculture and management, are required (Davidson 1989).

In Ethiopia, farmers seem to know better, when it comes to planting *Eucalyptus.* They plant dense stands and periodically coppice only part of the stand at a time so that there is a multi-layered canopy and they allow grass to grow. However, most of the State owned *Eucalyptus* plantations are harvested on clear felling scheme particularly on steep slopes that exposes the site for soil erosion. On the other hand, the State owned *Eucalyptus* plantation stands have been established at wider spacing particularly on gentle slope sites (Tesfaye Teshome 2009). Wider spacing has an advantage to let the penetration of sunrays to the forest floor, which is one of the many prerequisites for undergrowth development. The presence of ground vegetation cover minimizes the surface runoff.

A number of research results have showed that appropriate silvicultural techniques and management methods can help to improve the environmental and socio-economic benefits rendered by *Eucalyptus* species. For instance, the study made by Schönau (1984) showed that proper site selection, site preparation, establishment, fertilizing at time of planting, weeding, pruning, thinning, regeneration, and standard management methods increased the productivity of *E. grandis*. On the other hand, economically optimal coppice rotations are not frequently employed in *Eucalyptus* plantations management (Diaz-Balteiro and Rodriguez 2006). They considered *E. urophylla* plantations in Brazil and *E. globulus* plantations in Spain in order to evaluate the optimal rotations including carbon sequestration. Different clear-cut ages were established in each country, 5–9 years in Brazil and 13–18 years in Spain. The results revealed different rotations and optimal number of coppice rotations for each site index and case considered (wood or carbon). Moreover, to repeat the seedling rotation in the following coppice rotations usually is bad option.

In Portugal, *E. globulus* plantations have been expanded and intensively exploited as short rotations (8-14 years) coppiced stands for raw material for pulp. Most private *Eucalyptus* plantations in Thailand have a rotation length of 5 years and spacing of 2 m x 3 m. In the Ethiopian highlands, *E. globulus* produces a harvestable tree within 4-5 years although farmers on Vertisols prefer a longer rotation period (8-12 years) to maximize wood production (Selamyihun Kidanu 2004).

Silvicultural practices are currently developing towards an increased use of mixed forests. Mixed forests are generally believed to be biologically more diverse and ecologically more stable than monospecific plantation stands. As a result, mixed forests are seen as a means to sustainable forest management.

Arguments for and against planting *Eucalyptus*

Many people in Ethiopia are dependent on *Eucalyptus* as a source of fuel wood and construction material. This being the reality, the arguments for and against planting *Eucalyptus* in Ethiopia is mounting from time to time (Demel Teketay 2000). The arguments for planting *Eucalyptus* include:

- *Eucalyptus* appears to fill the vacuum created by the decimation of indigenous forest species (Legesse Negash 1999);
- Availability and easy propagation of seeds, tolerance to wide environmental conditions, fast growth, high coppicing ability, good economic returns, and tolerance to pests and diseases (von Breitenbach 1961; Poore and Fries 1985; FAO 1988; Davidson 1989; Pohjonen 1989; Turnbull 1999; Demel Teketay 2000);
- *Eucalyptus* can supply wood in good quantities within 4-5 years from comparatively small areas of land (Demel Teketay 2000);
- *Eucalyptus* can help to control soil erosion and improve soil fertility (FAO 1988; Davidson 1989; Demel Teketay 2000; Selamyihun Kidanu 2004; Tesfaye Teshome 2009);
- *Eucalyptus* plantations foster the regeneration of native woody species provided that there is ample seed source in the vicinity (Feyera Senbeta 1998; Yitebitu Moges 1998; Demel Teketay 2000);
- The negative impacts of *Eucalyptus* can be minimized provided that the choice of species and site as well as the management of the stands are appropriate (FAO 1988; Feyera Senbeta 1998; Yitebitu Moges 1998);
- No other species, be it indigenous or exotic, can replace *Eucalyptus* in the near future to bridge the ever-widening gap between demand and supply of wood (Davidson 1989; Turnbull 1999); and
- *Eucalyptus* does not seem to have upset local values and traditions; in fact, it has become an accepted part of rural and urban life in Ethiopia (Demel Teketay 2000; Tesfaye Teshome 2009).

The arguments against planting *Eucalyptus* include:

- Depletion of soil water and nutrients, allelopathic effects on native flora and provision of inadequate food and habitat for wildlife (FAO 1988; Davidson 1989; Legesse Negash 1999; Turnbull 1999); and
- Unsuitability to erosion control (Legesse Negash 1999).

Despite the growing concern against planting *Eucalyptus,* most of the reports available on *Eucalyptus* in Ethiopia and elsewhere are in favour of planting it.

Need for research on indigenous tree species

The reduction of indigenous tree species of Ethiopia is associated with two major problems, unwise exploitation, and lack of scientific knowledge about their physiology, reproductive biology, and techniques of propagation (Legesse Negash 1995). The silviculture of most indigenous species is not yet known (Feyisa Abate and Mebrate Mihretu 1994). The problems related with their silvicultural characteristics, low yield and late economic return discourage many foresters from using indigenous species on large-scale plantations. To establish stability to the Ethiopian rural environment and give a chance to the re-establishment of more and more natural vegetation in Ethiopia, urgent botanical research into the uses and silvicultural properties is badly needed (Tewolde Berhan Gebre Egziabher 1986).

Growing indigenous trees is ecologically sound even though the rotation age is long. Monoculture stands of fast growing exotic trees such as *Eucalyptus, Cupressus,* and *Pinus* are inferior to indigenous species to ecological sustainability (Feyisa Abate and Mebrate Mihretu 1994). In order to restore the dwindling indigenous tree species and use the potential multipurpose species in agroforestry systems and large-scale plantations, it is necessary to develop techniques for rapid propagation. Remarkable researches focusing on the biology, uses, and propagation techniques of some indigenous tree species of Ethiopia have been carried out by Legesse Negash (1995, 1999). Such works enable to bridge the knowledge gap and use indigenous species in massive plantations.

Conclusion and Recommendations

The natural forests of the country are decimating at unprecedented rate because of various reasons. Currently, the forest cover of the country is only about 2.5%. It is a sad! Therefore, it is high time to protect the existing natural forests and promote planting of indigenous as well as appropriate exotic tree species. In fact, it is much better when a land is covered by natural forests than a land covered by plantations of exotic tree species, which in turn is better than a bare land. *Eucalyptus* is one of the candidates to be widely planted in the Ethiopian environment since it is successful and has various ecological and socio-economic benefits.

Eucalyptus species are tolerant to severe periodic moisture stress, low soil fertility, fire, and insect attacks. A variety of species is available, which can be grown in all sites and ecological zones of the country except the most arid.

It is known that natural forests supply a wide variety of benefits that can be very important to the local communities in the long-term, but plantations may supply greater quantities of material within a short period. Ethiopia has been under severe deficit of wood, and the gap between supply and demand of wood is widening enormously. Thus, plantations are needed to meet the ever-increasing demand for wood associated with rapid human population growth. It is undeniable fact that *Eucalyptus* plantations have played and will continue to play a great role in alleviating the fuel wood and construction material problems of the community.

Eucalyptus is often considered to have adverse ecological effects, but this is not true. It has been found to be efficient water user. *Eucalyptus* plantation stands can provide wood and other products, rehabilitate degraded lands, conserve soil and water, foster the regeneration of native woody species, provide food and shelter for wildlife, drain swampy areas, control climate change, and provide amenity. In fact, the benefits of *Eucalyptus* are far greater than the negative impacts.

Eucalyptus plantations have become a subject for arguments in Ethiopia and elsewhere. Most of the reports available on *Eucalyptus* are in favour of planting it. However, the paradox mostly results from the poor management rather than its biological characteristics. This calls the need to apply appropriate silviculture and management in order to minimize the negative impacts and enhance the ecological and socio-economic significance of *Eucalyptus*. However, it has to be strongly emphasized that careful selection of appropriate species and matching of species with appropriate sites must be taken as prerequisites and the right management practices should be employed.

In Ethiopia, most of the rural and urban people are highly dependent on *Eucalyptus* for various purposes particularly fuel wood and construction material. Plantations of *Eucalyptus* and other tree species provide wood and thereby reduce the pressure on the natural forests. Thus, there is a need to enhance *Eucalyptus* planting in order to maintain the environment and solve socio-economic problems in the country.

Indigenous tree species are adaptive to the local conditions and can be used for various purposes. The discouraging reality is that there is little information about their growth, soil nutrient-plant interaction, water consumption, yield, silviculture, and management. Therefore, more research on indigenous tree species is needed in order to fill the knowledge gap and come up with more indigenous species pool for reforestation, afforestation and other forms of tree planting. Until such time, however, *Eucalyptus* seems to be widely planted in Ethiopia. As a concluding remark, it appears that there are no profound reasons not to continue *Eucalyptus* planting in Ethiopia. To minimize the negative impacts and enhance the ecological and socio-economic importance of *Eucalyptus,* the following recommendations are suggested.

- In *Eucalyptus* planting, selection of the appropriate species, site and management methods is very important;
- There is a need to adjust spacing, leave litter uncollected and establish mixed stands of *Eucalyptus* species and nitrogen-fixing species particularly *Acacia* and *Albizia* species so as to reduce soil erosion, improve soil fertility and provide suitable habitat for wildlife;

- In order to solve the problem of wood, control soil erosion, rehabilitate degraded lands and ensure the maintenance of natural forests in the country, there is a need to promote the planting of *Eucalyptus* in homesteads, farm boundaries, woodlots, roadsides, communal lands in rural areas, urban and peri-urban areas, compounds of institutions and schools, and around churches and monasteries; and
- There is a need to carry out more research on the ecological and socio-economic benefits, silviculture, management and propagation techniques of indigenous tree species so that they can be widely used in plantation programmes.

References

Betre Alemu. 1998. Spatial Study of Soil Nutrient Status After Natural Forest Conversion to Plantation and Secondary Forests at Munessa Montane Forest, Ethiopia. MSc Thesis, Swedish University of Agricultural Sciences, Skinnskatteberg.

Davidson J. 1989. The *Eucalyptus* Dilemma, Arguments for and against Eucalypt Planting in Ethiopia. Forestry Research Center Seminar Note Series 1, Addis Ababa.

Demel Teketay. 2000. Facts and Experiences on Eucalypts in Ethiopia and Elsewhere: Ground for Making Wise and Informed Decision. Walia 21, 25-46.

Diaz-Balteiro L, LCE Rodriguez. 2006. Optimal rotations on *Eucalyptus* plantations including carbon sequestration—A comparison of results in Brazil and Spain. Forest Ecology and Management 229(1-3), 247-258.

FAO. 1988. The Eucalypt Dilemma. FAO, Rome.

Feyera Senbeta. 1998. Native Woody Species Regeneration under the Canopy of Tree Plantations at Munessa-Shashemene Forest Project Area, Southern Oromia, Ethiopia. MSc Thesis, Swedish University of Agricultural Sciences, Skinnskatteberg.

Feyisa Abate, Mebrate Mihretu. 1994. Provenance Trial of *Cordia africana*. Provenance Trials of Some Exotic and Indigenous Tree Species. Research 3, 1-12.

Fichtl R, Admasu Adi. 1994. Honeybee Flora of Ethiopia. Margraf Verlag, Weikersheim.

Friis I. 1995. Myrtaceae. In: Edwards S, Mesfin Tadesse, Hedberg I (Eds.), Flora of Ethiopia and Eritrea 2(2). Addis Ababa University, Addis Ababa and Uppsala University, Uppsala, pp. 71-106.

Haileab Zegeye. 2009. Diversity and Regeneration Status of Tara Gedam and Abebaye Forests, Northwest Ethiopia. A Research Paper Submitted to the Research and Publications Office (RPO) of University of Gondar, Gondar.

Kidane Woldu. 1998. Natural Regeneration of *Juniperus procera* Hochst. in *Eucalyptus globulus* Labill. Plantation. MSc Thesis, Swedish University of Agricultural Sciences, Skinnskatteberg.

Legesse Negash. 1995. Indigenous Trees of Ethiopia: Biology, Uses and Propagation Techniques. Printed by the SLU Reprocentralen, Umeå.

Legesse Negash. 1999. The Tortuous Path Ahead: How Man is Destroying his Earth. Dryland Biodiversity Newsletter 3, 9-12.

Lisanework Nigatu, A Michelsen . 1993. Allelopathy in Agroforestry Systems: The Effects of Leaf Extracts of *Cuppressus lusitanica* and Three *Eucalyptus* spp. on Four Ethiopian Crops. Agroforestry Systems 21, 63-74.

Lisanework Nigatu, A Michelsen. 1994. Litterfall and Nutrient Release by Decomposition in Three Plantations Compared with a Natural Forest in the Ethiopian Highland. Forest Ecology and Management 65, 149-164.

Mebrate Mihretu. 1992. The Regeneration of *Juniperus procera* in *Eucalyptus globulus* Plantations. Forestry Research Centre Newsletter 3(1-3), 2-3.

Michelsen A, Lisanework Nigatu, I Friis. 1993. Impacts of Tree Plantations in the Ethiopian Highlands on Soil Fertility, Shoot and Root Growth, Nutrient Utilization and Mycorrhizal Colonization. Forest Ecology and Management 61, 299-324.

Michelsen A, Lisanework Nigatu, I Friis, N Holst. 1996. Comparison of Understorey Vegetation and Soil Fertility in Plantations and Adjacent Forests in the Ethiopian Highlands. Journal of Applied Ecology 33, 627-642.

Mooney HA, J Lubchenco, R Dirzo, OE Sala. 1995. Biodiversity and Ecosystem Functioning: Basic Principles. *In:* Heywood VH (ed.), Global Biodiversity Assessment. UNEP, Cambridge University Press, Cambridge, pp. 275-325.

Mulugeta Lemenih, Demel Teketay. 2004. Restoration of Native Forest Flora in the Degraded Highlands of Ethiopia: Constraints and Opportunities. SINET: Ethiopian Journal of Science 27(1), 75-90.

Mulugeta Lemenih, Taye Gidyelew, Demel Teketay. 2004. Effects of Canopy Cover and Understory Environment of Tree Plantations on Richness, Density, and Size of Colonizing Woody Species in Southern Ethiopia. Forest Ecology and Management 194, 1–10.

Onyewotu LOZ, MA Ogigirigi, CJ Stigter. 1994. A study of competitive effects between a *Eucalyptus camaldulensis* shelterbelt and an adjacent millet (*Pennisetum typhoides*) crop. Agriculture, Ecosystems and Environment 51(3), 281-286.

Pohjonen V. 1989. Establishment of Fuel wood Plantations in Ethiopia. Silva Cerelica 14, 1-388.

Poore MED, C Fries. 1985. The Ecological Effects of *Eucalyptus.* FAO Forestry Paper Series 59, Food and Agriculture Organization of the United Nations, Rome.

Schönau APG. 1984. Silvicultural considerations for high productivity of *Eucalyptus grandis*. Forest Ecology and Management 9(4), 295-314.

Selamyihun Kidanu. 2004. Using *Eucalyptus* for Soil and Water Conservation on the highland Vertisols of Ethiopia. PhD Thesis, Wageningen University and Research Center, Wageningen.

Tesfaye Teshome. 2009. Is *Eucalyptus* Ecologically Hazardous Tree Species? Ethiopian e-Journal for Research and Innovation Foresight 1(1), 128-134.

Tewolde Berhan Gebre Egziabher. 1986. Ethiopian Vegetation: Past, Present and Future Trends. SINET: Ethiopian Journal of Science 9(Suppl.), 1-11.

Tsegaye Bekele. 1996. Utilization of Sawn Boards from Young *Eucalyptus* Plantation Timber Grown in Ethiopia. PhD Thesis, Swedish University of Agricultural Sciences, Uppsala.

Turnbull JW. 1999. Eucalypt Plantations. New Forests 17, 37-52.

von Breitenbach F, 1961. Exotic Trees in Ethiopia. Ethiopian Forestry Review 2, 19-38.

Yitebetu Moges. 1998. The Role of Exotic Plantation Forests in Fostering the Regeneration of Native Trees in an Afromontane Forest Area in Ethiopia. MSc Thesis, Wageningen Agricultural University, Wageningen.

Appendix

List of *Eucalyptus* species in Ethiopia

1.	*E. amygdalina*	20.	*E. ficifolia*	39.	*E. parvifolia*
2.	*E. astringens*	21.	*E. globulus*	40.	*E. patens*
3.	*E. bosistonana*	22.	*E. gomphocephala*	41.	*E. pilularis*
4.	*E. botryoides*	23.	*E. goniocalyx*	42.	*E. planchoniana*
5.	*E. brockwayi*	24.	*E. grandis*	43.	*E. regnans*
6.	*E. camaldulensis*	25.	*E. gunnii*	44.	*E. resinifera*
7.	*E. cinerea*	26.	*E. incrassata*	45.	*E. robusta*
8.	*E. citriodora*	27.	*E. johnstonii*	46.	*E. rubida*
9.	*E. cladocalyx*	28.	*E. largiflorens*	47.	*E. saligna*
10.	*E. cloeziana*	29.	*E. leucoxylon*	48.	*E. salmonophloia*
11.	*E. cornuta*	30.	*E. maculata*	49.	*E. salubris*
12.	*E. crebra*	31.	*E. melliodora*	50.	*E. sideroxylon*
13.	*E. dalrympleana*	32.	*E. microcorys*	51.	*E. tereticornis*
14.	*E. deanei*	33.	*E. microtheca*	52.	*E. torelliana*
15.	*E. delegatensis*	34.	*E. nitens*	53.	*E. transcontinentalis*
16.	*E. diversicolor*	35.	*E. obliqua*	54.	*E. viminalis*
17.	*E. dundasii*	36.	*E. occidentalis*	55.	*E. wandoo*
18.	*E. dunnii*	37.	*E. ovata*		
19.	*E. fastigiata*	38.	*E. paniculata*		

Source: Friis (1995)

Eucalyptus farming in Ethiopia: The case of *Eucalyptus* farm and Village Woodlots in Amhara Region

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Abstract

Ethiopia is one of the 10 important *eucalyptus*-growing countries in the world, led by Brazil. Despite what is said and is written negatively by agriculturalists and policy makers, *Eucalyptus* is set to stay here and may grow in importance. Yields of *Eucalyptus* grown on lands normally used for arable crops give economic yields and benefits that are several folds at the ratio of 121 to 1 (as was found in Gondar Zuria) to that of crop and livestock production. However, of course crop and livestock production require considerable labour and external inputs unlike *Eucalyptus* growing. Similar results are available from Kenya. Yields from Chancho poor sites were six fold less than on good sites. The issue often associated to *Eucalyptus* being high in water consumption and depleting soil fertility is not true as water consumption to produce a unit of biomass by *Eucalyptus* is significantly lower than other trees and woody perennials and still much lower than agricultural crops. Soil nutrient depletion is also low in *Eucalyptus,* especially if leaves and the bark are left behind and not removed as the wood. Farmers in North Gondar and around Addis Ababa are known to establish tree densities in excess of 200,000 trees/ha and under extremely short rotations (3-4 years). The end use and product utilization from *Eucalyptus* needs to be expanded from the present use of fuel wood and construction pole. Its use in pulp and paper manufacturing and use in textile fiber production as well as in chemical products from *Eucalyptus* such as *Eucalyptus* oils and other wood preservative chemicals need to be harnessed to increase its role in industry. Establishing woodlots on agricultural lands by farmers needs to be done carefully as such land use is nearly permanent. However, farmers' method of establishing and maintaining mini-woodlots has wisdom and merit indeed. Do we have substitutes for on farm trees and woodlots if we want to displace *eucalyptus*? Grevillea is often mentioned as a possible candidate but much cost/benefit analysis needs to be done.

History of *Eucalyptus* Growing in Ethiopia

Introduction of *Eucalyptus*

The history of deforestation and loss of forest cover in Ethiopia is well documented. It is a sad history indeed. This problem did not escape some of the rulers of Ethiopia. Both Emperor Kaleb and Minilik II were very concerned. Emperor Minilik, assisted by his French technical advisor, introduced fast-growing tree species from southern Europe (Portugal, Italy, Greece, etc.) totalling some 15 species, but largely made up of several *Eucalyptus* species. The introduction and growing of such fast growing tree species was meant to supply fuel wood and construction wood to the new and growing new capital city, Addis Ababa. Other tree species introduced along with the *Eucalyptus* species were Australian *Acacia, Casuarina* and tropical pine species (*Pinus spp.)* that can still be seen in urban and peri-urban landscapes of highland Ethiopia.

Of the *Eucalyptus* species introduced between 1895 and 1898, *Eucalyptus camaldulensis* and *Eucalyptus globulus,* commonly referred to as red and white *Eucalyptus* respectively, performed well and their cultivation gradually spread throughout the country, especially in the woina dega and dega zones of the highlands. Alemaya Collage of Agriculture in 1958 introduced 37 *Eucalyptus* species and still later in the mid-60s, CADU and IAR introduced additional species for testing along with species and provinces earlier introduced at Chilalo (Arsi) and Holetta (Shewa) respectively.

The results on the relative performance of the 37 species was published by Adugna Zerihun (1969) which showed that other *Eucalyptus* species including *E. saligna* and *E. grandis* out-performed *E. globulus* and *E. cameldulensis*. Other trials including the species performance trials at Wondo Genet clearly demonstrated that these two commonly grown species are not necessarily the best performing species. In Wondo Genet, *E. donii* and *E. saligna* out-performed the red and white *Eucalyptus.* Because of the narrow genetic base of the red and white *Eucalyptus* introduced in Ethiopia, FRC in 1990 introduced many new provenances for these two species from Australia and the long-term trials have been established outside Addis Ababa.

Spread of *Eucalyptus*

The radius of *Eucalyptus* growing from Addis Ababa centre continued to increase during the first decade. The next stage of *Eucalyptus* growing outside Addis Ababa and environs was by missionaries in Ghimbi, DebreTabor, and Harar. Later still, especially after the 50s, *Eucalyptus* growing moved to rural areas from these first nodes, being planted first in urban areas, the homesteads and eventually on agricultural lands by farmers and urban dwellers. The period from 1975 to 1985 saw more *Eucalyptus* planting (a total of 500,000 seedlings of which most to was *eucalyptus*) under the government afforestation and plantation programs through Food-for-Work program of the World Food Program and bilateral and UN funded periurban plantations. Fast growing towns and cities of the Amhara National Regional State including Desse, Gondar, BahirDar, Dangla, and Debreberhan had large funded fuel wood/pole *Eucalyptus* plantations.

Eucalyptus growing in Ethiopia by farmers and the private sector, now and in the past, has been to generate cash through the sale of *Eucalyptus* poles and fuel wood to urban and periurban markets. Addis Ababa, Region 1 (Tigray) and Eritrea (before the 1998 war) represented the main external markets for the ANRS as well as for more than 2,000 urban centres within the ANRS itself. Both the red and white *Eucalyptus* species are suitable for the two key functions, namely for the construction of economical housing/fencing and for household fuel wood needs of both urban and rural households. *Eucalyptus* plantations in other countries are destined for industrial uses, fuel for energy power generation (Brazil, W. Samoa)), pulp/paper and the production of oils and turpentine elsewhere. *Eucalyptus globulus* is highly suited for the production of pulp/paper and oils while *E. camaldulensis* or its potential substitute, *E. saligna* is more suited as construction timber. These alternative uses of *Eucalyptus* can and need to be promoted in the event of decline of pole and fuel wood market prices.

Table 1 gives the list of important countries growing *Eucalyptus* including Ethiopia while Table 2 shows the rate of *Eucalyptus* growing in Ethiopia since its first introduction 100 years ago. More than 80% of the total was during the last 30 years. The estimated half million ha under *Eucalyptus,* under state, community and private *Eucalyptus* plantations and/or woodlots, places Ethiopia to be one of the ten major *Eucalyptus* growing in the world after Brazil and India. *Eucalyptus camaldulensis* is not grown commercially elsewhere except in Ethiopia. The only other country growing *E. globulus* outside Ethiopia is Argentina. Neighboring countries such as Kenya and Burundi also grow other *Eucalyptus* species, including *E. saligna, E. grandis* (Kenya), *E. maidenii,* and *E. grandis* (Burundi). Thus, globally important and commercially grown *Eucalyptus* species are *E. globulus, E. camaldulensis, E. saligna, E. grandis*, *E. teriticornis*, and *E. citriodora.* All of these species have been introduced and are grown in Ethiopia but only the red and white eucalyptuses are widely grown.

Reference was made above, to the results of long term species screening/evaluation trials conducted by Faculty of Agriculture (Alemaya), IAR/FRC (Holetta and other multi locations), by Wondo Genet College of Forestry (Wondo Genet) and more recently by the Hawassa College of Agriculture (multi location trials in the Rift Valley and adjacent highlands). These trials have adequately demonstrated that *Eucalyptus* growers should replace the red and white *Eucalyptus* species by other more productive species such as *E. saligna, E. grandis* and with the new hybrids. *Eucalyptus - saligna* for instance is now being used as floor parquet instead of mahogany, the latter now scare and expensive. However, neither this information nor seeds of these faster growing *Eucalyptus* species and new hybrids have been made available to the public, especially to the farmers. The very high yields in Brazil and in other *eucalyptus*-growing countries are largely from the use of these new hybrids and from the use of good nursery stock (planting material).

The National Tree Seed Unit of FRC is the only institution dealing with the supply of tree seeds but their seed stock list is determined by what can be collected from existing plantations and woodlots, as there are no tree seed orchards established and being maintained for such purpose. The Food-for-Work program has been used to collect seed from local sources by government nurseries in the past using food and cooking oil as a form of payment. The Unit's tree seed supply may include *E. saligna, E. grandis* but the quantity is very limited, and the price range is out of reach for farmers to procure. This sets the stage for farmers to continue collecting seed from their existing trees of *E. globulus* aura/and *E. cammaldulensis.* This practice, over a course of nearly 100 years has resulted in the dominance of these two species in the country. Certainly, the government, through its Ministry of Agriculture and the research institutions has not had extension service dealing with tree farming in general and *Eucalyptus* growing in particular.

Agroecology and Husbandry of *Eucalyptus* Farming

Method of growing and management of *Eucalyptus* in Ethiopia, especially by farmers, differ markedly from other *Eucalyptus* growing nations. Rotation length (years) is typically short and yields are low as shown in Table 3. Planting densities are, however, unusually high in Ethiopia ranging from below 3, 000 in government plantations and 10,000 to over 100,000 trees/ha in farmers' farm and village woodlots. Low-density plantings (under 3,000/ha) take more than 25 year (26 years for *E. globulus)* and less than 10 years for high-density plantings (i.e. 10,000 to over 100,000/ha on average on good sites in the highlands to reach economic harvest after 6 years from planting and only 3-4 years for each coppice harvest (when growth curves begin to decline).

Eucalyptus growing in Ethiopia is largely confined to the highlands (1,500 to 3, 200 m) where moisture and temperatures are suitable for tree growing. The two *Eucalyptus* species are normally altitude-based with red *Eucalyptus* being for lower (warmer) altitudes, that are the upper kola and Woyina dega zones and the white *Eucalyptus* for the cooler (higher), the dega and wurch zones.

Good growth, and thus, high level of income from large biomass yield in very short period only come if *Eucalyptus* is given good planting site and given good husbandry during establishment, much like that given to agricultural crops. Farmers are knowledgeable on these two key aspects of *Eucalyptus* farming. Farmers are hardly seen establishing and managing *Eucalyptus* on degraded or Bad Lands such as shallow, stony, and steep lands. On the contrary, the government, through its extension service, advocates that *Eucalyptus* growing be restricted to degraded or non-agricultural lands. Nevertheless, both rate (survival percentage) and growth rate (yield·ha^{-1}) on poor sites are always very low and un-economical (Asaye Asnake, 2000, and Amare Getahun, 1999).

The government has used *Eucalyptus* in afforestation of degraded hillsides but growth rate is invariably very unsatisfactory compared to the recovery and re-growth rate of indigenous or local woody species. There are now over 150,000 ha of *Eucalyptus* plantations under state and community ownership from the massive planting programs between 1975 and 1982 (mostly in the ANRS) with no management system in place. The largest concentration of such *Eucalyptus* plantations is in N. Shewa, N. and S. Wollo, N. and S. Gondar, and E. Gojam zones of the ANRS.

In a study on the impact of site condition on the performance of *Eucalyptus* block plantations in North Gondar Zone (Asaye Asnake, 2000, unpublished M.Sc. Thesis), in the 20,000 trees/ha density group, the best sites (i.e. flat croplands) gave economic yield (Birr) 8 times that of the poor sites (shallow, stony and sloppy lands). In terms of biomass yield for a 6-year rotation, the yields were 316, 112, and 25 m^3/ha^{-1} for best, medium, and poor sites, respectively. This translates to 52.7, 18.3, and 4.1 m^3/ha/yr respectively or Birr 25,572, 10,809 and 3,092 per year, respectively (Asaye Asnake, 2000). One only needs to compare what farmers get from crop farming from an equal land size after toiling and with the use of inputs. Annual income from crop farming ranged from Birr 530 to 3,500 (excluding livestock, which is not readily sold annually).

Table 1. Major *eucalyptus*-growing countries in the world

Countries	Area under *Eucalyptus*	Main species grown
Brazil	3,000,000	*E. grandis*
India	500,000	*E. teriticornis*
Ethiopia	506,000	*E. glob. E. camald.*
South Africa	470,000	*E. grandis*
China	400,000	*E. citridora*
Angola	390,000	*E. citridora*
Spain	390,000	*E. globulus*
Portugal	300,000	*E. globulus*
Chile	250,000	*E. globulus*
Argentina	240,000	*E. globulus*

Source: Compiled by author from various sources

Table 2. *Eucalyptus* growing in Ethiopia: 1898 -2000

Period	Years	Area under *Eucalyptus* (ha)	Total
1898	0	0	0
1899-1930	32	5,000	5,000
1931-1970	40	91,000	96,000
1971-1982	11	175,000	271,000
1983-1991	8	135,000	406,000
1992-2001	9	100,000	506,000

Source: compiled by author from various sources

Table 3. Comparison of yield and rotation length of selected countries

Eucalyptus species	Country	Rotation (years)	Yield, m^3/ha^{-1}
Eucalyptus grandis	Brazil	7	40
Eucalyptus grandis	S. Africa	8-10	20
Eucalyptus globulus	Chile	10-12	20
Eucalyptus globulus	Portugal	12-15	12
Eucalyptus globulus	Spain	12-15	10
Eucalyptus globulus	Ethiopia	6	17

On-farm Woodlots

Of the two most commonly grown *Eucalyptus* species in Ethiopia, *E. camaldulensis* has a much wider ecological range, ranging from upper kola to dega zones. Within this wide ecological amplitude, both species require good sites and good land preparation, Thus productivity of *Eucalyptus,* and hence profitability is influenced or is determined by the following natural resource conditions and husbandry:

- Soil moisture or rainfall
- Soil nutrients (both macro and minor elements)
- Soil organic matter (SOM)
- Effective rooting soil depth and soil friability (structure)
- Good planting site preparation
- Good weed control during establishment, and
- Good Seed and seedling quality

Indeed, farmers in the ANRS and elsewhere, use deep soils with good friability status (including good organic matter level) and areas with adequate rainfall (800-1500 mm/yr.) to grow *Eucalyptus* economically. The field (site) conditions under

1, 2, 3 and 4 are met in the HPP (High Potential Perennial) and LPC (Low Potential Cereal) zones of the highlands in the Ethiopian central and northern highlands. Farm woodlot establishment using the Taungya system as described below, ensures that the tree husbandry practices above (5, 6, and 7) are met effectively.

Farmers normally plough the tef fields 5 times or more before sowing and they weed the crop more than two times and protect the croplands from any grazing damage until after tef crop harvest. Once the tef has germinated, following broadcast sowing, farmers make deep furrows and plant *Eucalyptus* seedlings (container grown or bare roots seedlings). The following year, farmers may till the young *Eucalyptus* farm woodlot and plant finger millet (*Elusine coracona*) or just protect the fields from grazing for a cut-and-carry thatching grass harvest as cash crop.

Thus, only the cost of seedlings, transport, and furrow making are the direct costs of establishing the woodlot. All other land preparation and crop husbandry practices including the use of chemical fertilizers benefit the growth and yield of the woodlot. Unlike the common belief that *Eucalyptus* can grow at any site without weeding, *Eucalyptus* demands well-prepared planting site, weeding and application of fertilizers including microelements (i.e. Copper, cobalt, molybdenum). Competitive grass species significantly reduce *Eucalyptus* growth by restricting root density by as much as 40%. In addition, of course once established, there are no costs associated in *Eucalyptus* farm woodlots. Harvesting cost in clear-felling harvests is normally borne by the trader (the buyer).

Farmers' strong interest in *Eucalyptus* farming in homesteads, farm boundaries and on farms, to the dismay of the government, and to the exclusion of other tree species is due to the following reasons:

- *Eucalyptus* spp. (especially *E. globulus)* are not browsed by domestic or wildlife;
- Farmers' knowledge/experience on *Eucalyptus* growing is extensive (100 yrs.);
- Seed is locally available and seedling production time is short and relatively easy;
- Requires little or no husbandry after the first 18 months of establishment, or none if grown under the Taungya system (described above);
- Fast growing and highly coppicing;
- High local and national market demand;
- Very little known pest and disease problems; and
- No readily available species choice to replace *Eucalyptus*

In addition to the ecological and site requirements being met in the crop farming system, the strong and sustained interest for growing high-density short rotation *Eucalyptus* woodlots by farmers are:

- To generate cash income
- Due to the poor performance of crop farming and lack of grazing land/ feeds to produce livestock due to land shortage, and
- To reduce the risk of loss of land due to government land re-distribution.

The greatest driving force however is to generate cash income as and when needed. Farmers with *Eucalyptus* on farm woodlots are also free of the annual farm work, common in crop farming, because once established, the woodlots continue to generate cash for many coppice generations.

Eucalyptus was introduced in other East African countries such as Kenya, Uganda, Rwanda, and Burundi and in southern Africa, Zimbabwe, Zambia, and South Africa. In East Africa, *Eucalyptus* failed to make headway except in government plantations and by farmer's participating in tobacco growing for the British-American Tobacco Co. (BAT). In these countries, Grevillea (*Grevillea robusta*) became more important along with other species including tropical pines and Cyprus. Grevillea is not grown as woodlot or as a plantation. Instead, it is integrated into the farming system, grown as farm boundary tree or as scattered trees in croplands and along soil conservation structures. Tree establishment and management in East Africa is relatively easy in the absence of open and free grazing system so common in Ethiopia. Unfortunately, in Ethiopia, open grazing, especially following crop harvest is common where all vegetative material, dry and green is readily devoured and/or is carried off for other uses. Under such conditions, only *Eucalyptus* species are able to survive, as they are hardly grazed/ browsed.

Eucalyptus species also have aggressive mechanism that permits them to grow rapidly to escape browsing and other damages, especially when planted dense and under the Taungya system (FAO, 1976). This is accomplished through their indefinite shoots and naked buds on the leaf axis both of which is capable of continuous growth or can resume growth with the first opportunity of favourable weather or following damage. The crown of *Eucalyptus* is also made up of several sub-crowns (4 or more) all of which is capable of growth with no suppression from the top (apical) crown.

Economic benefits and wood demand

The growing of *Eucalyptus,* especially in the ANRS is largely motivated by the scarcity of construction wood, fuel wood as well as, to generate cash income. Unlike southern Ethiopia, which depends on coffee, chat, enset, sugar cane fruit as income sources, the ANRS has no strong tradition of growing cash crops. The growing of *Eucalyptus* therefore fills this important gap and farmers are quick to tell you that it is their green bank account, able to draw from it any time. The traditional role of livestock as a source of cash has declined. Therefore, farmers grow *Eucalyptus* largely to sell to the urban market and rarely for own use.

A survey conducted in North Gondar Zone in 1998, revealed that farmers; reasons for planting included (in the order listed):

- cash income;
- fear of future shortage of wood;
- acquired knowledge and experience of tree growing (especially *eucalyptus*); and
- MOA and Gondar Fuel wood Project extension and technical assistance

Farmers that do not plant *Eucalyptus* were more the exception than the rule. According to the survey, the few farmers that did not plant *Eucalyptus* or had no farm woodlots gave land shortage as the main reason (81.5%). In the survey area, and largely in the whole ANRS, farmers' interest in planting *Eucalyptus* on farms, farm boundaries and in homesteads, increased dramatically since 1992 with the demise of the Communist regime and its short-lived mixed economy policy in 1989-91. Farmers' interest in tree planting was not confined to *Eucalyptus* only as they were interested in and planted fruit trees (papaya, guava, white sapote, etc.), coffee, citrus fruits, geisho (*Rhamnus prinioides*), chat (*Catha edulis)* and to a lesser extent fodder trees (*Sesbania sesban,* chivha (*Ficus thonningii*) and Tree lucerne). For instance, in the Gondar Fuel wood Project impact highland Woredas, especially in Gondar Zuria Woreda, between 1992 and 1996, farmers of this area planted 28.3 million trees compared to only 4 million under community tree planting and only 2 million in government plantations.

Both community and government plantation establishment is no longer active and nearly all trees planting are by farmers and few private investors. *Eucalyptus* is certainly taking up valuable cropland (12% of the total land holding of the household or 0.20 ha out of 1.6 ha) and in the southern highlands, *Eucalyptus,* assisted by chat, is seen replacing coffee and enset in the home gardens, again because of the high cash income and its low labour input demand.

Benefit of Farm Woodlots: the Case of the Gondar Fuel wood Project

A survey conducted in 1998 revealed that more than 80% of the farmers in the 4 Woredas planted trees ranging from 200 to 60,000 per HH. As a result, *Eucalyptus* was able to replace 57% of the fuel wood/and construction pole demand of Gondar City in just 12 years, which traditionally came from indigenous forests and woodlands. Nevertheless, charcoal, which accounted for a small fraction of the fuel consumption, continued to come from indigenous sources. Farmers were also able to meet their most HH construction and fuel wood from *Eucalyptus.* Farmers normally used BLT (branch leaf and twigs) of *Eucalyptus* as the wood was always earmarked for sale.

Based on current low crop yields (of the non-participating farmers in the agricultural package program who are the majority) and defective markets, the annual net income from agriculture (excluding livestock and off-farm incomes) was found to be only BIRR 259/ha. On the other hand, the income from the two common woodlot densities of 10,000 and 40,000/ha was estimated at Birr 43,831 and 207,389 respectively using 8% discount rate. In other words, the net income from 1 ha of crop farming over a 20-year period is only Birr 10,580 compared to the income from the two woodlot densities of BIRR 703,360 and 2,631,540 over a 20-year period. Table 4 gives the projected pole harvest and value over a 20-year period for the 10,000 and 40,000 woodlot densities in Gondar Zuria woreda, planted on an agricultural land site under a Taungya system as described above. Clearly, on productive sites, high-density woodlots fetch much more income over time. The total pole harvested over 20-year period was only 99,000 from the 10,000 density while that from 40,000 was 349,000, Planting density of over 100,000 are not uncommon in central and southern highlands which result in correspondingly high pole yield and thus high income.

Table 4. Number of poles and value from 1 ha woodlot at 10,000 and 40,000 planting densities over a period of 20 years from planting in Gondar Zuria woreda.

Density	**Pole Harvest**							**Total Value (Birr)**
Harvest	1	2	3	4	5	6	20 yr Total	
10,000	9,000	18,000	18,000	18,000	18,000	18,000	99,000	703,360
40,000	36,000	54,000	54,000	54,000	54,000	54,000	349,000	2,631,540

Source: Amare Getahun 1999

More recently, price of *Eucalyptus* in North and South Gondar Zones have declined considerably forming local *Eucalyptus* glut. Using current low prices, Asaye Asnake (2,000) gives incomes (expressed in NPV) for three different ecological sites based on their productivity levels or land classes (Table 5).

Table 5. Income (NPV, BIRR) of *Eucalyptus* on farm woodlots from Gondar Zuria, North Gondar Administrative Zone, ANRS

Site Class	**20,000 density**	**10,000 density**
Good site	25,572	13,513
Medium site	10,809	7,371
Poor site	3,092	3,510

Source: Asaye Asnake, 2000

As can be seen, it pays more to plant on good sites and at high density as shown in Table 4 and 5 above. Conversely, it does not pay to increase the planting density in poor or bad sites as site conditions are so limiting for tree growth and establishment is difficult and costly. High densities, above 10,000/ha result in short rotations (5-6 years for maiden harvests and 3-4 years for coppice harvests).

Experiments using low density (3,000/ha) Block Plantations were carried out on the establishment and growing woodlots on grazing lands using three site classes, namely (A) grazing land, silt clay soil, 0-5% slope, (B) grazing land, sandy clay soil, 10% slope, and (C) shrub land grazing,, sandy degraded hill side, 15-30% slope, The sites were at Loza Mairam (A), Azezo Airport (B) and Jaira (C). These sites are not suitable for crop farming and can be classified as moderately good (A), marginal (B) and poor or highly degraded (C). The cost of plantation establishment was highest at Site C followed by B and A respectively. After repeated replanting, survival rate (%) at the end of 5 years was 45, 12 and 2.9 for A, B and C, respectively.

Table 6, Yield and income of Government Block Plantations, Gondar Zuria woreda, North Gondar Administrative Zone) 1999)

Site class	Age, yrs.	DBH (cm)	Height (m)	#Poles	Value (Birr)
A	4	17	15	127,487	1,784,818
B	4	15	16	44,000	616,000
C	5	10	11	41,600	499,200

Source: Amare Getahun, 1998

One can see than on hectare basis, yields from site B and C are too low compared to site A. Note that the age of site C is one year older compared to A and B. Not the size (DBH and height) is inferior. This clearly establishes that contrary to popular thinking (by government experts, not farmers) that *Eucalyptus* can be planted on degraded and Bad Lands, it hardly competes with the performance of local woody species. Indeed, in the Block Plantations described above (Table 6), at the end of three years of protection, the recovery of the native vegetation in site B and C was more impressive than the growth rate of the planted *Eucalyptus* and survival rate was too low (12 and 3% for B and C respectively) .

It can be concluded, based on the experience of the North Gondar Fuel wood Project reviewed above, that in general, the mean annual increment (MAI) in poor sites is uneconomical and ranged from 1.6 to 6.5 m^3 as compared to 20 m^3 for better sites and over 30 m^3 from the on-farm woodlots in the same ecological area.

Thus, both site selection and management are important considerations and farmers know these too well.

Ecological issues of *Eucalyptus* farming

The ecological issue and concern on *Eucalyptus* growing especially on farmlands and near riverbanks is not only due to *Eucalyptus* as an aggressive water and soil nutrient consumer but also due to the high planting density and short rotation. There is no question that both the red and white *Eucalyptus* are heavy and rapid feeders of both water and soil nutrients. On the other hand, as employed by farmers and private investors the economic benefits of high-density short rotation farm woodlots and as detailed above, is beyond repute.

It is now well established that *Eucalyptus* exploits water and soil nutrients such as N P K and micronutrients such as copper, boron and molybdenum, etc. at deeper soil horizons outside the agricultural crops feeding zone or soil depth, especially when grown at high density as in farm woodlots. The issue of water and nutrient depletion by *Eucalyptus,* often the subject of great debate is generally over exaggerated, especially in rainfall regimes higher than 400 mm/yr. (Davidson, 1995). Table 7 compares water use by annual crops, fruits, and forest trees in general, including *Eucalyptus.* It shows trees in general and eucalyptuses in particular are efficient users of soil moisture per unit of product or biomass produced. Only sorghum shows a lower rate of water consumption, according to Table 7.

Table 7. Water use (liters) by plants to produce 1 kg of produce or biomass

Species/group	lt./kg Biomass growth
Annual Crops	
Field pea	600
Horse bean	600
Sorghum	250
Maize	500
Potato	1000
Woody Perennials	
Cotton, coffee, Banana	800
Trees	
Dalbergia sissoo	890
Acacia auriculiformis	860
Syzigium (dokma)	610
Albizia lebbek	580
Eucalyptus hybrid	510

Source: Davidson, 1995

Table 8 shows soil nutrients use and removal through harvests. Here again the scientific evidence is that *Eucalyptus* is not heavy feeder of nutrients when compared to other group of plants. The nutrients removed by *Eucalyptus* harvest are often confined to the bark and leaves. It is reported that bark of *Eucalyptus* contains the following amounts (%) of the nutrients taken up from the soil (shown in Table 8) namely; 87% Ca, 48% K and 68% Mg (DFIS, 1999). Leaving the bark and leaves during harvest will contribute to sustainable resource use. This is not however done practically in Ethiopia unlike the common practice in commercial *Eucalyptus* plantations elsewhere in the world.

Indeed the annual litter fall of *Eucalyptus* ranges from 6.9 tonnes/ha in young plantations to 12.8 tonnes/ha in old and first rotations. Thus, the litter fall continues to increase with age as shown in Tale 9 and nutrient input in to the soil (N P K Ca) is proportional to the amount of litter fall The rate of litter decomposition is however slow in *Eucalyptus* and the impact is therefore long term. This fact has been documented in the long-term effects of *Eucalyptus* (*E. globulus)* on soil fertility and undergrowth in Menagesha State Forest, near Addis Ababa (compared to *Cupressus lusitanica, Juniperus procera,* and natural forest over a period of 40 years (Michelsen, Lisanework Nigatu and Friis, 1993). Tef growth was reduced when grown on soils from all three-plantation species. Vegetation under growth was good under *Eucalyptus* (better than Cyprus). Analysis of soil nutrient content showed that *E. globulus* and *Cupressus lusitanica* soils had lower nutrient content than the native *Juniperus procera*, however, according to this study.

Table 8. Soil nutrient - N P K consumed and removed by harvest (kg/ha-1) by *Eucalyptus* compared to other species

Types	Consumption			Exported by Harvest		
	N	P	K	N	P	K
Annual Crops	110	24	170	33	7	51
Fruit Trees	110	9	120	49	3	48
Forest Trees	307	10	110	50	3	18
Eucalyptus	76	6	43	11	1	12

Source: Davidson, l995

Table 9. Annual litter fall of *Eucalyptus* (tonnes/ha)

Stand type		Litter fall			
	Age (yrs.)	leaves	twigs	fruits	Total
Seedling (maiden harvest)	8	4.31	2.56	0	6.88
Coppice	13	8.31	2.56	0	10.87
Coppice	19	8.88	3.78	0.25	12.90

Source: Bernard-Reversal, F (ed).

Conclusions

The economic benefit of *Eucalyptus* farming by farmers in the ANRS is beyond repute. Farmers will need to continue growing *Eucalyptus* to meet urgent cash needs and as a means of accumulating wealth. Government must not consider and make farmers plant *Eucalyptus* on marginal and degraded sites as have been the case in the past nor should *Eucalyptus* be used in afforestation and enrichment planting of hillsides. It does not pay the efforts of growing the seedling; transporting and planting *Eucalyptus* on such poor sites as has been amply demonstrated from trials and enclosures in the past.

The central issue in growing *Eucalyptus* is that it can only be grown in monoculture except in the first year of planting where farmers carry out crop farming without any negative impact on the crop yield from *Eucalyptus.*. Thus, the strong interest of the government in integrated food and feed production with forestry as the current national task forces have been charged to develop cannot be accommodated. It is also impossible to intercrop under *Eucalyptus,* irrespective of density and age of the *Eucalyptus* woodlots and plantations. One must note however low density (under 1,000/ha) old stands of *Eucalyptus* s can support grazing as can be observed by the plantations established by MOA and through donor assistance in the past.

Government must not believe that *Eucalyptus* has solved the problem of rural and urban household energy needs. The over-dependence of rural household on non-woody biomass source of energy is still critical to natural resource management and sustainable land use. Rural households continue to relay on dung and crop residues and miscellaneous BLTs to meet their cooking and space heating as well as selling these products to the rural markets. Some of the crop residue also goes to meet dry season animal feed and for use in local houses construction.

Next to Region 1 (Tigray), the ANRS is the region most dependent on non-woody biomass energy with an average of 70% but ranging from 50 to 95% of the total energy demand and consumption. The most hard hit sub-regions in the ANRS are North Shewa Zone, WagHimra zone, N and S Wollo and N. and South Gondar (highlands). Those with medium conditions are the highlands of W and E Gojam, and Awi zone. The areas with good supply and currently the source of much of the exploitation include the Western lowlands (of North Gondar, Gojam and Awi zones), the escarpments of the three basins, namely Abay, Tekeze and Awash.

The extent of *Eucalyptus* farming by farmers of the Ethiopian highlands especially the central highlands making up much of the landmass of the ANRS and the economic importance has been demonstrated in the paper. *Eucalyptus,* once established, continues in the landscape because of its coppicing ability, which in part has made it difficult to find a suitable replacement species. The ecological negative impact of small farm woodlots is not discernible in the field as streams continue to flow and woodlot productivity does not appear to be significant over the years. The extent of farmer's interest in *Eucalyptus* growing is such that it is nearly impossible to do away with *Eucalyptus.* A more definitive research by Zerfu Hailu (2002) which should make it clear that there is no inherent ecological damage that *Eucalyptus* does. Its problem in this regard is its fast growing aspect which results in depleting water before the next recharge by rainfall unlike other slow but more water consuming trees and food crops as shown in the data presented in this paper.

It is possible and necessary to revisit the issue of these high-density short rotation *Eucalyptus* plantations and woodlots *vis a vis* local and generalized hydrology. Government and its experts must not continue to cry foul on the water depletion issue of *Eucalyptus* when there is no case of water use by farmers, who are often seen draining off their cereal farms each growing season to remove water, which also initiate soil erosion (gully erosion).

The need to find a suitable tree or woody species to *Eucalyptus* has often been expressed by researchers and policy makers. The current efforts by GTZ, EIAR, ARARI, and other partner NGOs to find replacement species such as *Grevillea robusta, Populus hybrids, Calliandra calothyrus, Sesbania sesban* and some local species need to be supported and accelerated. There is no adequate evidence of farmers given extension advice and service on which species to grow and how to manage them.

References

Amare Getahun. 1998. Project Evaluation Report: Plantations establishment and integrated rural development in the North Gondar zone, Ethiopia. UNSO/ETH/86/X01. Pp48.

Amare Getahun. 1999a. Farmers-led on farm tree planting in the mixed farming system of the degraded Ethiopian highlands, North Gondar Administrative Zone. UNSO/ETH/86/X01. 43pp.

Amare Getahun. 1999b. Woodfuel/HH energy. Technical Report. ANRS Forestry Action Plan. Vol. II Part 6. CEDEP, Addis Abeba. (Draft Report)

Amare Getahun. 1999c. The benefit of tree planting: The case of the Gondar Fuel wood Project. 35pp

Davidson J. 1995. The *Eucalyptus* dilemma: Arguments for and against *Eucalyptus* planting in Ethiopia. FRC Seminar Notes Series No. 1.

Amare Getahun, Zerfu Hailu. 2000. *Eucalyptus* in Ethiopia: Its Past and Future. Paper of Amhara National Regional State (ANRS) and SIDA Cooperation in Rural Development.

Asaye Asnake. 2000. Comparative Studies of *Eucalyptus* in North Gondar (Gondar Zuria). MSc. Thesis.

Department of Agriculture, North Gondar Zone. 1998. Report on the fuel wood consumption and its environmental impact. Land Use and Environmental Protection Section. North Gondar. 37pp.

Department of Agriculture, North Gondar Zone. 19997. Report on the community and private tree resources (potential) assessment. Land Use and Environmental Protection Section. North Gonad. Pp 37.

FAO. 1988. The *Eucalyptus* dilemma. FAO Rome. 26pp.

Michelsen A, Lessanework Negatu, Ib Fris. 1993. Impacts of tree planting in Ethiopian highlands on soil fertility, shoot and root growth, nutrient utilization and mycorhizal colonization. Forest Ecol. and Management. 61:329-324

Stage O, P Rekve. 1998. Food Security and food self-sufficiency: The economic strategies of pesants in Eastern Ethiopia. The European Journal of Development Research 10 (1) : 189-200.

Social and Environmental Debates on *Eucalyptus* in Galicia, Spain

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Abstract

In the case of Galicia, a region in the Northwest of Spain, the *Eucalyptus* together with the pine is the basis of the production in the forest sector. *Eucalyptus* felling represented 50% of the total in 2009. The Forest sector represents 3.5% of Galician's Gross National Product. It can even be said that *Eucalyptus* plantations have changed Galician's landscape, often bare and deforested, as was the case at the end of the 19th century and beginning of 20 century. Such important changes have been the cause of social controversy. Serious environmental impact or even incapability to produce other goods and ecological services has been alleged from diverse social environments. Nowadays there is scepticism in the best of cases as a result, and even prohibitions in others. The message permeating society regarding the *Eucalyptus,* and reforestation in general is fraught with demagogy. Public opinion has evolved together with society, as owners' experiences with reforestation and forestry operations have increased. The truth about the facts indicates that different opinions coexist, with 80% of *Eucalyptus* plantations taking place in the ownership of small landowners. One of the purposes of this paper is to identify and characterise the different typology of answers coming from the different sectors. The main factors, which affect public opinion's acceptance and how industry should participate in *Eucalyptus* plantations, are analysed.

Keywords: *Eucalyptus,* Galicia, social and environmental debates,

Introduction

Eucalyptus is contributing greatly to income output in areas where they are fortunate enough to be able to grow it, together with its undeniable environmental benefits. Nevertheless, it is an unfairly reviled species. It has been accused without scientific basis of draining and poisoning the grounds where they live and going through all water reserves as well as native vegetation due to a supposedly aggressive expansion and the excessive desire to repopulate by the Estate or unclear business interests.

In the case of Galicia, Northwest Spanish region, the *Eucalyptus* together with the pine is the main forest resource and the basis for its restructuring. Thanks to

Eucalyptus and pine plantations, hundreds of kilometres of tracks have been rebuilt and are being maintained in the hills as well as other basic structures. *Eucalyptus* felling represented 50% in 2009 in contrast with the total. The forest sector contributes to the generation of wealth and the improvement of all population's livelihood, representing 3.5% of Galician's Gross National Product. In addition, plantations are renewable resource, which in some particular way generates better shared-out wealth and a better contribution to income and employment in the most disadvantaged areas. In most rural areas, transformation industry figures amongst the three primary industrial activities to generate employment.

Serious environmental impact and even inability to produce other goods and ecological services have been alleged from a diversity of social environments (press, politicians, ecology, and even scientists). Nowadays there is scepticism in the best of cases as a result, and even prohibitions in others. The message permeating society regarding the *Eucalyptus,* and reforestation in general is fraught with demagogy.

Neither foresters nor the forest industry have really known how to transfer a more positive and realistic image to society, even though the native European forest, particularly Galician's, is in constant increase according to statistics. Despite extended belief, the *Eucalyptus* has not substituted the Galician Oak wood. What's more, it has been the bare and deforested landscape from the end of the 19th century and beginning of the 20 century that has given way to pine and *Eucalyptus* plantations. It has been private reforestation initiative, as will later be seen, which has naturalized it and increased its surface (Calvo de Anta, 1992: Valdés and Gil, 2001).

In Europe, as in other parts of the globe, there is a great deficit between demand and provision of timber. That is why the use of plantations with fast-growth species, which also contribute to the sequestration of CO_2, is unavoidable. Its administration should not be perceived as an element of the process our planet is taking to become artificial, but as an instrument to preserve biological diversity, to maintain the planet's climatology and to improve our way of life. Changing a perception that governments and landowners have so that they take their decisions based on scientific arguments must be nowadays the industry's priority if they want to reverse negative public opinions. This is now the challenge that must be faced.

Forest Sector and *Eucalyptus* in Spain

Galician forestry culture is largely linked to its property and economical structure. In Galicia diverse aspects, which have deeply tinged the present perspective and views had by the population regarding the mountain and its uses, can be identified. Amongst them, the following could be pointed out: property's regime, property's typology, the size of the property, public administration's intervention, population movements, and the evolution of the farming sector, forest fires and the development and evolution of the wood chain in Galicia.

Regarding typology, regime, and size of property, it could be said that Galicia is a small green region in the Northwest of Spain, covered in trees and populated by people who grow trees. That is the case considering that having 2.9 million hectares (figure 1), 2 million ha are for forest use (68%) and 1.4 million hectares are covered in trees (47%). This number accounts for 10% of the Spanish forest covering and 3% of the European one.

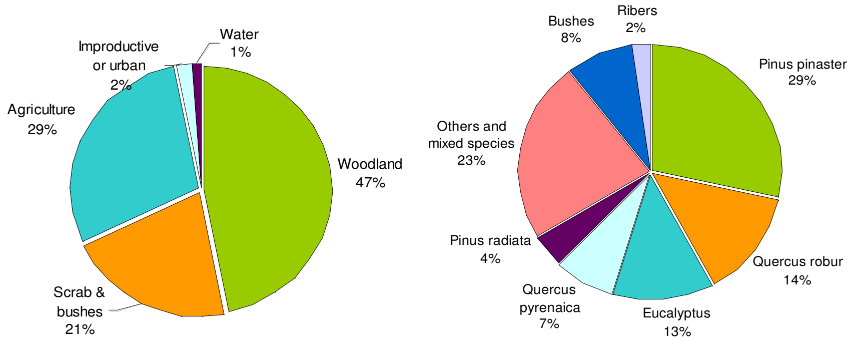

Figure 1.. Relative distribution of the use of ground in Galicia
Source: IFN3 Galicia

The distribution of these amounts in species (Figure 2.2) shows a prevalence of the Galician pine (*Pinus pinaster*), being 29%, above the oak (*Quercus robur* and *Q. pyrenaica*), with 21%, and above the *Eucalyptus* (mostly *Eucalyptus globulus*) with 13%. It should be noticed that there is a high presence of mixed species in a variety of rotations, like the pine and the *Eucalyptus* or even with a larger or smaller presence of oaks. This fact is not advisable in the slightest for technical reasons, since it makes management difficult and it reduces productivity, even when those species are intimately linked.

Forest property is mostly private, and individual landowners play a crucial role in the future of forestry activity. That is the case as one in four inhabitants is a forest owner. That means 672,000 owners in a population of 2.8 million inhabitants. Thus, four categories of landowners can be distinguished in Galicia: private owners, Neighbouring Mountain Communities as Commonwealth (CMVMC)[14],

[14]The origin of The Neighboring Mountain Communities as Commonwealth (CMVMC) is the traditional exploitation, which was characterized by the neighbors common lease of mountain landscapes, complement to farming exploitation as they provided shelter for the cattle, fertilization, crop and grazing fields, wood, firewood…

Local and Regional Authorities and the Estate. For management purposes, local authorities can be considered as private owners, as it has been done in figure 2. Amongst private owners, (65.4%) and Mountain Communities (32.9%) they own 98.3% of Galician forest surface (figure 2.3), which can give an indication of the importance of its extent when analysing forest culture.

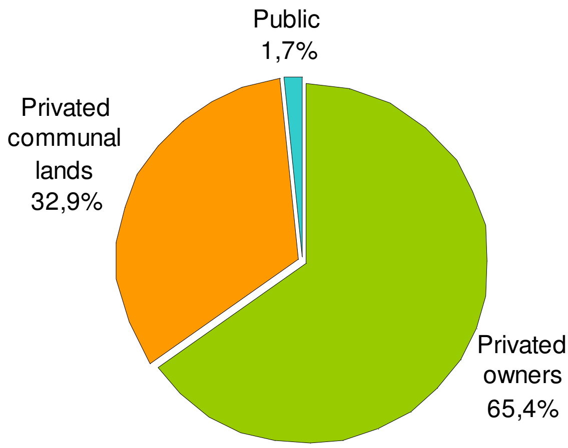

Figure 2. Forest property distribution in Galicia
Source: Galicia Forest Association

The average size of a property is 1.78 ha divided in various plots, only timbered. Besides its small size, the property also carries fragmentation problems. Approximately 80% of registered plots are smaller than 0.5 ha. This size does not permit national economical and environmental efficient management. However, less than 3% of owners belong to some sort of association. An exception comes in the way of neighbouring mountains, which extend to 213.3 ha. Although public administration does directly hold a sheer of 1% of the surface, it controls 20% of it by means of agreements. Large businesses cannot be said to hold a significant percentage, since they hardly manage 12,000 ha due to some sort of agreement. However, even under these conditions private property produces the biggest amount of wood in Galicia.

In fact, approximately 35,000 trees are cut down annually, resulting in a production in 2009 almost as big as the one from the UK, or as big as Italy's and Belgium has put together: 8,000,000 m^3. Therefore, Galicia, having 10% of Spain's woodland, produces 50% of Spain's timber. Within such high production, this makes Galicia Spain's Woodland, the *Eucalyptus* contributing between 45-50% annually.

Introduction and First Plantations

First studies by European botanists

The first written reference to *Eucalyptus* goes back to 2 December 1642 in Heemskerk and Zeehaen crews' logbooks at the helm of Janszoon Tasman (1603-1659). He was captain to one of the biggest and most ambitious exploration enterprises in the northern hemisphere. In one of his incursions to land, they surprisingly discovered two trees of dimensions never seen, with a diameter of 4 metres and a clean bole of about 20 m until the first branches appeared.

After Abel J. Tasman's journey, which left the first testimony of the existence of these magnificent trees in Tasmania, it was not until 1770 when the naturalists Joseph Banks (England, 1743-1820) and his friend Daniel C. Solander (Sweden, 1733-1783) started their systematic study. These botanist and explorers travelled as the crew of the famous ship HMB Endeavour with Captain James Cook in his first journey (1768-1771). After visiting Tahiti and New Zealand, they reached the eastern coast of Australia to take possession in the name of Great Britain. In that journey Joseph Banks, botanists' team collected over a thousand new species for science. Amongst them were *E. gummifera* and *E. platyphylla* although neither of them was known with that name at the time.

One of the samples collected during Captain James Cook's third expedition (1777) by botanist David Nelson in Bruny Island (South Tasmania) was taken to the British Museum in London. In 1789 French botanist, Charles Louis L'Hèritier from Bertelle described the species as *Eucalyptus oblicua* and assigned the name of the genus that has remained until our days. The word "*Eucalyptus*" is the Latin transcription of the Greek **eu kalyptos** (eu kalyptus), which means "well hidden," alluding to a characteristic of its flowers and fruits, the operculum, which protects its inner sections.

It was a few years later, in 1799, when French botanist Jacques-Julien Houton from Labillardiére classified the species and named it *Eucalyptus globulus* Labill for the first times on sheets of paper for samples collected in Tasmania. Its first European destination was precisely Paris, when gardener and botanist Ant. Greichenot, from Paris Botanical Gardens, took its seeds to the old continent in 1804.

The first Spanish specialist who had contact with this genus was the famous botanist and naturalist Antonio José Cavanilles (1745-1804), who also studied samples of *Eucalyptus* and drafted some botanical engravings produced by a famous engraver of his time (Figure 3). He described and named some species, origin of some of its synonyms today.

Figure3. Engraving of *Eucalyptus* platypodos Cav.
Drafted by Cavanilles in 1797. Source: L. Gil

Eucalyptus platypodos Cav. was described by the Spanish botanist in 1797, although the synonym *Eucalyptus botryoides* Sm. as was also described in 1797 is presently accepted. Cavanilles was an internationally acclaimed botanist. He studied in Valencia, Madrid and Paris, where he resided for a decade. He was director of the Royal Botanical Gardens of Madrid. He curiously maintained a harsh controversy with the French scientist Charles Louis L'Heritier.

This great journey that began on the onset of the 20th century has had moments of intensity as well as other moments of complete neglect. Nonetheless, it has taken the *Eucalyptus* to be nowadays the most extensively distributed species in the world due to its countless uses, its fast growth, and its majestic aspect. It is available in Portugal, Spain, Italy, Ireland, India, Uruguay, Chile, Peru, Argentina, Brazil, Ecuador, Bolivia, Colombia, USA (California), Morocco, Ethiopia and South Africa amongst other countries.

First European and Iberian Plantations

The first plantations in Europe when gardener and botanist Ant. Greichenot, from Paris Botanical Gardens brought ~~its~~ *Eucalyptus* seeds in 1804 had to suffer from adverse climatic conditions. France did not present an adequate climate for its development and thus the farming of the *Eucalyptus* did not have great impact. However, France did play an active role in the spread of the species overseas, mainly to Algeria, Morocco, and Madagascar.

In the beginnings of the *Eucalyptus* journey around the old continent, it was about the middle of the 20th century, the real prophet of the *Eucalyptus* was Ferdinand von Mueller, due to his work and enthusiasm, which he transmitted to many men. He worked as director for the Botanical Gardens in Melbourne from 1852, devoting himself to the study of *Eucalyptus.* He was very prolific with scientific writings and contributed to the creation of the works *Flora Australiensis*. He is said to be the one who showed the qualities of *Eucalyptus globulus* to French Prosper Ramel in his Botanical Gardens in 1854. Enthusiasm was attributed many of the first reforesting initiatives of Ramel, from his return to Europe in 1858, along the whole of the Mediterranean coast, including the south of France, Italy, Corsica, Spain, Algeria, and Egypt.

The first *Eucalyptus* to arrive in the Iberian Peninsula did it doubtlessly through Portugal. It is believed that they were introduced by Carlos Butler to establish a plantation in Vila Nova de Gaia –very close to Porto- in 1829, according to Mendes Almeida in 1918. It is in fact very likely that it was there where the first *Eucalyptus* timber in Europe was created. The reason that preceded this tree due to its spectacular size and medical properties was the cause for small plantations in palace gardens and manors to be established. Some of them have lasted to the present day, as it is the case of the plantation set by baron Massarelos in 1852 in his "Quinta de Formiga" and in Vila Nova de Gaia.

Between the years 1866 and 1870, the *Serviços Hidráulicos* in Mondego and Figueira da Foz in Portugal, planted more than 35,000 eucalyptuses in actions destined to the fixing of soil in Coimbra's environment. Thus, the *Eucalyptus* changed from being a tree to be found in gardens and private estates to have an extensive and generalised forestry use for its protection and production values.

The first reference to the presence of eucalyptuses in Spain is commonly attributed to Fray Rosendo Salvado (Bishop in Nueva Nursia) in 1863; there is an indirect reference (Areses, 1953, pg. 300-301) that places its origin to Fray Rosendo sending some seeds of *Eucalyptus marginata* from Australia to his family in Tui.

Other sources seem to place its entry in Madrid and Barcelona somewhat confusedly. Dr. Pío Font Quer, author of the interesting book *Pharmaceutical Flora in Spain and Portugal,* quotes Texidor in his work *The Renewed Dioscorides* from 1871. Thus, according to this author *E. globulus* was grown in Barcerlona's Farm for medical uses and flourished in 1865, pointing out that it was known in Madrid's Botanical Gardens. This comment refers to Cavanilles' work, which could even have brought some seeds from Paris. However, forester Ernesto da Silva Reis Goes (1977) points out that the eucalyptuses in the Botanical Garden had been planted in 1868, mistakenly placing its entry to Spain on that date.

Figure 4. *Eucalyptus* shaft mapping, as cultivated in private estates in Redondela (Pontevedra) in 1926.
Note over the terrain by the author (Anderson, R.M, 1939, courtesy of The Hispanic Society of America, New York).

However, it is very likely that the *Eucalyptus* first entry in Spain took place at a much earlier date than 1860 and was done through Portugal towards Tui (Pontevedra), since it was then when its use was expanding rapidly in Portugal, and not only as a gardening and ornamental plant but also as a means to protecting the soil. During Ruth Matilda Anderson's photographic tour of Galicia during 1924 and 1926, she photographed some landscapes in the south of Pontevedra (Anderson, R.M., 1939) where an abundance of *Eucalyptus* mapping of great dimensions in private estates could be observed (image 3.2). Moreover, there are singular specimens in Galicia with a documented origin dating between 1860 and 1870 as the *Eucalyptus* in Casa Reimunde (Foz, Lugo, *Eucalyptus globulus*) or in 1884 as O Avó in Chavín (Viveiro, Lugo. *Eucalyptus glubulus)* (Rodriguez-Dacal and Izco, 2003) and in 1885 Paderne's *Eucalyptus* (Betanzos, La Coruña).

Vicente Pardo de Lama cultivated in 1870 several plantations of diverse species of *Eucalyptus* in Galicia. Latterly, in an article published in 1921 by–his grandson Federico Maciñeira, he explain how in spite of the bad name and discredit of its timber during those days, if worked with adequate methods, it meets such prominent conditions that it even exceeds those timbers belonging to the country (Touza, 2002).

Its introduction in Cantabria is due to the dynamic banker and promoter Marcelino Sáinz de Sautuola. This businessperson introduced some seeds, also in 1860, proceeding from the d'Hyères Islands, near Toulòn (Cotes dÁzur). The biggest and oldest *Eucalyptus* in Cantabria can be found in Viérnoles (Torrelavega), measuring a perimeter of 13 m at the base of its trunk and about 50 m in height.

However it may have been, the white *Eucalyptus* found especially favourable climatic conditions in the Spanish Atlantic region and started advancing across its territory. To such extent in 1870, its presence by the river Sor, at the north of the Galician community is cited.

A first reforesting impulse gradually commences with great work done with forestry criteria. In this first season, the biggest reforested areas concentrate above all in the north half of Portugal. The year 1880 can be stressed as their beginning, date in which reforestation works are undertaken in around 600 ha near Abrantes (Portugal). One of the estates, the object of these actions, was curiously christened *Nova Australia*.

One of their first uses and, doubtlessly, one of the most important to take place during this stage, was the restoration or draining of flooded and marshy areas. These flooded areas constituted an important focal point for diseases, which those days, and still today in some countries, were lethal, as is malaria. 23 ha were planted in 1910 with this purpose in Figueira da Foz, in the marsh of *Juncal Gordo*, and in the 1920s in San Vicente de la Barquera, en Cantabria.

Plantations grown to obtain firewood, mining support (pit props) or railroad ties were also important. During the first years of the reforesting initiatives of small significance followed in Huelva. Its use was for railway companies around Rio Tinto. The first big plantation in Spain took place afterwards, in 1912, with *E. camaldulensis* by the Mining and Metallurgy Company Pañarroya (Peñarro 20th centrury ya-Pueblonuevo, Córdoba) in 1,740 ha of a land known as La Garganta, which later on became the property of Papelera del Sur and is one of the most important hunting lands in Spain today.

First plantations in Galicia and reactions from its rural society

Galician's deforested grounds landscape was evidence of the need to begin intense reforestation programmes. During the second half of the 20th century, reforestation acts performed by forestry districts were scarce, hardly going over the hundred hectares of which none was the *Eucalyptus* the protagonist. Perhaps due to a lack of resources or perhaps due to the misunderstandings between public and private properties, conflicts arose that led to the failure of the created masses.

There are several references to the deforestation that Galicia sufferred at the beginning of the 20^{th} century. References to this situation can be found in photographic archives as well as in the press and technical literature of the time. The increase in prices motivated private owners to look for new produce in their lands. Timber market in Galicia found itself shaken by the cease of imports caused by World War I. Besides, the increase in production in the coalmines in Asturias and León caused a rise in the demand for pit-props and railroad ties. This increase in the demand derived into an intensive exploitation of woodlands and a rise in timber prices, which was already a constant since 1890 (Carrera, 1921).

However, politicians were also conscious of the deforestation issue, and in 1918, the Law for Forest Defence dated 24th June was issued to avoid overexploitation. Nevertheless, its success was rather average due to the Forestry Nursery meagre means, since it was scarce and badly paid. In reality, it could be said that the latest motivations politicians had were limited to a tree conservational pretence with an aesthetical and social purpose.

Due to this, private owners chose the fast growth of *Pinus pinaster*, species that mostly became the centre of their interests. Associations, Friends of the Trees Societies and even unions put into action an intense campaign to inform the public through conferences, leaflets, press articles, etc. In 1910 "The *Eucalyptus globulus* and Tree Reforestation" was published (Álvarez, 1910) and in 1913 the Friends of the Trees Society from La Coruña published the monograph "The *Eucalyptus,* instructions for its spread" within the collection "Interesting timbering trees for Galicia". During these campaigns, fast-growing species like pines and *Eucalyptus* were promoted (Balboa López, 1990). Precisely with the purpose of promotion of this concept of reforestation, the spread of the tree becomes institutionalised. In it, planting is organised, etc, as well as other educational activities aimed at children.

With the arrival of Daniel de la Sota (1877-1958) to the presidency of Pontevedra's Council in 1924, a real impulse for institutional reforestation can be observed. De la Sota offers Rafael Areses the necessary institutional support to develop his forestry programme. Pontevedra became the first Spanish province to start a *consortium* among the Estate, the Provincial Council and the local governments in 1927 to defray reforestation costs. Alfonso XIII signed this agreement for cooperation among institutions, which would later be–adopted by other Spanish provinces (López-Torre, 2009).

Areses purpose, as he was a Forestry Engineer, was the reforestation for environmental, social, and economical purposes. In the meantime, De la Sota believed in it as a generator of wealth for the whole province, promoting, thus, its future industrialization.

Nevertheless, neighbouring protests against reforestation followed, as they carried restrictions to cattle entrance and other uses. In spite of the dedication and effort made by so many forest rangers=managers who performed an essential watch and control task, fires were also present during these beginnings. The fact is that a fifth of the 4,583 ha that Pontevedra's Council had reforested between 1929 and 1934 were engulfed in flames.

An important milestone during this period is the installation in 1925 of the Portuguese business CAIMA in Albergaria (north Portugal), which started its production then, although the company had been established in 1878. CAIMA was the first business in the world to use timber from *E. globulus* to make cellulose by means of bisulphite processing.

In this context and already towards the end of the 20s, private initiative did include the *Eucalyptus.* Private initiative interest in reforestation with Maritime Pine (*Pinus pinaster)* due to its fast growth did also increase. The novelty was also that the administration and the very own unions put in place publicity campaigns and campaigns in favour of reforestation directed to farmers and local authorities. Conferences, school workshops, and leaflets were organised to promote fast-growth species pines, *Eucalyptus,* and black poplars.

After the Civil War (1936-1939) we can consider the start of a second period, in which the Forestry Heritage Commission carried out the majority of official reforestations, .This Agency was established in 1939 and refurbished in 1941 according to the new Regime. This great Estate Agency carried out massive reforestations through the consortium, leaning on the management of the neighbouring mountains. The Forestry Heritage Commission had reforested 24,330 ha during its first decade in Galicia, during the period going between 1941 and 1950. Of these, hardly 130 ha were *Eucalyptus,* reason why the *Eucalyptus* cannot be considered the main role-player in public initiative reforestations during this time.

On the other hand, during the period between 1941 and 1971 reforestations carried out by private initiatives in Galicia amounted to at least 322,143 ha (Prada, 1941), especially in La Coruña. During this period, at least 566,000 ha had been reforested together with public initiative, more than 19% of Galician surface. In the 1930s reforestations were going to change the bare and deforested landscape from the beginning of the 20th century.

The rate of *Eucalyptus* plantations also rose gradually and 9,556 ha were accounted for until the year 1975: an average of 380 ha per year. Its use in official programmes was minimal, barely representing 4% of the total of the reforested surface by the administration, mainly the Forestry Heritage Commission. This fact refutes the extended belief that it had been Franco's Regime policy what reforested Galician's mountain with *Eucalyptus.* On the contrary, reforesting actions with this species correspond to private initiative. 80% of planted *Eucalyptus* in Galicia had been planted in private properties.

A frequent criticism regarding reforestation, and especially in this period of maximum activity (1950-1965), said that pines and *Eucalyptus* reforestations were general after the previous removal of the native lush vegetation. This statement lacks real grounds, on the one hand because what was then predominant in Galician's mountains was deforestation, and on the other hand because of the high cost of ploughing and uprooting the grounds and even the technical impossibility to do so at a precise rate. It seems more accurate to think that reforestations were made on farming lands or deforested mountain or scrubland.

Various studies (FAO, 2007) about the origin and causes for deforestation in developing areas indicate that the main reasons were external factors to the forestry sector. Demographic pressure, consumption pattern changes, subsistence agricultural expansion (Africa and Asia), resettlements, agriculture and infrastructure (Latin America and Asia) have over forestry resources that other internal factors in the sector and/or directly controlled over it, and the continuous tendency. Due to this, it is important to produce a historical perspective over deforestation causes to know better and understand this process. It is better and more adequate to analyse processes than to compare "fixed images" as applied statistics may be.

The facts support this, since on the other hand the increase in farming surface from 1860 to 1930 was approximately 150% in 3 of the 4 Galician's provinces (Valdés and Gil, 2001).

The third period starts with a determined bid for the industrialisation of the sector when in Pontevedra they reach the 25th anniversary of their reforestation (1952). The reforestation volume reached allows the proposition of industrialization as an aspiration. This favoured a good welcome for TAFISA (board) and ENCE (cellulose past of the *kraft* type) industrial projects. The building of the facilities for TAFISA began in 1956, and its production two years later.

Perceptions about the Forestry Sector and Attitudes towards *Eucalyptus*

Opinions about the *Eucalyptus* in the rural environment

This change in rural society can be verified by professors González Gurriarán and Figueroa Dorrego's research in 2005 for ENCE; both from the department of Sociology in the University of Vigo. The fieldwork was carried out on a target population of private owners and small forestry service enterprises and considered its diverse socio-economical aspect. This population was named "border agents."

The various agents (forest owners and small business bidders for forest services) were asked about their opinion regarding production of *Eucalyptus* in general terms. 87.4% of them pointed out that they considered such production more beneficial than harmful, and only 6.9% pointed out the opposite, that production of eucalyptuses was more harmful than beneficial.

The four aspects that were most often associated to the forest growth of *Eucalyptus* by those polled were in this order:

- Forest growth of *Eucalyptus* produces employment and favours economical development in rural areas (82,.8%);
- Forest growth of *Eucalyptus* is economically more profitable (64.4%);
- Forest growth of *Eucalyptus* means more reforestations (51.7%); and
- Forest growth of *Eucalyptus* promotes the good care and maintenance of the mountain (47.1%).

The positive economical approach extracted from the opinions of those surveys about the *Eucalyptus* is obvious. It must also be emphasised that the variable "it means more reforestations" is not perceived as initially negative by those polled, but as a natural characteristic of this species.

In relation to mountain preservation in the areas were *Eucalyptus* plantations exist, 60.9% of those polled indicate that it is cared for and preserved, 19.5% consider that it has deteriorated and 18.4% consider that it is the same as always been.

A high percentage of those polled point out that the mountain from which an economical profit is obtained is kept in minimal appropriate conditions; whilst those mountains, which are not considered to be used for clear forest exploitation, are left abandoned by their owners with serious incidence.

Survival of urban myths

With regards to the more concrete case which is society's attitudes towards the *Eucalyptus,* the work carried out in Galicia in 1991 entitled "Bases for the making of a forestry culture divulgation plan" for the *Dirección Xeral de Montes y Medio Ambiente Natural (Consellería de Agricultura Ganadería e Montes, Xunta de Galicia)* will fundamentally be used. In this research, the opinions belonging to teachers of educational centres other than universities regarding those same aspects are collated.

This research provides with substantial and qualified information regarding the arguments that diverse opinion leaders possess and spread, as description and quantification of opinions, attitudes, values, and beliefs; information mainly

derived from the Forest Culture Poll[15] (EFC, May 1991). It also allows for the analysis of the evolution and different views and perspectives that the different parts of Galician society have about the mountain, and especially the reflected attitudes towards the *Eucalyptus.*
With this purpose the results of this poll can be compared with the ones obtained about the border agents' opinions (González and Figueroa, 2005), although these results should be employed here with maximum reservations, even if they contribute to the completion of a more complete and integrated social view. 91% of the population understand that *Eucalyptus* impoverish the soil, as opposed to the 78% of teachers, and only 22% of the population point out that they quite agree or greatly agree with the statement that *Eucalyptus* avoids erosion and creates soil.

The previous questions give an idea of the negative opinion held by the general population regarding this species and the misinformation or partly lack of it existing, since there is a variety of scientific studies which disprove each and one of these "beliefs", which we could say are rooted in Galician's population.

In relation to economical maters, 46% of the population point out that *Eucalyptus* plantation generates less employment than other type of forests, being this percentage high also in teachers' opinion, reaching 43%. That means, around 1 in 2 polled people consider that *Eucalyptus* plantations generate less employment than other type of forest. This is a difficult fact to prove or compare with. In fact, many studies show just the opposite, that is, a bigger capacity to generate employment in comparison with other species.

This supports the idea that the public is not informed sufficiently, in spite of the overabundance of environmental information that present day society has. What's more, at the European level there are many contradictions and controversies in public opinion regarding the forests and the forestry (UNECE, 2003), as it has been highlighted in FAO and UNECE's revision in 2003.

Amongst the main answers given by the European, it is worth noticing the enormous influence that feelings and personal impressions have about what forests are thought to represent. Forests were mainly seen as a symbol of nature. Most reject the statement: "the use of timber helps forests."

A majority has the belief that woodland is diminishing (almost) everywhere. However, national statistics and the MCPFE report "State of Europe's Forests 2003" show that just the opposite is occurring, particularly in Europe. Despite

[15] *For more detailed information chapter 3 of Galician's Forest Plan (1992), Council for Agriculture, Farming and Mountains / Dirección Xeral de Montes e Medio Ambiente Natural, can be consulted. ECF investigation 1991 includes a total of 2570 interviews (sample belonging to a range of over 18s residing in Galicia), 350 pilot interviews to teachers in non-university education, 260 interviews to forest agents and 36 interviews to Local Heads of the Agricultural Extension Service.*

timber being seen as a produce that is environmentally friendly, the connection between forests and forest produce is not established. In addition, of course there is a lesser connection still with forest activities such as felling, processing, and transformation. Only in the Nordic countries is the forest industry curiously seen as having great importance.

Analysis and Conclusions Regarding the Evolution of Perceptions about *Eucalyptus*

How have we evolved from those neighbouring protests, when they systematically set fire to those reforestations, to this society in which the *Eucalyptus* is being grown and is been named "eucalipto do país".

Continuous *Eucalyptus* production and high rate of private initiative plantations has called for a compromise on behalf of the owner with *Eucalyptus* growth. In rural areas, the cultivation of *Eucalyptus* has meant an alternative to the low income in rural society. Far from the monopolistic accusations to the *Eucalyptus* market, Galicia is today, thanks to *Eucalyptus globulus* the objective for many international commerce groups to export their timber. Besides, traditional uses, new drying, and harvesting technologies have consolidated a new path for the multiple use of *Eucalyptus* timber.

Strangely enough, the majority of the urban population in industrialised countries perceives the forest as one of the last refuges in real nature. This conception of the forest has acquired great relevance during the last 30 years as part of that context to return to nature, and has found this argument about conservation and biological diversity a very vast field of expression, which is as fertile as controversial, charged with light and shade.

Environmental groups point to the forest industry as one of the maximum responsible for massive deforestation, especially in tropical countries. In the press, documentaries, and opinion forums, a direct link has been established between environmental risks and forest industry. Consequently, the public opinion perceives the message that the more paper and timber they consume, the more deforestation of the tropical forest there is.

The consumer chooses products based on metal, plastic or cement, which do not have their real environmental costs attached. Timber represents 50% of all the materials used for building. However, it only needs 4% of the consumed energy to transform raw materials into useful products for construction. The other 96% of the energy is consumed by metal, plastic, and cement.

The consequence from these opinions and contradictions becomes true in the market, between the choice of timber products and its replacements. Sadly, it has tremendous social, economical, and environmental consequences. Forest industry needs first to beat this competitive disadvantage timber has before reaching to fight for a market share in competition with other regions, products and business.

On the contrary, forest industry and forest management have acquired ample scientific and technological grounds to the highest level, which allows for a clean and precise administration of a renewable resource. However, this message has not reached society and a negative perception of all forestry, forest-products, and more so forest~~ry~~ industry persists.

Meanwhile, in rural areas, border agents have expressed clear opinions in favour of the cultivation of *Eucalyptus.* Therefore, it is worth noting how these border agents' experience of rural society has derived into a social tolerance to grow this species. "Social acceptance of the results of forest administration is a process of personal judgement and decision with which each individual; compares perceived reality with its known alternatives; and decides whether the real condition is superior or sufficiently similar to the most favourable alternative. If the existing real situation or condition is not considered better, the individual will start a form of behaviour, normally within a group, which will make it possible to change the conditions towards a more favourable alternative"~~,~~ (Brunson, 1996). Acceptability opinions are based in individual perceptions. Perceptions can be influenced by science, experience, knowledge and ethical preoccupations, values, attitudes and beliefs, and its individual relationship with the landscape.

The existing perception will not simply be changed with information regarding forest management and technique or regarding the threats forests suffer from. Some researchers suggest, in fact, that aesthetic judgement, such which is lead by emotions, is very efficient. Therefore, cognitive evaluations regarding the different technical and forestry data that can be produced play a very limited role. People will not necessarily interpret information similarly or will draw the same conclusions about what is more appropriate to do in forest administration (Murray and Nelson, 2005).

A direct witness in this process of social acceptance has been Ricardo Llorente (General Manager in NORFOR, Pontevedra), who has been working in the forest sector for 35 years. Due to his experience and knowledge he has become one of the most qualified and prestigious experts in *Eucalyptus* issues and their market in the Iberian Peninsula. According to him, what has changed the social perception in the rural environment has been the individual perception because of their direct experience and an individual process of comparison between the real known alternatives.

"When I arrived in Galicia in 1975 there was already a myth against the *Eucalyptus* in rural areas […] In small villages, people realised after 10 or 15 years that the catastrophe announced wasn't such and that underneath *Eucalyptus,* bushes, oaks and chestnuts were growing…"

Due to all this, the industry needs to maintain long-term programmes with the purpose of **environmental education** that bring highlight to a positive perception in the minds of the youngest ones. Robert Legg, Director, and CEO in Beaverton, Oregon-based Temperate Forest Foundation pointed out that one of the long-term solutions for public perception problems is education. The 10 year experience with the programme Teachers' Tours this Foundation has proven that only a couple of well planned days in contact with the forest and plantations as well as the factories belonging to the forest industry are necessary to convert a sceptical teacher into an advocate of such industry, as sustainable forest management should be socially acceptable, nature friendly and economically viable. This logic requires a long-term investment.

The forests sector must accept this challenge and earn the trust of the public opinion for society would also support the economical function and the forest exploitation if they see that the foresters claim to be the guardians and wardens of nature (UNECE, 2003). Only thus we will be able to avoid the circumstances by which in Europe forest grow old inadequately with negative and irreversible phenomena for lack of a necessary intense management, when at the same time imports abound.

By means of credible communication, forest industry must transmit to the public that responsible forest management is now a reality. Society can understand that timber is a unique resource, renewable, recyclable, biodegradable, versatile, decorative, and very energetically efficient. This means a benefit not only for foresters, including the very own industry, but also for other stakeholders (J.K. Rawat, Indian Forest Service; Emile Mokiki Wongolo, Secretary General of the African Timber Organization).

References

Anonymous 1913. Árboles maderables interesantes para Galicia. Sociedad de Amigos de los Árboles, La Coruña.

Álvarez González, J., 1910. El *Eucalyptus globulus* y la repoblación arbórea. Imprenta de C. Peón. Pontevedra.

Anderson, R.M., 1939. Gallegan provinces of Spain. Pontevedra and La Coruña, The Hispanic Society of America, New York, 496 pp.

Areses Vidal, R., 1953. La provincial de Pontevedra y la restauración forestal de sus montes. Montes, nº 50, pp. 95-107.

Balboa López, X., 1990. O monte en Galicia, Xerais, Vigo, 359 pp.

Bermúdez Alvite,J., Touza Vázquez,M.C., Sanz Infante. F., 2002. El manual de la madera de eucalipto blanco. Fundación para o Fomento da Calidade Industrial e

Desenvolvimento Tecnolóxico da Galicia, San Cibrao das Viñas, Ourense, Spain, 143 pp.

Brunson, M. W., 1996. "A definition of "social acceptability" in ecosystem management. In M.Brunson, L. Kruger, C. Tyler, S. Schroeder (Eds.), Definig social acceptability in ecosystem management: a workshop proceedings. General Technical Report PNW-369. Portland, OR: U.S. Forest Service.

Calvo de Anta, R., 1992. El eucalipto en Galicia. Sus relaciones con el medio natural. Universidade de Santiago de Compostela, Santiago de Compostela, 211 pp.

Carrera Cejudo, A., 1920. La repoblación forestal, un año en Galicia. Imprenta de Julio Toscano, Madrid, 221 pp.

Dirección Xeral de Montes e Medio Ambiente, 1992. Consellería de Agricultura, Gandería e Montes. Plan Forestal de Galicia. Xunta de Galicia, Santiago de Compostela.

FAO, 2007. Public Perception of Forestry Industry and Environment. Advisory Committee on Paper and Wood Products. Shanghai, China, 28 pp.

Goes, E. 1977. Os Eucaliptos. Ecología, cultura, produçoes e rentabilidade. Portucel, Venda Nova, 367 pp.

González Gurriarán, J. Figueroa Dorrego, P., 2005. Análisis y Diagnóstico Económico-Social de la Actividad de Norfor en los Aprovechamientos Forestales del Eucalipto en Galicia. Universidade de Vigo y Norfor. Pontevedra, 359 pp.

López Torre, R., 2009. De la reforestación de Pontevedra. El gran proyecto de Daniel de la Sota hecho realidad 1927-1958. Tekla, Pontevedra, 245 pp.

Mendes de Almeida, A. 1904. Valorizaço dos terenos incultos, Lisboa, Typ. La Bécarre, 26 pp.

Murray S., Nelson P., 2005. "How the Public Perceives Forestry (and Why It Matters), University of Washingthon.

Prada Blanco, A., 1941. Monte e Industria. O circuito da Madeira en Galícia, Fundación Caixa Galícia, Vigo, 306 pp.

Rodríguez Dacal, C., Izco, J., 2003. Árboles monumentales en el patrimonio cultural de Galicia. Consellería de Cultura, Comunicación Social e Turismo. Xunta de Galicia, Santiago de Compostela, vol2. 820 pp.

UNECE -United National Economic Commission for Europe. 2003. "What do Forest mean for Europeans". (http://www.unece.org/trade/timber/pr/publist/doc%20to%20upload/Europeans%20and%20their%20forests.pdf)

Valdes, C.M., Gil, L., 2001. La transformación histórica del paisaje forestal en Galicia. Tercer Inventario Forestal Nacional, Ministerio de Medio Ambiente, Madrid, 159 pp.

Chapter III

Nursery and Plantation Techniques

Provenance Variation in Germination and Seedling Growth of *Eucalyptus Globulus*

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Abstract

The aim of the study was to evaluate provenance variation on the seedling growth of *E. globulus* sub species *globulus* and its seed germination under nursery conditions. Seeds of *E. globulus* of two provenances from Spain (La Coruña and Huelva) and of one provenance from Ethiopia (Dire) were used in the study. For each provenance, hundred pots (with the sizes of 15cm height and 10 cm diameters), filled in a 2:1:1 ratio of sand, mineral soil and forest soil respectively was used. The 100 pots used for each provenance were sub-divided into four replications, each having 25 sets of seedlings in a block. Seedlings were supervised and managed in the nursery for a total of 90 days. Data on each seedlings root collar diameter (RCD), height, taproot length, number of secondary roots and leaves of each provenance seedling were collected, independently. Germination assessed in a seed labouratory. The results indicated Dire, La Coruna, and Huelva provenances had a germination of 99%, 98%, and 98%, respectively. There was no significant difference in the RCD and tape root length among the provenances. However, there was significant difference in height, number of leaves and secondary roots among the provenances ($P < 0.05$). The LSD test result indicated the seedlings of Dire provenance attained better height, number of leaves and secondary roots as compared with the two provenances of Spain. When the two Spanish provenances were compared with each other Huelva provenance seedlings were vigorous than La Coruna provenance. Therefore, if Spanish provenances are demanded in Ethiopia to establish seed sources for further planting in the country Huelva provenance is recommended.

Keywords: Dire; *Eucalyptus globulus*; Provenance; Seedlings; Spain; Variation

Introduction

Eucalyptus globulus Labill, also commonly known as blue gum, is a forest tree species occurring naturally in Tasmania, Victoria, and New South Wales (NSW), Australia (Brooker and Kleinig 2006). It was one of the first eucalypt species to be both validly named and cultivated within Australia and overseas. *E. globulus* subsp. *globulus* was the first of the eucalypts to become widely known outside Australia and its early successes led to its becoming the most extensively planted eucalypt species in the world (FAO 1979). Its rapid growth and adaptability to a range of conditions is responsible for its popularity (Hillis and Brown 1984). Now days the species is planted widely in southern Australia, Portugal, Spain, Chile and the equatorial highlands of Africa and Latin America for a range of uses including firewood, pulpwood and timber (Eldridge et al. 1993).

E. globulus was introduced into Ethiopia in 1894–1895 directly from Australia and planted in the central highlands of Ethiopia (Pohjonen and Pukkala 1990). Now days, it is amongst the successful introduced plantation species, being quickly adopted by farmers, and widely distributed throughout the highlands of Ethiopia. So far, more than 100 000 ha planted stands of the species are found in the country, and it is currently perceived as an 'indigenous' species among local communities (Pohjonen and Pukkala 1991; Tesfaye et al. 2007). Its widespread is attributed to its fast growth, coppicing ability and less management requirements, the unpalatability of leaves, and its adaptability to a wide range of site conditions (Turnbull and Pryor 1978; FAO 1981). Results of previous species elimination trials in Ethiopia have confirmed *E. globulus* to be the best-performing species in the central highlands, with mean annual productivity of plantations 10-30 m^3 ha^{-1} a^{-1} (Pohjonen and Pukkala 1990).

Although the first introductions of *E. globulus* to Ethiopia were successful, the origins of the provenances of these introductions are unknown (Ethiopian Forestry Action Plan 1994; Davidson 1995). Yet, information on provenance variation of the species to produce quality seedlings is lacking. In this paper, we report the results of variation in germination and seedling growth of *E. globulus* of three provenances (Dire provenance from Ethiopia, La Coruna and Huelva provenances from Spain) in order to help develop a strategy for the production of quality seedling for afforestation/reforestation of degraded lands in Ethiopia. The objective of the study was to evaluate provenance variation on germination and seedling growth of *E.globulus*. It was hypothesized that there is variation in seedling growth and seed germination among the three provenances.

Materials and Methods

Seed germination and seedling growth

For the labouratory germination experiment, a completely randomized design was employed. Each provenance was represented by five replicated Petri dishes each consisting of 20 seeds. The test was run under room temperature. Whatman filter paper was used as a germination media in Petri dishes. The seeds were supplied with distilled water manually. Germination inspection for the seeds was done daily for two weeks. The seedling growth study involved nursery experiment using polythen plastic pots of size 15 cm height and 10 cm diameter in the nursery of Forestry Research Center, in Addis Ababa, Ethiopia. The pots were filled with sand, clay and forest soil in a 2:1:1 ratio, respectively. The seedling pots were arranged in the nursery in blocks that comprised 25 pots each. Each block was considered as an experimental unit or replication for the study, and each provenance had four replications. Seeds of *E. globulus* of the respective provenance were directly sown at 0.5 cm depth in the pots. They were watered manually once a day in the morning. Weeding of seedlings was also done at regular interval. Shade prepared from grasses was used to protect the seedlings against intensive sun radiation. The seedlings growth study in the nursery was made for 90 days.

Data collection

In the seed germination study, data on seed germination were collected daily. Seeds were considered germinated when the radical appeared. Once a seed was recorded as germinated, it was removed from the germination tray to avoid confusion with the newly germinating seeds. At the end of the third month all seedlings were carefully separated from the soil and measured for shoot length, tap root length, collar diameter, and leaf and secondary root numbers. Shoot and taproot length and collar diameter was measured using plastic ruler and caliper, respectively.

Data analysis

Seed germination and seedling growth data were handled, independently. Data were organized in an Excel spreadsheet. Mean values of shoot and taproot length, collar diameter, number of leaves and number of secondary roots of each provenance were calculated in Excel using the statistical data analysis function. Statgraphics 15.2 was used to analyze statistical differences among the provenances and means were separated using Fisher's least significant difference (LSD) procedure at 95.0 % confidence level. The germination rate of seeds were calculated in percentage by dividing the number of germinated seeds of each provenance by number of seeds sown for each provenance and multiplying it by hundred.

Results and Discussion

Labouratory experiments of seed germination results showed that Dire, La Coruna, and Huelva provenances had a germination of 99%, 98%, and 98%, respectively. All the provenances had a high germination percentage that can show their potential in producing viable seeds. The nursery study result showed that Dire, La Coruna, and Huelva provenances had a mean root collar diameter of 0.31 cm, 0.29 cm, and 0.34 cm, respectively (Table 1). Even if it seems that Huelva provenance had a higher root collar diameter (RCD) the F-test statistics ($f_{0.05}$ (292) = 2.44, f_{cal} = 0.089) result did not show a significant difference among the provenances (Table 1).

Table 1. Mean values of seedling parameters assessed for *E. globulus* provenances

Provenance	Mean shoot length (cm)	Total leaf number	RCD (cm)	Root length (cm)	No of secondary roots
Dire	44.3± 3 A	30±2A	0.31±0.03A	10.3±0.7A	15± 1A
La Coruna	38.5± 2.5 B	22±2B	0.29±0.02A	9.9±0.6A	12±1 B
Huelva	43.4± 3C	28± 2C	0.34±0.03A	10.2±0.7A	12± 1C
P in ANOVA	0.026	0.007	0.089	0.68	0.0001

Means with the same letters along the same column are not significantly different at P=0.05

The average seedling height of Dire provenance was 44.3 cm and that of La Coruna and Huelva provenances were 38.5 cm and 43.4 cm, respectively. This result showed that Dire provenance had a higher growth rate than La Coruna and Huelva provenances. The statistical test result also showed a significant differences ($f_{0.05}$ (292) = 0.026, f_{cal} = 3.70) in the height growth of the three provenances ($P < 0.05$), (Table 1). The higher height growth of Dire provenance could be an adaptation to the climate of the area since it has been naturalizing itself in the country over the past 100 years as compared with the two Spanish provenances. It might be also associated with its higher root mass, important for the efficient nutrient, and water absorption. Moreover, its leaf number was higher as compared to the two Spanish provenances that might also contribute to a high rate of photosynthesis, which in turn resulted in a higher growth rate. Although seedling growth is frequently used to evaluate vigorous, it must be used with care, since vigorous in height and seed traits can be influenced by a large number of environmental variables (Nanda et al. 1969). Poor seedling growth in some provenances could be associated with poor genotypes because of differentiation of superior stock through commercial exploitation (Greaves 1978).

A primary root system increases the surface area available for the uptake of water and mineral elements and, with its architecture provides physical support to the developing shoot. Vigorous root systems are as essential as vigorous shoots for growth and development of healthy plants (Silvana 1984). The mean taproot length of Dire, La Coruña, and Huelva provenances were 10.3 cm, 9.9 cm, and 10.2 cm, respectively (Table 1). Although Dire provenance had greater taproot length, the statistical test result indicated no significant differences ($f_{0.05}$ (292) = 0.683, f_{cal} = 0.38) among the provenances (Table 1), $P > 0.05$. Number of secondary roots of Dire provenance was 15, and 12 for both La Coruna and Huelva provenances had 12 and 12 (Table 1). Dire provenance had a higher number of secondary roots than La Coruna and Huelva provenances. The statistical test result also showed a significant difference ($f_{0.05}$ (292) = 0.0001, f_{cal} = 10.48) in the number of secondary roots among provenances (Table 1), $P< 0.05$. Early seedling root growth and development determine the optimum root system throughout the entire life of a plant, consequently affecting growth during this period and potentially leading to optimization of yields (Leskovar and Stoffella 1995; Lynch 1995). It means that higher number of secondary roots of Dire provenance can indicate the species rooting potential intern plays a role for its higher survival and better growth at plantings in the field.

The number of leaves counted in Dire provenance was 30, and that of La Coruna and Huelva provenances were 22 and 28, respectively (Table 1). The statistical test result showed a significant differences ($f_{0.05}$ (292) = 0.0074, f_{cal} = 4.99) in the total number of leaves counted among the provenances, $P< 0.05$ (Table 1The higher number of leafs counted in Dire provenance may contribute to higher photosynthesis potential which later, at plantation level, results higher wood biomass. The root collar diameter of Dire, La Coruna, and Huelva provenances were 0.31cm, 0.29 cm, and 0.34 cm, respectively (Table 1). The statistical test result showed no significant differences ($f_{0.05}$ (292) = 0.089, f_{cal} = 2.44) in root collar diameter among provenances $P>0.05$, (Table 1).

Conclusion

Selection of quality seedlings in the nursery is important for raising fast-growing trees for production of fuel wood and other products. Based on the present study seedlings raised from Dire provenance had a higher number of leafs, secondary roots and growth which indicates its potential as a seed source. Relatively, the seedlings of Huelva provenance were vigorous than La Coruna provenance.

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References

Brooker MI, DA Kleinig. 2006. Field Guide to Eucalypts, Vol. I, South-eastern Australia, Bloomings Books Pty Ltd, Melbourne.

Eldridge K, J Davidson, C Harwood, G Vanwyk. 1993. *Eucalyptus* Domestication and Breading. Oxford University Press. New York.

Hillis WE, AG Brown. 1984. Eucalypts for Wood Production. CSIRO/Academic Press, Melbourne.

FAO. 1979. *Eucalyptus* for Planting. FAO, Rome.

FAO. 1981. Eucalypts for Planting: FAO Forestry and Forest Products Studies 11. FAO, Rome

Greaves A. 1978. Description of seed sources and collections for provenances of *Pinus aribaea* No. 12. Tropical Forestry Paper, Department of Forestry, Oxford University.

Leskovar DI, PJ Stoffella. 1995. Vegetable seedling root systems: Morphology, development, and importance. HortScience 30:1153-1159.

Lynch J. 1995. Root architecture and plant productivity. Plant Physiology 109, 7-13.

MacIsaac SA, VK Sawhney, Y Pohorecky. 1989. Regulation of lateral root formation in lettuce (*Lactuca sativa*) seedling roots: Interacting effects of anaphthalenacetic acid and kinetin. Physiologia Plantarum 77, 287-293.

Nanda KK, AN Purohit, VK Kochhar. 1969. Effect of auxins and light on rooting stem cutting a of Populus nigra, Salix tetrasperma, Ipomea fistulosa and Hibiscus notodus in relation to polarity. Physiologia Plantarum 22(6), 113-20.

Pohjonen V, T Pukkala. 1991. Which eucalypt grows best in Ethiopian highlands?. Biomass and Bioenergy (1) 4, 193-198.

Pohjonen V, T Pukkala . 1990. *Eucalyptus globulus* in Ethiopian forestry. Forest Ecology and Management 36, 19–31.

Silvana N. 1998. Understanding root systems to improve seedling quality. HortTechnology, Italy.

Tesfaye H, G Belachew, H Chris. 2007. Genetic variation in survival and growth of *Eucalyptus globulus* ssp. *globulus* in Ethiopia, Report. Australian Forestry.

Turnbull JW, LD Pryor. 1978. Choice of species and seed source. In: Hillis WE, AG Brown (eds). *Eucalyptus* for Wood Production. CSIRO, Adelaide, Australia, pp. 6–65.

Vegetative Propagation Techniques and Genetic Improvement in *Eucalyptus globulus*

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Abstract

The dispersion of the genus *Eucalyptus* in nature is by seeds. Nevertheless, the interest from breeders to reproduce outstanding trees by cuttings encourages the development and adjustment of techniques for agamic propagation. These techniques may be classified as *in vitro* and *in vivo*, according to the environment in which they take place. While *in vivo* stem cutting are widely employed in *Eucalyptus* mass propagation, *in vitro* techniques are standing by for their use. Cuttings play an important role in tree improvement because they capture desirable genes without recombination as occurs in seed production. The access to clonal culture enhances the possibility of hybrids. *Eucalypus* hybrids have the attractiveness of combining two features in a single individual, each one contributed by one of the parental species. Explorative inter-specific control crosses have been largely undertaken and some combinations of tropical species come up as core genetic material in plantation at commercial scale. In particular, *E. globulus* was acknowledged a recalcitrant species for rooting but in early 1990´s, ENCE changed this qualification and started using vegetative mass propagation of clones in operational plantations. The techniques for rooting cuttings were adjusted first for macro and then for mini-cuttings, thereby generating a production of 6 millions cuttings per year. Vegetative propagation is an accepted tool to achieve great gains in a short time. The deployment of selected clones by ENCE was successful because it almost duplicated pulp wood production yield at rotation age. In advance selection the criteria of wood properties was included. However, these traits are not the only feature of interest, also uniformity in plantation is a valuable advantage for management and wood logging. The clonal strategy needs a well-planned breeding program. Only the support of a broad breeding program guarantees sustainable gains by way of more productive new clones also for the establishment of new markets or identification of new invasive pest or diseases.

Keywords: nursery, cuttings, cloning, clonal forestry

Introduction

Eucalypts are endemic to Australia and few Islands to immediate north (Eldridge *et al.* 1993). Recent taxonomic revision includes more than 700 species in a broad sense (*Angophora*, *Corymbia,* and *Eucalyptus*). Some of the species grow as small shrubs but others as tall trees up to 100 meter height. The genus has distinctive biological features that contribute to give diverse mechanisms of adaptation. Most species are heteroblastic with leaves changing from sessile, horizontal oriented juvenile form to petiolated, vertical oriented adult (Potts 2004). The time of leaf transition is under strong quantitative genetic control (Jordan *et al.* 1999). This leaf change leaves causes differences in anatomy, physiology, chemistry, and impact of susceptibility to pest and diseases, growth and wood properties. After forest fire, many species of eucalypts have ability to resprout from lignotubers or epicormic shoots. Nevertheless, regeneration in nature mainly occurs by small seeds germination and seedlings establishment. Under natural regeneration, the distance of dispersal is very limited. Generally, seeds have no adaptation for dispersal and the force of wind or gravity will carry seeds no greater distance than twice the height of the tree (Cremer 1977). The dispersal constraint can easily be overcome when people move seeds to diverse places around the world in order to develop new plantations. In fact, this has already occurred extensively.

Since *Eucalyptus* was discovery in Australia by Europeans, its seeds have been spread widely and rapidly. By the mid 1800´s, plantings of *E. globulus* were established in Southern Europe and Northern Africa (Penfold and Willis 1961). Nowadays, it is the main eucalypt species cultivated in many temperate part of the world, i.e. Portugal, Spain, Chile (Potts *et al.* 2004). Additionally, *E. grandis* and *E. camaldulensis* have become important components of forestry plantation in many tropical and subtropical areas. First plantations of all these species have being established by seedlings. The importance of eucalypts increased over the time, mainly because of iys potential to supply wood to the cellulose industries. This fact produced a fast process of domestication and genetic program started in many countries (Potts *et al.* 2004). Driving to a point where the interest from breeders to reproduce outstanding trees by rooted cuttings encourages the development and justifies the adjustment of techniques for agamic propagation.

This review highlight the following main points: (i) state of the vegetative propagation techniques developed and adjusted for *Eucalyptus* taking into account the types used for mass propagation; (ii) make focus on ENCE genetic improvement program of *E. globulus* and the experience of cuttings deployment, and (iii) attempt to demonstrate the benefit of encouraging of the use of feasible vegetative propagation tools for deploying successfully advance generation of eucalypts by other programs.

Types of vegetative propagation

Plants have been propagated vegetatively by human since long ago. In some cases, the varieties are reproduced by grafting (e.g. oranges, apples). Others are reproduced by rooted cuttings (i.e. roses, eucalypts). In every case, it is necessary to have a donor plant that contributes a portion of tissues able to generate roots and consequently a new plant. We will focus the attention on rooted cuttings because this is an efficient way to propagate trees in several forest taxa (i.e. *Salicaceas*, *Picea* sp., *Cryptomeria japonica*, *Eucalyptus*). Nevertheless, a revision of other types of vegetative propagation is included. These may be classified according to the environment where the process of propagation occurs, mainly as *in vivo* or *in vitro*. Some techniques are summarized in each of these types in Table 1. The types will be addressed under separate titles; first the section named rooted cutting which include *in vivo* propagation and following the organogenesis and embryogenesis section which are undertaken *in vitro* under complete environmental control in labouratory.

Table 1. Type of vegetative propagation, techniques used and example of species propagated by each technique

Types	Technique	Species applied
in vivo	simple cuttings	*E. deglupta*
	macro cuttings	*E. camaldulensis*
	mini cuttings	*E. urograndis*
in vitro	Organogenesis	*E. dunnii*
	Embryogenesis	*E. globulus*

Rooted cuttings

Cuttings play an important role in tree improvement because they capture desirable genes without recombination as occurs by seed production. Propagation by stem cuttings is a normal practice used in poplars but in eucalypts, only *E. deglupta* has similar simplicity to be propagated without need for rejuvenation. Any attempt further in other species is only worthwhile if there are good genotypes to be propagated that justify the effort. In the 1950´s, first experiments were undertakes in Morocco to develop the technique for rooting cuttings of *Eucalyptus* (Franclet 1956). By the end of the seventies, a few clonal programs began mass propagation of *Eucalyptus* by cuttings such as in Congo (Chaperon 1984) and Brazil (Campinhos and Ikemori 1983).

As starting point, the clonal strategy includes the selection of trees well adapted to the target area for plantation. Early selections chose outstanding phenotypes within existing plantation. For example in Congo, individuals were selected in plantation and reproduced at commercial scale during many years of successive widening of plantation areas (Chaperon 1984). The extent of the success depends on the criteria of selection applied. In the case of Brazil, plantations of *E. grandis* were suffering severe attack of stem canker and the key was to select trees that were resistant to canker (Eldridge *et al.* 1993). In the Southwestern Spain, the limiting factor to the cultivation of *E. globulus* was the summer drought. Therefore, the selection of best drought resistant trees was the key in the clonal strategy (Cañas *et al.* 1994).

In addition to cutting strategy, progress in breeding allows advance generation of clones originated from crosses between top parents with knowledge of their full pedigree as in Brazil (Bertolucci *et al.* 1995). More sophisticated crossing designs involving mono-specific inter-provenances crosses were undertaken aimed to get better results of expected heterotic effects, not always confirmed or with little evidence for significant heterosis as reported by Volker *et al.* (2008).

Clonal propagation and hybrid breeding has become a powerful contribution tool for the improvement of wood quality (Gratapaglia and Kirst 2008) and other adaptation traits. The access to clonal culture enhances the possibility of reproducing *Eucalyptus* hybrids. The control of techniques to reproduce trees by rooting cuttings permits transfers the use of eucalypts hybrids. *Eucalyptus* hybrids have the attractiveness of specific combinations among complementary traits. Therefore, it is possible to combine two features in a single individual, each one contributed by one of the parental species. Simple examples are the hybrids developed for improving the tolerance to biotic or abiotic stresses, or ability to grow under marginal conditions of a high value species, such as *E. globulus*. The germ of this strategy comes from spontaneous putative hybrids detected in Brazil and Congo with the addition of explorative inter-specific controlled crosses being artificially and largely undertaken (Griffing *et al.* 2000). The success was clearly manifested by Bouvet *et al.* (2007) in the evolution from first natural hybrids of *E. alba* x *E. grandis* to the breed *E. urophylla* x *E. grandis.* This strategic work increases productivity from a rage of 10-15 to 15-20 m3/ha/year. Extensive research on hybrids has been done in the last 50 years (reviewed in Potts and Dungey 2004, see examples in Table 2) and has added general knowledge for opening new crossing program for new forest projects.

Table 2 Examples of *Eucalyptus* hybrids combinations exploring different combination traits.

Country	Trait explored	Sp. crossed	Author
Russia	Frost resistant	*E. viminalis*, *E. rubida*	Pilipenka 1969
Australia	Frost resistant	*E. nitens*, *E. globulus*	Tibbits 1986
France	Frost resistant	*E. gunnii*, *E. dalrympleana*	Potts and Potts 1986
Chile	Frost resistant	*E. nitens*, *E. globulus*	Espejo *et al.* 2000
Brazil	Disease resistant	*E. grandis*, *E. urophylla*	Eldridge *et al.* 1993
South Africa	Frost resistant	*E. grandis*, *E. nitens*	
Congo	Adaptation	*E. grandis*, *E. urophylla*	Bouvet *et al.* 2007
Australia	Salt adaptation	*E. camaldulenis*, *E. globulus*	Hardner *et al.* 2010

Some hybrid combinations originated from tropical species come up as core genetic material in plantation at commercial scale. These hybrid combinations were successfully enough to mark the history of hybridization in *Eucalyptus.* The most remarkably are the *E. urophylla* x *E. grandis* in current use for planting in

Brazil, South Africa, Congo and more recently also in China (Mo *et al.* 2003). Another major combination is *E. camaldulensis* x *E. grandis* that combine adaptation to stresses and fast growth. These hybrids succeed in driest environments of South Africa and in central plateau of Brazil. Second generation clones derived from hybridise with *E. globulus*, the top species for wood quality, has allowed a further economic improvement of 20% in the use of wood for cellulose manufacturing in Brazil (de Assis *et al.* 2005).

In vitro organogenesis and embryogenesis

In vitro Eucalyptus propagation dates from the sixties and many references were reporting the feasibility of successful organogenesis propagation and protocols for more than 30 species of *Eucalyptus* (for details see Pinto *et al.* 2010). Nevertheless, no progress for mass propagation was adopted nor transfer to the operation scale has occurred to this day. The process of eucalypt plant regeneration and its protocol were depicted for micropropagate but still seem to be a complex system for operational use. Wilson (1996) mentioned that to produce 30 trees to field trial by macro cuttings or *in vitro* take almost similar time. Occasionally, *in vitro* technique is used for delivery new fresh mother plants to create hedges or stool beds of new clones or for conservation issues.

More recently, the evolution of biotechnological manipulation of forest trees approach for commercial application has appeared. Advances in somatic embryogenesis (SE) have brought mass clonal propagation of top commercial trees closer to reality and resulting in the delivery of millions of pines plants per year. The regeneration process has also been achieved with a few species of *Eucalyptus.* Somatic embryogenesis in *E. globulus* was obtained by *Nugent et al.* (2001) and the protocol has been available since 2002 (Pinto *et al.* 2010).

The effort was more justified in pines because the general difficulties in juvenility to rooting stem cuttings and the delay between the synthesis of the genetic material and the gathering of field results. In addition, SE puts together cryoconservation and posterior propagation facility (perhaps 20 years late). Meanwhile, in eucalypts the feasibility for rooting cuttings and the short term that represent in forestry from generation, evaluation, selection, and propagation is a realistic short cut. Perhaps the huge opportunity for SE of eucalypts will be more associated with the management of genetic modification of clones with a high value. The potential environmental and social impacts of the release of transgenic trees have become a controversial topic that will require more attention if we are keen to use these technologies to their full advantage. The times of the *in vitro* will arrive. Nonetheless, the adaptation for propagation of *Eucalyptus* at commercial scale is still to come.

ENCE experience with *Eucalyptus globulus*

The premier species for the cellulose industry is *E. globulus* because its wood properties and its plantation have been extended in the last half of the century. However, for many years *E. globulus* had been considered recalcitrant for rooting until the experiences developed in the Iberian Peninsula (Wilson 1993; Cañas *et al.* 1994). Today, clones of *E. globulus* are of common use in Spain, Portugal, Uruguay, Chile, and Australia. ENCE Company pioneered in the implementation of clonal varieties at large scale for plantation in Southwester Spain since in the early 1990. The program strategy deliver genetic gains though stem cuttings propagation. The aim of the program was to capture best tree to resist summer drought and consequently the further pest *Phoracantha* sp. The process of selection took place over local land race of *E. globulus*. Almost 2000 adult trees were selected in field plantation, fell it to rejuvenate; the rooting test was undertaken on sprouts of 700 genotypes and about 100 clones tested in field trials across the area target for planting. The result was the generation of 16 clones delivered to operational scale propagation (Cañas *et al.* 1994). This low rate of genotypes with successful rooting ability could be confirmed later by other programs, i.e., England 2007.

After more than two decades of clonal mass propagation by macro cuttings in ENCE, the technique of mini cuttings was introduced by year 2005 following the guidance described by de Assis (2001). Small variants were introduced to adapt the system to our species, environment, and facilities. The process of production include the following activities in different places: (i) the production of coppice material in hedges or mother plants, (ii) the preparation of cuttings in a working area, (iii) the setting of the cuttings to root in shade house, and the final weaning in outdoor nursery.

The main phases are presented separate for macro and mini cuttings. The macro cuttings process maintains the hedges on the ground growing under controlled water-irrigation to keep a balanced nutrition status of the mother plants. Stem are harvested weekly and cuttings from 8 to 10 cm length are prepared including two nodes with the leaf area reduced 50% (Graph 1). Straight away, cuttings are set without hormone application in individual containers with a coconut fiber and peat medium in a shade house under a careful control of the humidity of the air trying to avoid the dryness of the cutting. Depending on the season, cuttings require 4-6 weeks to develop a rooting system able to continue the growth in the nursery without different management that a seedling (3 -4 months).

Mini cuttings differ from macro cutting mainly because the stem is more juvenile (no more than 2 week old) and consist of the full length of the full growth including the apical shoot meristem (see Graph 1). The hedges are intensively cultivated in containers to maintain a perfect control of nutrients and water availability. Despite that, the system of growing the hedges for mini cuttings is more susceptible to the risk of diseases and pest vulnerability than the macro. Each system show some advantages over the other, e. g. mini cuttings root system are better more juvenile and fasciculate than the macro cutting roots; mini cuttings root somewhat faster than macro. In reference to the growth or further development of the plant, no statistically differences arise for diameter and height traits between the two propagation techniques (Oliveira *et al.* 2006).

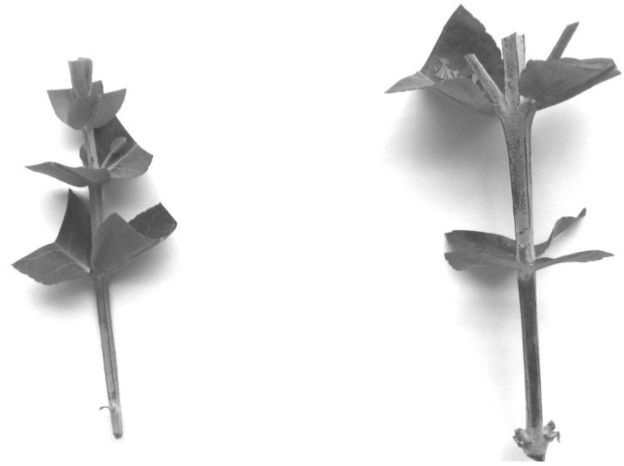

Fig .1. Stem cuttings for propagation (mini cutting in the left and macro cutting in the right side of the picture)

Today, ENCE nursery located in Huelva produces 6 millions of cuttings per year, around 50% are by macro cuttings and the another 50% by mini cuttings. While the breeding program achieved improvement in adaptation traits, other key trait as rooting ability for the program is also in a line of breeding. Studies showed that it is under moderate control genetic (Cañas *et al.* 2004) and selection for rooting has given good results.

Advantages of mass vegetative propagation

The main advantage of adopt selected clones in Spain was demonstrated by their adaptation to drought conditions and resistance to *Phoracantha*. At some location, the gains in final pulpwood production were over 200% compared to seedlings from the land race. From the tree improvement point of view the gains are deploy in a short time compare to the development of seed orchard production, which need reproductive maturation. The turnover of improvement is faster for traits of relative low to moderate heritability, such as drought resistant and *Phoracantha* resistance (Dutkowski 1995; Soria and Borralho 1997, respectively). Another important trait of improvement is wood properties. In advance generation selection it was included in addition to adaptation and growth. However, these traits are not the only feature of interest; there are also other issues of economic impact, such as uniformity of forestry. The advantage of the clonal forestry allows adjust fine practices and management know as clonal silviculture which has impact in harvesting and homogeneity in quality of supply to the pulp mill.

Conclusion

Certainly, vegetative mass propagation in *Eucalyptus* is the trend to move for the future and clonal forestry is turning a profitable forestry model able to supply high-quality biomass for industrial use. Meanwhile, a reduction of pressure on native forest occurs. On the other hand clonal strategy, needs well-planned breeding program of big population size for selection and maintain sustainability in the medium and long term. The deployment of limited number of genotypes increases risk of susceptibility to disease, pest, and changes in the final products. Sustainable gains by way of new clones to renew diversity across ages and space is obligatory. The spread of pest and diseases spread are faster than before and changes in the market or final use of the wood is more dynamic. For this reason, breeders have also to act in response.

References

de Assis TF. 2001. Evolution of technology for cloning *Eucalyptus* in large scale. In: “Developing the eucalypt of the future” CD Proceedings of IUFRO Conference, 10-15 September 2001, Valdivia, Chile.

de Assis TF, GDSP Rezende, AM Aguiar. 2005. Current status of breeding and deployment for clonal forestry with tropical eucalypt hybrids in Brazil. International Forestry Review **7**: 61

Bertolucci F, G Rezende, R Penchel. 1995. Produçao e utilizaçao de híbridos de eucalitpo. Silvicultura **51**: 12-16

Bouvet JM, P Vigneron, A Saya, E Villar, R Gouma. 2007. Age-related trends in genetic parameters in *Eucalyptus* hybrid populations in the Congo: consequences for optimal age of selection. *In:* “Eucalypts and Diversity: Balancing Productivity and Sustainability” CD Proceedings of IUFRO Conference, 22-26 October 2007, Durban, South Africa.

Campinhos E, YK Ikemori. 1983. Nova técnica para a produçao de mudas de essências florestais. IPEF **23**: 47-52

Cañas I, F Soria, G Toval. 1994. Produccion clonal de *Eucalyptus globulus* en la provincial de Huelva. Montes **37**:41-44

Cañas I, F Soria, G Lopez, R Astorga, G Toval. 2004. Genetic parameters for rooting trait in *Eucalyptus globulus* (Labill.). *In:* Borralho NMG *et al.*) (eds). “*Eucalyptus* in a changing world” Proceedings of IUFRO Conference, 11-15 October 2004, Aveiro, Portugal. pp 159-160

Chaperon H. 1984. Influence of propagation by cuttings on the breeding strategy of forest trees. *In:* Barnes RD, Gibson GL(eds). "Provenance and genetic improvement strategies in tropical forest trees" Proceedings IUFRO Conference, Mutare pp 135-148

Cremer KW. 1977. Distance of seed dispersal in eucalypts estimated from seed weights. Australian Forest Research **7**: 225-228

Dutkowski GW. 1995. Genetic variation in drought suceptibility of *Eucalyptus globulus* ssp. *globulus* in plantation in Western Australia. *In:* BM Potts, NMG Borralho, JB Reid, RN Cromer, WN Tibbits, CA Raymond (eds).. 'Eucalypt plantations: Improving Fibre Yield and Quality, Proc. CRCTHF-IUFRO Conf., 19-24 Feb.'. Hobart, Tasmania. pp 199-203

Eldridge K, J Davidson, C Harwood, G van Wyk. 1993. Eucalypt Domestication and Breeding. Clarendon Press, Oxford.

England N. 2007. Tree improvement and cuttings propagation of *Eucalyptus globulus* at Albany Forestry Research Centre. In: The Australasian Forest Genetics Conference, 11-14 April 2007, Hobart, Tasmania. Available at http://proceedings.com.au/afgc/. Accessed in June 2010

Espejo JE, NF England, AR Griffin. 1995. Results of a crossing program with *Eucalyptus nitens* and *E. globulus* in Chile. In: BM Potts, NMG Borralho, JB Reid, RN Cromer, WN Tibbits, CA Raymond (eds). 'Eucalypt plantations: Improving Fibre Yield and Quality, Proc. CRCTHF-IUFRO Conf., 19-24 Feb.'. Hobart, Tasmania. pp 239-240

Franclet A. 1956. Premier travaux d´Amélioration génétique des *Eucalyptus.* Annales de la Recherche Forestière au Maroc **4**: 65-85

Gratapaglia D, M Kirst. 2008. *Eucalyptus* applied genomics from gene sequences to breeding tools. New Phytologist **179**: 911-929

Griffin R, J Harbard, C Centurion, P Santini. 2000. Breeding *Eucalyptus grandis* x *globulus* and other inter-specific hybrids with high inviability – Problem analysis and experience at Shell Forestry project in Uruguay and Chile. In: 'Hybrid Breeding and Genetics of Forest Trees'. (Compiled by Dungey HS, Dieters MJ, Nikles DG). Proceedings of QFRI/CRC-SPF Symposium 9-14th April 2000, Noosa, Queensland. pp 1-13

Hardner CM, M Dieters, G Dale, I DeLacy, KE Basford. 2010. Patterns of genotype-by-environment interaction in diameter at breast height at age 3 for eucalypt hybrid clones grown for reafforestation of lands affected by salinity. Tree Genetics and Genome (in press)

Jordan GJ, BM Potts, RJE Wiltshire. 1999. Strong independent quantitative genetic control of vegetative phase change and first flowering in *Eucalyptus globulus* ssp. *globulus*. Heredity **83**: 179-187

Mo X, S Peng, T Long, W Chen, X Yang. 2003. Important traits and combined evaluation of eucalypt clones. In: Proceedings of the International Symposium *Eucalyptus* plantations, research, management and development (Eds. Wei and Xu) Guangzhou, China. pp 102-110

Nugent G, SF Chhandler, P Whitemn, T Stevensin. 2001. Somatic embryogenesis in *Eucalyptus globulus*. Plant Cell Tiss. Organ. Cult. **67**: 85-88

Oliveira ML, A Xavier, AP dos Santos, HB Andrade. 2006. Efeito da estaquia, miniestaquia, microestaquia e micropropagaçao no desempenho silvicultural de clones híbridos de *Eucalyptus* spp. Revista Arvore **30**: 503-512

Penfold AR, JL Willis. 1961. The Eucalypts. Botany, Cultivation, Chemistry and Utilization. Leonard Hill Limited, London

Pilipenka FS. 1969. 'Hybridisation of eucalypts in the USSR.' Akademiya Nauk SSSR. Botanicheski Institut. Trudy 6th series. Introduktsiya Rastenii Zelende Stroitel'stvd Vol. 9

Pinto G, Y Park, J Loureiro, L Neves, C Araujo, S Silva, C Santos. 2010. Somatic embryogenesis in *Eucalyptus* – An update to 2009. *In:* "Applications of Plant Biotechnology"

Potts BM. 2004. Genetic improvement of eucalypts. *In:* Evans J, Burley J, Youngquist (eds). 'Encyclopedia of Forest Science' J pp. 1480-1490. (Elsevier Science, Oxford)

Potts BM, HS Dungey. 2004. Hybridisation of *Eucalyptus*: Key issues for breeders and geneticists. New Forests **27**: 115-138

Potts BM, WC Potts. 1986. Eucalypt breeding in France. Australian Forestry **49**: 210-218

Potts B, R Vaillancourt, G Jordan, G Dutkowski, J Costa e Silva, G McKinnon, D Steane, Volker P, Lopez G, Apiolaza L, Li Y, Marques C, Borralho N, 2004. Exploration of the *Eucalyptus globulus* gene pool. *In:* Borralho NMG *et al*. (eds). "*Eucalyptus* in a changing world" Proceedings of IUFRO Conference, 11-15 October 2004, Aveiro, Portugal. pp 46-61

Soria F, NMG Borralho. 1997. The genetics of resistance to *Phoracantha semipuntacta* attack in *Eucalyptus globulus* in Spain. Silvae Genetica **46**: 365-369

Tibbits WN. 1986. Controlled pollination studies with *E. globulus* and *E. nitens*. *In:* Griffin R, Volker P (eds). "Proceedings of the ninth meeting of representatives of the Research" Working Group No. 1 (Forest Genetics) of the Australian Forestry Council. Somerset, Tasmania, Australian Forestry Council, pp 125–126

Volker PW, BM Potts, NMG Borralho. 2008. Genetic parameters of intra- and inter-specific hybrids of *Eucalyptus globulus* and *E. nitens*. Tree Genetics and Genome **4**: 445-460

Wilson PJ. 1993. Propagation characteristics of *Eucalyptus globulus* Labill, ssp. *globulus* stem cuttings in relation to their original position in the parent shoot. Journal of Horticultural Science **68**: 715-724

Wilson PJ. 1996. Multiplication rates in vitro and by stem cuttings propagation, and clonal development from *Eucalyptus globulus* seedlings. Forest Science **42**: 415-418

Provenance Variation in Growth Traits and Survival of *Eucalyptus globulus* Labill in the Ethiopian Highlands

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Abstract

Eucalyptus globulus is the most planted tree species in the Ethiopian highlands due to its potentiality to satisfy the wood demand of an increasing population. An optimization of its uses is achieved through the combination of an intensive tree planting in degraded lands together with a higher productivity. The latter can be enhanced through the implementation of tree breeding programs. Growth traits and survival of three different provenances from Spain and Ethiopia were studied. Significant differences among the provenances were observed for one-year survival, with Dire (Ethiopia) and Huelva (Spain) provenances performing in a similar way and better than A Coruña (Spain) provenance. A strong correlation between root collar diameter and height was observed. The poor performance of the seedlings during two years of plantation could be explained by the influence of frost, drought, waterlogging and human error during plantation.

Keywords: Ethiopia, *Eucalyptus globulus*, growth traits, provenance, survival

Introduction

Ethiopia's remaining forest cover is estimated to be diminishing at a rate of 141,000 hectares per year (FAO 2006). This fact together with the high demand for woody biomass from an ever-growing population makes critical the need to increase biomass significantly these days and in the coming future. Scarcity of fuel wood in rural areas compels population to burn dung and crop residues for household energy, thus implying a decrease in agricultural yields, while also causing soil degradation and accelerated erosion (Pohjonen and Pukkala 1990; EARO 2000; Taddese et al. 2003; Berry 2003). Furthermore, approximately 95% of the total demand for wood and woody biomass in rural Ethiopia is used for fuel wood, leaving little woody material for construction and other purposes (MoNREP 1994; EARO 2000). It is in this context that the establishment of plantations on suitable lands becomes necessary not only to meet wood demand and reduce defforestation by decreasing pressures on natural forests, but also to restore

degraded lands and enhance biodiversity (Parrotta 1992; Tiarks et al. 1998; EARO 2000; Jagger and Pender 2003).
However, in order to satisfy the biomass energy demand of the country, 6% of the total usable land area would have to be put under tree plantations by 2014; thus requiring a major land use shift (Böjo and Cassels 1995). In this sense, the choice of the tree species having the best potential for conversion of soil nutrients and water into biomass together with the selection of the planting sites constitutes an important decision-making process. Use of short rotation, high-yield plantations to grow an adequate supply of the renewable resource has several advantages (Marsh 1962; Sedjo and Botkin 1997; Tiarks et al. 1998) and appears to offer an efficient and cost effective solution to Ethiopia's woody biomass crisis (Pohjonen and Pukkala 1990; Jagger and Pender 2000).

Results on both indigenous and exotic species trials conducted in the Ethiopian highlands showed that for this specific area, under most conditions, the genus *Eucalyptus* is the most efficient converter of energy into biomass (Newcombe 1989; Pohjonen and Pukkala 1990; Stiles et al. 1991). More specifically, *E. globulus* is the best-performing species, with mean annual productivity of plantations between 10 and 30 m^3 ha^{-1} in poor site classes (Pohjonen and Pukkala 1990). Suitable sites for establishing these plantations are degraded, low oportunity cost lands, which are in good supply (Pohjonen and Pukkala 1990; EARO 2000; Jagger and Pender 2000).

E. globulus was introduced to Ethiopia as early as the 1870s and initially established around major towns in order to supply fuel wood for urban population (Bristow 1995, reference there in Jagger and Pender 2000). Nevertheless, it was not until 1985 that the establishment of large-scale plantations started (Pandey 1995). Nowadays, *E. globulus* is the prevailing characteristic feature of the rural landscape in the Ethiopian highlands and it is a very important part of smallholder livelihood (FAO 2009). As a matter of fact, *E. globulus* is almost perceived as 'indigenous' among local communities (Pohjonen and Pukkala 1990; Hunde et al. 2007) who have exhibited a strong preference for this species (Jagger and Pender 2003). In this regard, Pojhonen and Pukala (1990) stated that *E. globulus* is the most important plantation species in Ethiopia. The species has characteristics that suit ideally to the requirements of wood users, to the prevailing ecological, economic, and social conditions of the country.

Despite the aforementioned significance of the species to Ethiopia, information on the genetic status of the local populations is limited. Although the first introductions of *E. globulus* to Ethiopia were successful, their provenance origins and genetic base are unknown and probably sub-optimal, since there has not been a systematic selection and use of the best-performing provenances. Likewise, there could also be a high degree of inbreeding in the developed land races[16] (MoNREP 1994; Davidson 1995).

The use of genetically based geographic variation is the first step in tree breeding when assembling a suitable base population for future generations of selection, crossing and genetic improvement (Eldridge et al. 1994). In other words, provenance research should be given highest priority at the outset of any program of forest tree improvement (Callaham 1963).

In this study, *E. globulus* provenance trial consisting of 3 provenances from Spain and Ethiopia was established at Gefarsa, located in the central highlands of Ethiopia. The objective of this study is threefold: (a) to assess the variation in growth traits and survival among the provenances, (b) to evaluate correlations between growth traits, and (c) to select the most suitable provenances for further plantation establishment. The present study can be considered as a starting point to perform a *E. globulus* long-term breeding program, which is of great importance in Ethiopia. Its result may have a practical implication in raising and managing *E. globulus* plantations in the Ethiopian highlands with better seed and planting material and eventually improving their productivity.

Material and Methods

A provenance test was established in June 2008 with seedlings of *E. globulus* of 3 different provenances, namely Huelva (Spain), A Coruña (Spain), and Dire (Ethiopia). Geographic attributes of the provenances are provided in Table 1.

Table 1. Geographic data of *E. globulus* provenances tested in the field trial established at Gefarsa, central highlands of Ethiopia.

Provenance code	Provenance name	Latitude	Longitude	Altitude (m)
P1	Dire (Ethiopia)	38º 54'E	9º 11'N	2756
P2	Huelva (Spain)	6º 54'O	37º 16'N	19
P3	A Coruña (Spain)	8º 25' O	43º 22'N	58

The trial was carried out at Gefarsa, 18 Km west of Addis Ababa (latitude 38° 38' E, longitude 9° 4' N, altitude 2,545 m). The mean annual rainfall varies, but the 5 decades mean average 1931-1979 was 1,225 mm, 95 % of which was received from June to September (FAO 1982, reference therein Hunde 1999). The site is almost flat with reddish brown clay-loam soil (Murphy 1968, reference therein Hunde 1999).

[16] *For practical purposes the terms 'provenance' and 'land race' will be used as synonyms, employing them indistinctively to describe any genetic material of trees with a specific origin.*

Five-month-old potted seedlings raised in the nursery of Forestry Research Center (Addis Ababa), were planted in the field in a completely randomised design (CRD). 45 plots, 15 for each provenance, were established. Each plot comprised 100 trees planted at a spacing of 2 x 2 m. The spacing between plots was 4 m. After the establishment of the trial, some parts of the terrain were covered with abundant recruitment of *Cupressus lusitanica* and weeds covered its total area, existing a strong competition for water, sunlight, and soil nutrients. The experiment was first established in June 2007. Nevertheless, survival rate was almost null after one year. The cause of seedling mortality was assumed frost damage. Lack of belg rains could have also influenced growth and survival of the seedlings. Then, the experiment was repeated in June 2008, after uprooting the remaining 2007 *E. globulus* plants.

Traits assessed were survival (%) at age of 17 months, just after 1 year since the establishment of the seedlings in the field, and root collar diameter (RCD) (cm), height (m) and survival (%) at age of 29 months, after 2 years. Aleatory samples of selected seedlings from each plot were measured.

All data were tested for normality with the Shapiro-Wilk test and with plots of residuals. Independence and homoscedasticity were verified using lag-1 autocorrelation functions, Bartlett, and Levene's tests, respectively. The assumptions about normally distributed data could not be met regarding seedling survival. Hence, percentage survival was subjected to arcsin square root transformation before analysis of variance. The analysis of variance for growth traits (height and RCD) was carried out at the individual tree level, while survival was evaluated on plot means. Significant differences were further analyzed using Tukey's honestly significant difference (HSD) test.

The following mixed model was fitted to the data:

$$Y_{jkl} = \mu + provenance_j + plot_k(provenance_j) + \varepsilon_{jkl}$$

Where Y_{jkl} is the observed trait value of the l^{th} individual seedling of j provenance in k plot, μ is the grand mean, $provenance_j$ is the fixed effect of provenance j, $plot_k(provenance_j)$ is the random effect of plot k within provenance j and ε_{jkl} is the residual variation; j=1...J, J=3 (J is the number of provenances), k=1...K, K=45 (K is the number of plots), l=1...L (L is the number of trees per plot). In order to evaluate seedling survival, the term $plot_k$ $(provenance_j)$ was removed.

Correlation between growth traits was measured by the Spearman rank correlation coefficient. STATGRAPHICS Centurion XV Version 15.2.05 was the statistical program used.

Results and Discussion

Survival percent after one year of the establishment of the seedlings in the field was relatively low, with a mean of 38.2%, irrespective of provenances. Despite the overall low percent, survival differed significantly ($P < 0.01$) among the provenances. However, neither growth traits nor survival percent after two years of planting showed significant differences (Table 2). Dire and Huelva provenances showed similar survival in the first year of plantation and higher than that of A Coruña provenance.

Although traits evaluated in the second year of plantation did not differ significantly among the provenances, some tendencies can be observed. Huelva provenance attained maximum RCD, height, and 2-year survival means (1.80 cm; 1.40 m; 19.2%). Minimum RCD (1.55 cm) and height (1.29 m) were both registered for Dire provenance, and minimum survival was recorded for A Coruña provenance (11.9%). Many of the seedlings of the trial suffered from dieback and and resprouted. The resprouts may be the cause of the the relatively low means of RCD and height for all the provenances. 25% of the total number of seedlings had individual values of these traits lower than 1.0 cm and 1.0 m and 50% of them, lower than 1.6 cm and 1.5 m. In general, the two Spanish provenances showed better growth performance than the Ethiopian one, while in terms of survival Dire and Huelva provenances showed comparable values, higher than that of A Coruña provenance.

Tabla 2: Mean (standard error), range, coefficient of variation and F test results for measured attributes of *E. globulus* provenances at Gefarsa

Provenance	Growth traits		Survival (%)	
	RCD (cm)	Height (m)	1st year	2nd year
Dire	1.55 (0.11)	1.29 (0.07)	43.9a (0.2)	16.7 (0.2)
Huelva	1.80 (0.12)	1.50 (0.08)	44,6a (0.2)	19.2 (0.2)
A Coruña	1.79 (0.14)	1.40 (0.09)	26.7b (0.2)	11.9 (0.2)
Grand mean	1.71 (0.05)	1.40 (0.03)	38.2 (0.1)	15.8 (0.1)
Range	4.20	2.70	72.0	46.0
CV (%)	55.9	42.2	44.3	64.4
Provenance F value	1.65 ns	1.82 ns	5.96**	1.55 ns
Plot(provenance) F value	2.48***	2.16**	-	-

*Means with different letters were significantly different; *P < 0.05; **P < 0.01; ***P < 0.001; ns P > 0.05.*

The high coefficient of variation and range in the data analyses revealed the existence of high variability in the variable attributes studied, especially in survival percentage. This may indicate the existence of high probability for further selection among the provenances.

RCD and height were found to have a strong positive correlation (r = 0.934, P < 0.001), demonstrating the possibility of substituting measurement of one of the attributes with the other/indirect selection for one trait based on direct selection for another. (Table 3).

Table 3: Spearman correlation coefficient (r) among the measured growth traits of *E. globulus* provenances at Gefarsa

	RCD	Height
RCD	1.000	
Height	0.934***	1.000

****P < 0.001*

The absence of clear differences in the performance of the provenances could denote the absence of genetic differences among these tested provenances. Nevertheless, the overall poor survival and growth exhibited by the seedlings may imply the existence of external factors influencing on the expression of these traits for all the provenances. Such factors might be frost, drought, waterlogging, and/or failure in planting. Competition due to the presence of weeds and recruitment of *Cupressus lusitanica* and occasional presence of livestock could also have been influential. *E. globulus* is frost sensitive (Potts and Sava 1989; Skolmen and Ledig 1990), especially one- or two-year-old seedlings and resprouts (FAO 1979; Skolmen and Ledig 1990), with critical temperatures of -6ºC or -7ºC (Turnbull and Pryor 1978; Elridge et al. 1994). Sellers (1910) affirmed saplings die at -5ºC. Frost related mortality of the species has been reported in Ethiopia when established in regions with mean annual rainfall up to 1200 mm but affected by unusual dry years, particularly on shallow soils (FAO 1979).

Water stress is also known to be one of the main factors that restrict the productivity of eucalypts in natural and managed stands, even in areas considered favourable for its growth (Beadle et al. 1995). For instance, after a 20-year period of good performance, *E. globulus* trees planted in Nairobi arboretum (mean annual rainfall: 838 mm), Kenya, failed due to four consecutive years of low rainfall (1928-31) (Streets 1962, reference there in FAO 1979). Hence, adverse climatic conditions (extreme minimum temperatures, lack of rains) affecting the area at least since the establishment of the first trial in June 2007 (National Meteorological Agency 2007, 2008, 2009a, b, c, 2010a, b; Zappacosta and Robinson 2009), could be the cause of the high mortality rate and growth inhibition of the aerial part of the seedlings. On the other hand, seedling clusters were detected within the plots of the trial. This could be a result of the presence of microsites of relatively longer duration of waterlogging in the trial area, as observed after its establishment. Unfavourable heavy rains over the trial site were also reported by National Meteorological Angency (2007, 2008, 2009c, 2010a). Although *E. globulus* grows well on a wide range of soils, it requires good drainage (FAO 1979; Skolmen and

Ledig 1990; Bell 1999). Furthermore, effects of adverse climatic conditions on plants, as those referred, are multiplied by negative effects of the soil where they occur (FAO 1979). This spatial pattern could also be a consequence of human error during plantation, since seedlings were not planted in a systematic way by a team formed by both trained and non-trained workers. The analysis of variance showed significant differences in plot nested in provenance term of the employed model for RCD ($P<0.001$) and height ($P<0.01$), which confirms the spatial heterogeneity of the trial site.

Presence of recruitment of *Cupressus lusitanica* and weeds could have influenced the performance of the seedlings due to competition for nutrients, water, and/or sunlight. Finally, although grazing animals do not eat *E. globulus* trees (Pohjonen and Pukkala 1990), trampling has a negative effect on seedling survival. Skolmen and Ledig (1990) declared they should be excluded from young plantations.

To sum up, although significant differences among the provenances for one-year survival were found, we can conclude that the trial has not been efficient enough in revealing differences between Spanish and Ethiopian provenances. It must be pointed out that other differences could have appeared by managing the trials properly through time. On top of it, age of trees should also be considered since early selection for breeding and deployment usually occurs between 4 and 6 years of age (Borralho et al. 1992; McRae et al. 2003) and traits were evaluated at 2 years of age. Establishing other trials under different environmental and edaphic conditions might reveal significant differences among the provenances. Yet, the genetic resources established in this trial if managed to maturity can still contribute to widen the genetic base of *E. globulus* in Ethiopia, an important aspect due to the possible high degree of inbreeding in provenances developed in the country.

Conclusion

The results obtained from this trial evidenced significant differences among the established provenances in survival for the first year of plantation, revealing similar values for Dire and Huelva provenances, both higher than A Coruña provenance. However, they did not show significant differences for either growth traits or two-year survival. Over all the seedlings of all the provenances performed poorly. We recommend the study to be replicated in different agro-ecological areas of the country in order to evaluate accurately genotype-environment interactions for growth traits and survival. Nonetheless, the introduction of the two new provenances from Spain by itself helps in broadening the genetic base of *E. globulus* in the country. Plantation forestry efforts related to strong tree improvement program in *E. globulus* should be undertaken not only to broaden the mentioned genetic base through promotion of conservation of the species by adding new provenances, but also to improve the productivity of the plantations of this species in the Ethiopian highlands.

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References

Beadle CL, JL Honeysett, CRA Turnbull, DA White. 1995. Site limits to achieving genetic potential. In: Potts B M, Borralho N M G, Reid J B, Tibbits W N, Raymond C A (eds.), Eucalypt Plantations: Improving Fibre Yield and Quality, Proceedings of CRCTHF-IUFRO Conference, CRC for Temperate Hardwood Forestry, Hobart, 325-330.

Bell TD. 1999. Australian Trees for the Rehabilitation of Waterlogged and Salinity-damaged Landscapes. Australian Journal of Botany, 47(5), 697-716.

Berry L. 2003. Land degradation in Ethiopia: Its extent and impact. Commissioned by the GM with World Bank support, pp. 25. Retrieved from http://www.fao.org.

Böjo J, D Cassells. 1995. Land degradation and rehabilitation in Ethiopia: A reassessment. AFTES Working Paper 17. The World Bank, Washington DC, pp. 48.

Borralho NMG, PP Cotterill, PJ Kajnowski. 1992. Genetic control of growth of *Eucalyptus globulus* in Portugal. I. Genetic and phenotypic parameters. Silvae Genetica 41: 39-45.

Callaham RZ. 1963. Provenance research: investigation of genetic diversity associated with geography. In: Unasylva, 18(2-3), 73-74. Food and Agriculture Organization of the United Nations, pp. 2-12.

Davidson J. 1995. *Eucalyptus* tree improvement and breeding. Ministry of Natural Resources, Development and Environmental Protection, Forestry Research Centre, Addis Ababa, pp. 96.

EARO. 2000. Forestry Research Strategic Plan. EARO (Ethiopian Agricultural Research Organization), Addis Ababa, pp. 99.

Elridge K, J Davidson, C Harwood, G van Wyk. 1994. *Eucalyptus* domestication and breeding. Oxford University Press, Claredon Press, Oxford, pp. 312.

FAO. 1979. *Eucalyptus* for planting. FAO Forestry series 11. FAO, Rome, pp. 667.

FAO. 2006. Global Forest Resources Assessment 2005. Progress towards sustainable forest management. FAO Forestry Paper 147. FAO, Rome, pp. 320.

FAO. 2009: *Eucalyptus* in East Africa. The socio-economic and environment issues. FAO Sub-regional Office Eastern Africa, Addis Ababa, pp.40.

Hunde T. 1999. Effect of different site preparation methods on growth and survival of *Eucalyptus globulus* Labill. at Gefersa, Ethiopia. Ethiopian Journal of Natural Resources 1(2): 251-258.

Hunde T, B Gizachew, C Harwood. 2007. Genetic variation in survival and growth of *Eucalyptus globulus* ssp. *globulus* in Ethiopia. Australian Forestry, 70: 48-52.

Jagger P, J Pender. 2000. The role of trees for sustainable management of less-favoured lands: The case of *Eucalyptus* in Ethiopia. EPTD Discussion Paper 65. EPTD, IFPRI, Washington DC, pp. 81.

Jagger P, J Pender. 2003. The role of trees for sustainable management of less-favored lands: the case of *Eucalyptus* in Ethiopia. Forest Policy and Economics 5, 83–95.

Marsh EK. 1962. The introduction of fast growing exotic tree species to meet the timber requirements of developing countries. In: Papers, UNSAT Conference, Geneva, pp. 6.

McRae TA, LA Apiolaza, GW Dutkowski, RJ Kerr, DJ Pilbeam, MB Powel, B Tier. 2003. TREEPLANT-A genetic evaluation system for forest trees. In: 27th Southern Forest Tree Improvement Conference, Stillwater, Oklahoma.

MoNREP. 1994. Ethiopian Forestry Action Plan. (EFAP). The Challenge for Development. Final Report. Vol. II. MoNREP (Ministry of Natural Resources and Environmental Protection), Addis Ababa, pp. 95.

National Meteorological Agency. 2007. Kiremt 2007. Seasonal Agrometeorological Bulletin, National Meteorological Agency Agrometeorological Bulletin 17 (26).

National Meteorological Agency. 2008. Bega 2007/8. Seasonal Agrometeorological Bulletin, National Meteorological Agency Agrometeorological Bulletin 18 (3).

National Meteorological Agency 2009a. Bega 2008/9. Seasonal Agrometeorological. Bulletin, National Meteorological Agency Agrometeorological Bulletin 19 (3).

National Meteorological Agency. 2009b. Belg 2009. Seasonal Agrometeorological Bulletin, National Meteorological Agency Agrometeorological Bulletin 19 (15).

National Meteorological Agency. 2009c. Kiremt 2009. Seasonal Agrometeorological Bulletin, National Meteorological Agency Agrometeorological Bulletin 19 (27).

National Meteorological Agency. 2010a. Bega 2009/2010. Seasonal Agrometeorological Bulletin, National Meteorological Agency Agrometeorological Bulletin 20 (3).

National Meteorological Agency. 2010b. Belg 2010. Seasonal Agrometeorological Bulletin, National Meteorological Agency Agrometeorological Bulletin 20 (15).

Newcombe K. 1989. An economic justification for rural afforestation: The case of Ethiopia. *In:* Scharamm G, JJ Warford (eds.). Environmental management and economic development. Johns Hopkins University Press, Baltimore, London, pp. 117-138.

Pandey D. 1995. Forest resources assessment 1990. Tropical forest plantation resources. FAO Forestry Paper 128, Rome, pp. 95.

Parrota JA. 1992. The role of plantation forests in rehabilitating degraded tropical ecosystems. Agriculture, Ecosystems and Environment 41, 115-133.

Pohjonen V, T Pukkala T. 1990. *Eucalyptus globulus* in Ethiopian forestry. Forest Ecology and Management 36, 19-31.

Potts BM, M Sava. 1989. The crossability of *Eucalyptus globulus*. *In:* Gibson GL, AR Griffin, Ac Matheson (eds.). Breeding tropical trees: Population structure and genetic improvement strategies in clonal and seedling forestry. Proceedings of the IUFRO Conference, Pattaya, Thailand, November 1988. Oxford Forestry Institute, Oxford, pp. 420-422.

Sedjo RA, D Botkin. 1997. Using forest plantations to spare natural forests. Environment 39(10), 14–20, 30.

Sellers CH. 1910. *Eucalyptus,* its history, growth and utilization. AJ Johnston Company, Printer, Sacamento.

Skolmen RG; TF Ledig. 1990. *Eucalyptus globulus* Labill. Bluegum eucalyptus. In: Burns R; B Honkala (eds.). Silvics of North America: 2. Hardwoods. Agriculture Handbook 654. US Department of Agriculture, Forest Service, Washington DC, pp. 299-304.

Stiles D, V Pohjonen, F Weber. 1991. Reforestation: The Ethiopian experience, 1984-1989. Technical Publication Series 4. UNSO (United Nations Sudano-Sahelian Office), New York, pp.27.

Tadesse G, D Peden, A Abiye, A Wagnew. 2003. Effect of manure on grazing lands in Ethiopia, East African Highlands. Mountain Research and Development 23(2), 156-160.

Tiarks A, EKS Nambiar, C Cossalter. 1998. Site management and productivity in tropical forest plantations. Occasional Paper 16. CIFOR (Center for International Forestry Research), Bogor, pp.11.

Turnbull JW, LD Pryor. 1978. Choice of species and seed sources. *In:* Hillis WE, AG Brown (eds). Eucalypts for wood production. CSIRO, Australia, pp 6-65.

Zappacosta M, I Robinson. 2009. Special Report. FAO/WFP Crop and Food Security Assessment Mission to Ethiopia, Phases 1 and 2: Integrating the crop and food supply and the emergency food security assessments). FAO, WFP, Rome.

Seed Origin, Seedling Raising, Plantation Techniques and Tree Improvement Practices on *Eucalyptus* Species in Ethiopia

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Abstract

Ever since the introduction of the Australian tree to Ethiopia towards the end of the 19th century, *Eucalyptus* plantations became popular in the country. The objective of this paper is to highlight on *Eucalyptus* species seed origin, seedling raising, plantation techniques and tree improvement practices in Ethiopia. Area coverage with eucalypts is expanding. It is now 250,000 ha. Plantations are mainly found in, around large settlements, cities and towns, villages, and on farm boundaries and riverbanks including woodlots planted by peasant associations and some blanket plantations established by the government and NGOs. The first establishment is by planting seedlings on a new site followed by coppice regeneration. Repeated coppice regenerations are practiced and rarely uprooted. Depending on site characteristics, seedling and coppice plantations can be harvested in 5-7 years. If the objective is to grow large poles and timber, the time taken to harvest has to be longer. *Eucalyptus* harvest is often dictated by market price and owners' preference for quick income. All parts of the plant fetch attractive prices in large settlements. The number of people involved in *Eucalyptus* development and utilization in the country has not been reported. However, the farmers a substantial amount of cash income to farmers. *Eucalyptus* is so versatile that one might not imagine construction without it. It means that almost all necessities have been fulfilled with *Eucalyptus* wood. With regard to environmental protection, one of the most important roles of utilizing *Eucalyptus* wood is the reduction of pressure on the natural vegetation, and if that was not the case, all the natural forests would have gone by now. Eucalypts are also important in controlling soil erosion by water including the role *Eucalyptus* trees play for shade and shelter. Another role of *Eucalyptus* plantations practiced fostering indigenous species such as *Juniperus procera*, *Podocarpus falcatus*, *Olea,* and other native species under its canopy. Eucalypts grow faster and take large amount of moisture but this is not unique to the species, there are tree species, which are more demanding, for instance pines, and as to *Eucalyptus,* the loss of moisture most probably might have been compensated by the volume of wood produced in the short term. Nonetheless, *Eucalyptus* plantations have changed the landscape of Ethiopia, so also the energy and construction industries.

Key words: Nursery practice, plantation techniques, provenance trial, seed origin, tree improvement

Introduction

Eucalyptus species were introduced to Ethiopia towards the end of the 19th century. Soon after the introduction, eucalypts had earned acceptance by the growers in which some of them like *Eucalyptus globulus* have unique characteristics-that it is not browsed by livestock, higher survival on marginal soils, rapid growth rates, straight bole form and coppicing ability after felling are among the good qualities why eucalypts have been widely planted. These qualities have encouraged farmers to plant *Eucalyptus* on available sites.

The two eucalypts, *E.globulus* and *E.camaldulensis* have practically covered the major agroecolocgical zones of the country, in wet and dry highlands, mid-altitudes. In Ethiopia *E.globulus* grows from about 1900-2800 m and above; while *E. camaldulensis* grows 1200 to 2800 m (Azene, 2007) and strives well over a wide range of soils in a rainfall.

Eucalypts are important in Ethiopia, where they are used for fuel wood, building poles, transmission poles, fence posts, sawn wood for boxes and crates, fiberboard and particleboard, (FAO, 1979). The species is also used for windbreaks and shelterbelts. Considered valuable for erosion control, amenity, roadside planting, and environmental protection since it is wind firm, and has a wide spreading dense, lateral root system. Other uses include leaf oil, honey, parquet flooring, veneer, and furniture.

Results of the early trials were encouraging where some of these plots have been used as sources of seed for more trials and large scale planting. Plantations of other eucalypts apart from *E. globulus* and *E. camaldulensis* have been less significant, because the two eucalypts have already been popularized that users are not eager to plant. After 100 years, *Eucalyptus* plantations are relatively healthy and productive with rare complaints coming from users.

Seed Origin and Distribution

Almost all *Eucalyptus* species seed introduced to Ethiopia had directly or indirectly their origin in Australia. Davidson (1995), suggested that the early introductions notably those 15 eucalypts selected by Mondon-Vidaillhet (French railway engineer), were probably chosen for their availability from North African-Mediterranean region, having been introduced there from Australia during the 19th century. No new introductions were made until 1967 under the sponsorship of Chilalo Agricultural Development Unit (CADU), where plantations were established at the Project Centre at Asela. Some 35 species were tested, in unreplicated plots (Davidson, 1995). The sources of tree seeds were from 178 origins, from stands in Ethiopia (Wonji area), South Africa, Tanzania, and Australia.

Based on previous gains, further introductions of *Eucalyptus* aimed at diversifying the species choice for different agro-ecologies and uses have been made by some organizations at different times: (i)CADU (Chilalo Agricultural Development Unit) 1967-1971 introduced some 35 species and were planted in the Project Centre at Asela in arboretum style, (ii) FRC (Forestry Research Centre) 1975 introductions single or in some case several plots with basic plot area of 0.25 ha and space replicated at Menagesha- Suba, Hamulo, Belete and Yerer. All were not planted in common in those sites owing perhaps to pre-screening of species as related to specific requirements, (iii) FRC 1986 introduction consisted of 39 species and provenances. Among the total dispatch 16 were new to Ethiopia, these were to be planted in eight agroecological zones, but only five have been covered and (iv) There had been *Eucalyptus* introduction of 37 species by the then Alemaya College of Agriculture, which was established in an arboretum in its campus, and the other is at Holeta where *E.globulus* and *E.saligna* were planted along with several species of other families.

Un-replicated trials continued in 1975 by the then Research/Silviculture Unit of the Forestry and Wildlife Conservation and Development Authority (FAWCDA) at Hamulo (near Shashamene), Menagesha (western part of Mount Wochecha), Yerer and one at Belete in Kefa administrative region. According to Davidson (1995), only *E. bosistoana*, *E. citriodora*, *E. ficifolia*, *E .leucoxylon* and *E. pilularis* were added to the CADU list. The seed sources included those from Australia (New South Wales, Queens land), Tasmania, Holland (Busum Holand), Tanzania (Lushoto Tanzania), and from Japan.

Another 16 new species of the total 39 were among those introduced for the Australian Development Assistance Bureau (ADAB) sponsored trials. During the 1987 and 1988 planting seasons, FRC succeeded in establishing trials in five out of eight different site categories envisaged in the original experimental plan.

Nevertheless, *Eucalyptus* species introductions by different institutions and at different times show species overlap, i.e. some species were investigated commonly, and it appeared that there had not been a nationally coordinated effort in the type of species selection for introducing. Established tree seed sources in Ethiopia by FRC have been indicated in Table 1.

Table 2: Established *Eucalyptus* tree seed sources

Species	Location	Area (ha)	Planting year
Eucalyptus globulus+ Juniperus procera	Arjo, Wollega	1.6	1989
E. globulus, P.radiata, Cupresus lusitanica	Gefersa	16	1948
E. grandis, E.globulus, P. patula,P. radiata, + Juniperus procera	Holetta	16	1948
E. globulus	Ilala Gojo, (Holota)	16	1982
Eucalyptus grandis	Duna, Arsi	2	1978
Eucalyptus viminalis	Elena, Arsi	11	1978
Eucalyptus citriodora	Yirgalem	3.3	1979
Eucalyptus citriodora	Sekela Mariam, Gojam	4	1986
Eucalyptus citriodora	Wondo Genet	2.1	1992
Eucalyptus saligna	Wolkite	4	1988
Eucalyptus deglupta	Aman, Mizan Teferi	0.05	1987
Eucalyptus camaldulensis	Mankusa	11	1983
Eucalyptus regnans	Asela	2	1978

Propagation Techniques

In Ethiopia, usually, the initial establishment technique is by means of planting seedlings either bare-rooted or containerized. Attempt was made in the 1980's to propagate *E.globulus* by cutting using hormones, but poor rooting and survival of cuttings had discouraged the research work.

Direct sowing, for example, by farmers in Awi Zone, near Bure where the farmers had to manage 40,000 seedlings/ha has been used in some cases. This is very dense, and appeared difficult to manage. They had their own argument for their choice; they would apply singling at sapling stage and use the small stems for fuel wood. This practice would continue until the required pole size and number have been achieved. It seems the farmer is maximizing production from his plot of land. However, the forester may criticize this practice.

The other method of propagation is to let *Eucalyptus* (eucalypts that have coppicing ability) coppices grow after harvest. The farmer usually allows all sprouting coppices on the stools to grow and rarely does thinning to reduce competition; if he does, he would earn some income or can use the small stems for cooking. The dominant coppice stems attain the required size in 5-7 years depending on site condition and there could be as many as 3-5 small diameter poles per stool. This system of coppice management has the advantage of bypassing seed purchase, rising of planting stock in the nursery and the establishment expenses that must be met in conventional silvicultural practices.

Seedling raising

Nursery practice

The objective of forest nursery is to produce good quality plants as cheaply as possible. It means producing sturdy seedlings with a well-balanced root and shoot and with a well-developed fibrous root system (Forestry Commission, 1978). For the nursery practice the following are important: Availability of sufficient water, seedbed preparation, soil mix for seedbed, soil mix to fill polythene tube (usually forest soil: sand in the proportion 3:2 can be varied) and seedlings can be raised bare rooted or potted

Seed sowing and germination

Sowing density is important and depends on the species being sown and the viability of the seed. Mixing *Eucalyptus* seed with soil ensures uniform distribution when directly sown. Proper mixing of small amount of seed with large amount of soil helps to avoid concentration of seed in one spot/area, while sowing. The soil is usually taken from the same spot where the seed is to be sown. The second method is sowing the seed with the chaff and the purpose is the same as above.

Labouratory tests for *E. globulus, E. citriodora, E. camaldulensis, E. grandis,* and *E. saligna* show that there is no need for pre-treatment of seeds of these species. The test duration for all was 14 days except *E. citriodora* that took 21 days (Leulseged Demelash and Girma Balcha, 1999). After germination, tending operations are necessary, such as shade, weeding, watering, root pruning, pest, and disease control measures.

Pot size determination

Conventionally pot size ratio is 2:1 (circumference to height) or 1: 1.5 lay flat plastic diameters to height. In practice, in the highland and wet areas 8 cm lay flat can be used while in the lowland and hot environment up to 12 cm lay flat is appropriate. The larger pot size can retain sufficient nutrients and water where the growth and physiological activity is much higher. Conventional, no special treatment was required to raise seedlings.

Generally, seedlings in the Government and Non-government Organizations are produced in plastic pots. Using appropriate size and quality plastic pot is determined by the economic level and availability on the market. In developed countries, the required amount of water, moisture, and soil structure is availed in a plastic pot that assumes the normal medium. Under Ethiopian condition, small and uniform cylindrical plastic tubes are used. Root coiling jeopardizes the growth and development of the lateral roots if the right plastic pot has not been used. Up until early 70's planting was carried out without removing the plastic tube that resulted in hampering the development of both lateral root and the tap root system and formed girdling that subsequently resulted in leaning tree, which would be liable to wind, throw.

Eucalyptus coppice

Eucalypts, especially the two widely planted species (*E. globulus* and *E. camaldulensis*) have good coppicing abilities. This is why they are preferred by Ethiopian farmers. The coppicing ability of the two species is interesting that gave the plant the highest acceptance by the farmers even in free grazing farming system where animals contribute the largest share in plant loss. Coppicing ability is not affected by the following factors: (i) *Eucalyptus* is evergreen; there is no dormancy in the plant life, (ii) Eucalypts coppice if cut along the entire bole height, there will be coppices at the nodes and (iii) In the life time of *Eucalyptus* from seedling, sapling and subsequent stages of development, the stump can coppice and grow indefinitely.

Tending Operations

Planting site preparation and planting techniques

Planting site preparation trial was established at Gefersa in the outskirts of Addis Ababa with treatments: complete cultivation, furrow cultivation, spot hoeing, and pitting. There was an increase in survival rate with increase in site preparation intensities. The complete cultivation gave higher survival compared to the rest of the treatments. The other treatments were not significantly different from each other. Complete cultivation of site was found to be the best treatment for the establishment of *E.globulus*, Figure 2 (Tesfaye Hunde, 2003).

E. globulus and *E. camaldulensis* can easily survive on marginal soils; this advantage has been responsible for small and large scale planting throughout the country. In semi-arid areas and degraded highlands, planting site preparations employ different approaches. In semi-arid areas, the objective is to conserve moisture around the plant; and in degraded sites is to conserve the soil by checking erosion caused by run-off. Various methods were tried at Meki (east Shewa) and Degem (north Shewa) using sunken hole, half moon, mulch and conventional pits, (Mebrate Mihretu and Belay Gebre, 2005). The results showed significant differences indicating that sunken hole is appropriate in semi-arid areas and half-moon for degraded lands (Mebrate et al. 2006).

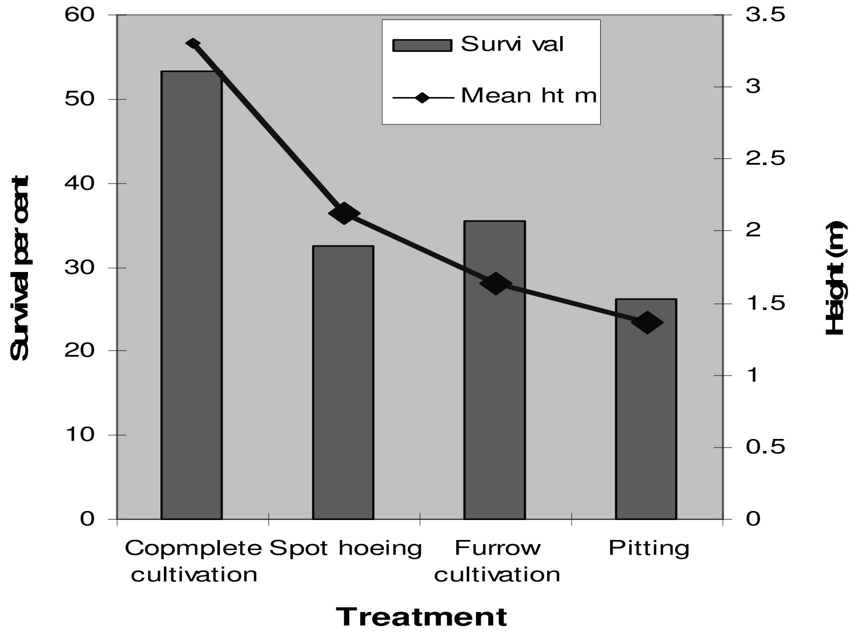

Figure 1: Impact of different site preparation on the performance of *Eucalyptus globulus* at Gefersa (Tesfaye Hunde, 1999).

Spacing of plants

Though 2m x 2m and 2.5m x 2.5m and 3m x 3m have been recommended for spacing; depending on the objectives for planting; often times, 1m x 1m, 1m x 1.5 m, 2m x 2m, 2.5 x 2m, and 2.5 x2.5m have been practiced. However, none of them so far was analyzed in terms of financial returns for preferring one method to the other. The farmer strictly speaking does not appear to follow one type of pacing; however, it is common in many areas that he plants seedlings ranging from 4,000 to 10,000 seedlings per hectare and he has his own convincing argument. Government owned plantations usually adopt 2m x 2m or 2m x 2.5m, and in early research practices 2m x 2m including 2.5m x 2.5m was observed. In most cases, the objective is to produce small diameter poles for construction and fuel wood.

Weed competition

Unlike other exotic species, such as pines, *Eucalyptus* cannot stand root competition. Thus, the planting site has to be free from weeds. Many studies have been made in Australia on competition from weeds and the effect on growth. Root length density at soil depth ranging from 0-10, 10-20, 20-30, 30-40 and 40-50 cm averaged approximately 33, 7.5, 5, 3 and 1.5 (Nambiar and Sand,1990). The orientation of roots confined in shallower depth, which will make the degree of competition higher in newly established young seedlings and that, occupies the shallower depth of the soil profile.

Weed control is beneficial to survival and performance in *Eucalyptus* planting. *Eucalyptus* cannot stand root competition. In Australia over 50% of the farmers use herbicides, cultivation, mulching with the other method of direct planting by spade tree planter etc. Even direct planting has an effective weed control, (Dechassa, 1994). Survival was over 75% in the dry sites of Victoria. The same paper compares and contrasts that the weeds of Australia are so thin that *Eucalyptus* evolved through weak root competition compared to Ethiopia where competition with coach and Kikuyu grasses is harmful. Currently, farmers in Ethiopia are ploughing repeatedly to make the planting site weed free. Around Addis Ababa Blue Gum is successfully established by competent inversion and burial of the aggressive competing grasses. The sub-soil despite low organic matter supported successful establishment and growth of *Eucalyptus.*

Performance of *eucalyptus*

In the past, *E. globulus* was considered as the fastest growing and was taken as a standard against which other species are compared; observations have later revealed that it was not always true, for in some sites like Belete; the performance of *E. globulus* ranked fourth in the *Eucalyptus* series. At Hamulo, a trial site not far from Shashemene, E. *globulus* has outperformed all the rest including E. *saligna* and E. *grandis*, and this is in agreement with the FAO (1979) observation (Figs. 2, 3 and 4)

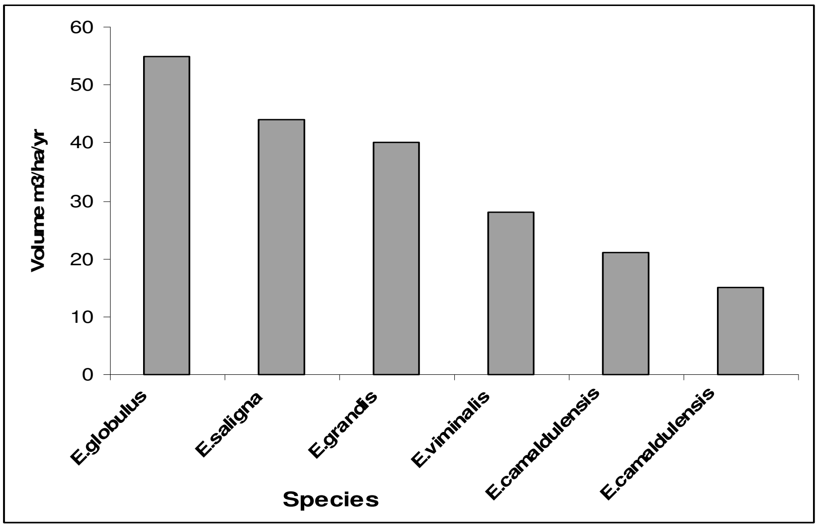

Figure 2: Volume increment of some eucalypts at Hamulo, age10 years (Hamulo- ltitude: 800m; Rainfall: 970mm). Source: Davidson, (1995)

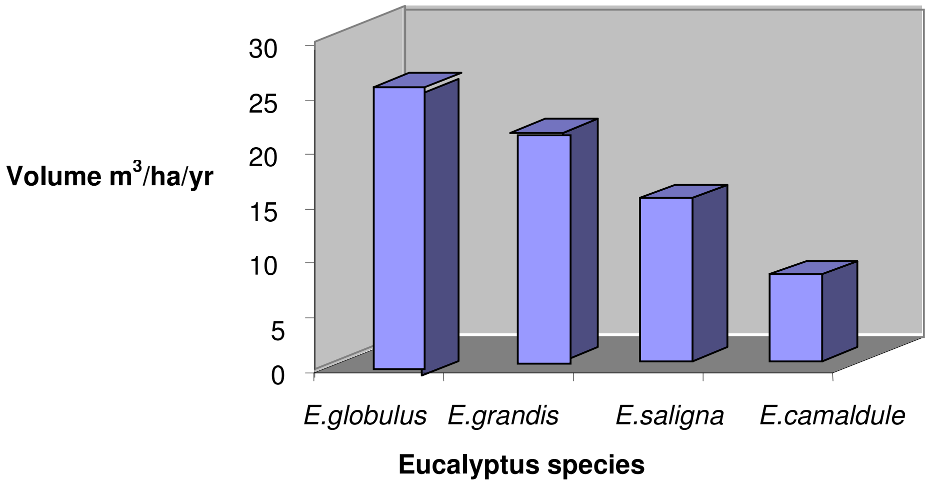

Figure 3: Volume increment of some eucalypts at Menagesha, age10 years (Menagesha-Altitude: 2400m; Rainfall: 1050mm). Source: Davidson (1995)

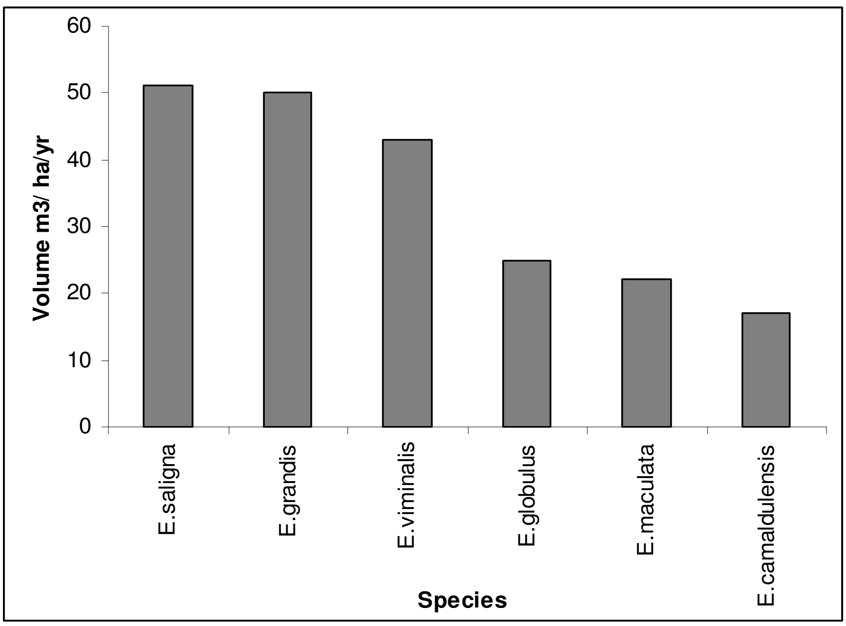

Figure 4. Volume increment of some eucalypts at Belete, age 10 years (Belete-Altitude: 1900m; Rainfall: 1550mm). Source: Davidson, (1995)

Rotation age

According to Daba Wirtu and Piechen Gong (2000), for all site classes and management settings, the optimum rotation for the seedling rotation is between 5 and 11 years with 10% discounting rate. Similarly, the optimal rotation age for the coppice stand was in the range of 6 to 10 years with the same discount rate.

In most cases, the optimal financial rotation age has followed the fertility status of the sites in both seedling and coppice stands. The optimal financial rotation is shorter in site class I that is the most fertile planting site, followed by site classes II, III, and IV. The study revealed that planting more *Eucalyptus* trees per hectare showed higher financial returns. Accordingly, planting 4440 plants per hectare has shown the highest financial return among tested planting densities 1660, 2500 and 4440 plants per ha.

Pukkala and Pohjonen (1989) reported that in Ethiopia the volume growth (CAI) of a seedling stand is most rapid at the age of 10 years. MAI is at its maximum at the age of 18 or 19 years. This rotation length thus, gives the maximum wood production in a seedling stand. The maximum annual increment is 44 m^3/ha in site class I, 29 m^3/ha in site class II, 17 m^3/ha in site class III and 9 m^3/ha in site class IV. In coppice stand, the volume growth is rapid already during the first years because of the great numbers of stems and the existing root system. The greatest annual increment reaches its maximum 5 years earlier than in a seedling stand at the age of 14 years.

The wood is useful for pulp, fuel, and round timbers. Plantations are cut on a coppice rotation of about 8-12 years, (there are intermediaries depending on site condition and the owners judgment for early/late harvest dictated by circumstances for generating income, usually 5-7 years coppice rotation), normally, only 2-3 times. In Ethiopia, where uprooting is not commonly practised, many coppices have been grown without regard to diminishing production before replanting.

Farmers in the Southern Nation and Nationalities have adopted the natural management system of stump burning for the last 60 years. There are places around Dembidolo, in Western Wollegga where such practices have been experienced for the last 70 years (personal observation).

Provenance Trials

Provenance research is an important phase in tree improvement processes. Research results revealed that there are variations between and within provenances. The programme enables to identify variations among provenances of a species with a wide range of natural occurrence.

The Forestry Research Centre aware of the existence of different seed source/provenance, the growing demand for improved propagation material and research information had established provenance trials of exotic and few indigenous species. The research programme also included internationally coordinated provenance trials with the purpose to test provenance suitability in selected tropical and some sub-tropical countries prior to recommendation for domestication, commercialisation, and large-scale production of each species.

The early provenance trials

In Ethiopia, the programme started in the late 1980's with *Eucalyptus camaldulensis* (11 provenances) the first to have been tested in July 1978, in Tigray at a locality called Mynebri; in Wollo at Negusgale, July 1980 and in 1981 at Dakalole in Shewa located near the shore of Lake Langano. As to the first two trials there is doubt if there was any design, but at Dakalole it is certainly no design or replication. It appears that the foresters then were convinced with the idea that, there was no need for replication or any type of design and depended only on the survival per cent for selecting provenances.

Recent provenance experiments

Among the introduction of 1986, and those species suggested for planting by Turn Bull and Pryor at Aman (Bench- Maji Zone), consisted of *E. grandis* with 3 provenances, *E. cloeziana* 2, *E. tereticornis* 2 and *E. urophylla* 1. Those species suggested by the same experts for planting at Didessa in Wollega, consisted of 5 provenances of *E. camaldulensis, E. microtheca* had 2, *E. largiflorens* 1, and *E. alba* was represented by a single provenance. There were differences between provenances, some differences were significant, but others were not.

Early in 1992 provenance experiments of *Eucalyptus grandis,* (13) and *Eucalyptus saligna* (11) were tested in Wondo Genet College of Forestry. Species provenance tests revealed that there are no significant differences between provenances of *E.saligna* (Tesfaye Hunde et al. 2002). Provenances of *E.grandis* showed significant differences in stem diameter and branch thickness. Where there are significant differences of the seed origins, the implication is that their diversity can be further investigated to improve desirable qualities of the species. Superior provenances are to be promoted to the growth trial and finally to be planted on larger plots for a full rotation known as pilot plantation or simply plantation trial. At this stage, seed from these trees in the plantation phase are ready for dissemination for further test. Generally, the genetic variations among provenances need to be maintained for future tree improvement. Hence, stands of the provenance trials should be protected in *ex-situ* in order to revisit their origin for breeding regardless of their performance in the initial phase.

Of all eucalypts as stated earlier, *E .globulus* and *E. camaldulensis* have been widely planted in Ethiopia. This was appropriate for initiating tree improvement programmes for the two widely used eucalypts.

Eucalyptus globulus, one of the earliest eucalypts to be named, it was also one of the first to be distributed widely as an exotic. It was given the common name "blue gum" and the term "gum tree" entered common usage to refer to all eucalypts (Davidson, 1995).

The best-known ssp. *E.globulus* ssp.*globulus* occurs naturally mainly in Eastern Tasmania. Its early success in the survival rate and other advantage over several other eucalypts in Ethiopia according to Davidson (1995), were aided by the unpalatable properties of the juvenile foliage.

Plantation yields of ssp. *globulus* is very high on the most favourable sites in other parts of Ethiopia (30-33 cubic m/ha/yr stem wood overbark) while the norm in other countries is lower (10-20 cubic m/ha/yr).

Tree improvement

Eucalyptus globulus* ssp *globulus

With FAO/UNDP assistance, the Forest Research Centre in Ethiopia has been able to join these collabourative efforts and had received 299 parent trees of *E.globulus* representing 52 provenances, mainly well-documented sources from the 1988 collections (Davidson, 1995). These and other collections were used to establish large progeny trials, which are currently the basis of selection, breeding and vegetative propagation. Seed orchards were established at Ilala Gojo near Holeta for *E. globulus* and Mankusa for *E. camaldulensis* (collected from 405 parent trees). Both species seeds originated from Australia, *E. globulus* with 299 open pollinated families and one landrace collected in Ethiopia were tested (Tesfaye Hunde et al. 2007). Nine years after planting more than 61% of trees had survived, with breast height diameter (dbh) 16.4 cm and height 21.2 m. Significant differences in survival, height and dbh were found.

In Ethiopia, the strategy is to use this seed to establish separately a base population and a combined progeny trial and a seed production area. In the progeny trial the best families would be selected for retention and the remainder removed before seed production commences. There would be an opportunity later to select elite trees within the best families for clonal propagation. The strategy would also encounter the widely held suspicion that the genetic base of the two most widespread species now found in Ethiopia was small and potential for inbreeding was great (Davidson, 1995).

With regard to *E. globulus* trial at Illala Gojo, trees have hardly produced seed after 20 years or so. The alternative strategy is to try clonal propagation from the best progenies based on their performance.

Currently, seed for commercial planting is collected from trees occurring along roadsides in several places such as Sululta, Sendaffa, Legedadi, Asela and scattered trees found around houses and farms in Arsi region and elsewhere.

The existing source of seed is unsatisfactory for several reasons:

- the origin and size of the base population is unknown,
- the parent trees are of unknown genetic quality,
- mating may be between related individuals leading to inbreeding depression,
- trees spaced out in a single line (such as roadside trees on the way to Sendafa) are more likely to set selfed seed because of fewer available nearby pollen contributing parents than there would in a block.

Eucalyptus camaldulensis

The River Red Gum is most important inland hardwood species in Australia. The tree is valuable for many purposes including honey, shelterbelts, sawnwood, railway sleepers, and charcoal. The species is the widest ranging of the eucalypts in Australia, extending across the continent east to west and from about 12^0S to 38^0S latitude. Unnecessary

E. camaldulensis is one of the most widely planted eucalypt species in seasonally dry climates particularly in dry tropical Africa. Like *E. globulus, E. camaldulensis* was one of the 15 eucalypt species first introduced to Ethiopia in 1895. According to Davidson (1995), much of the *E. camaldulensis* now growing in Ethiopia seems to be hybrid with *E. tereticornis* and it is uncertain whether it was already a hybrid when introduced or hybridization occurred later.

Breeding strategy: It was decided to use a family selection strategy similar to that of *E.globulus* ssp. *globulus*. The difference is that the families come from within a single provenance region rather than across the natural range of the species as was the case for *E. globulus* ssp. *globulus*.

With the collabouration of the Australian Tree Seed Centre, CSIRO, Canbera and assistance from FAO/UNDP, a special collection from 405 trees was made from the Petford region and introduced to Ethiopia. *E.camaldulensis* seedlings were planted in randomized complete block design in a 4-tree-plot with 10 replications at Mankusa (west Gojam). The progeny trial was later thinned to provide a seed production area (seedling seed orchard). This was planned to provide seed for planting from about the year 1995 onwards, though seed is now being collected; it has not been disseminated as scheduled for wider planting.

Conclusions and Recommendations

Provenance trials nearly always will be necessary but growth trials or a species proving phase may not be necessary where species have been in use for many years, e.g., *E.globulus* ssp. *globulus* and *E.camaldulensis.*

There is a requirement for the *ex-situ* conservation of the full-set of gene resources for both

E. globulus ssp. *globulus* and *E. camaldulensis* brought to Ethiopia, by maintaining a separate base population line. Otherwise, part of the original genetic base would be lost when the progeny trial is thinned to make a seed production area.

Over one hundred years after introduction, *Eucalyptus* plantations are relatively healthy and produced large amount of wood with rare complaints about the plant from users. This has been perhaps the reason why researchers have not made substantial effort for investigation. Since *Eucalyptus* plantations appeared relatively free of diseases except the juvenile leaves attacked by aphid and when replaced by adult leaves, the aphid disappear; there has not been a push for investigation. However, previous research efforts on *Eucalyptus* diversification should continue in case the current widely planted species would have been attacked by pests in the future.

Nevertheless, despite a number of uses, considerable complaints have been voiced by individuals, environmentalists, and politicians who claim that *Eucalyptus* has been responsible for draining off moisture from the surrounds and turning the site dry, hence, causing moisture deficit leading to environmental imbalance. Research has to solve such long-standing issue and advise the stakeholders where and which species among the lot are appropriate to plant at a given area to end the controversy.

It is high time that promoters of the *Eucalyptus* as causing hazard to the environment considered the dependence of the society on *Eucalyptus* wood, or suggest other options that could substitute *Eucalyptus* as a source for energy and construction in Ethiopia.

The disadvantages of *Eucalyptus* may be improved through interplanting/mixed plantation e.g. with leguminous tree species which will compensate for lost nutrients. Obviously, leguminous plants have the ability to fix atmospheric nitrogen and make it available to plants.

References

Azene Bekele-Tessema. 2007. Useful trees and shrubs for Ethiopia. Identification, propagation and management for 17 Agroecolgy Zones. Technical Manual No.6. *In:* Bo Tengnas, Ensermu Kelbesa, Sebsibe Demissew, Patrick Mandu (eds). World Agroforestry Center Nairobi. Kenya.550 pp.

Daba Wirtu, Piechen Gong. 2000. The economics of growing *Eucalyptus globulus* Labill. on the highlands of Oromiyaa Ethiopia: with special reference to Intoto and Chancho areas. Ethiopian Journal of Natural Resources, Vol. 2 No. 2: December 2000.

Davidson J. 1995. *Eucalyptus* tree improvement and breeding. Ministry of Natural Resources Development and Environmental Protection, Forestry Research Centre, Addis Ababa.

Dechassa Jiru. 1994. Possible alternative trees on farms: an assessment of farmers' perspectives on tree planting in Ethiopia and western Victoria, Australia. A Thesis presented in partial fulfillment of the requirement for the Degree of Master of Forest Science, Faculty of Agriculture and Forestry, University of Melbourne.

FAO.1979. *Eucalyptus* for planting. Food and Agriculture Organization of the United Nations, Rome.

FAO. 1988. The eucalypt dilemma. Food and Agriculture Organization of the United Nations, Rome.

Forestry Commission. 1978. Forestry Practice. Her Majesty's Stationery Office, London.

Forestry Research Centre. 1986. Growth of some forest trees in Ethiopia and suggestions for species selection in different climatic zones. Research Note Number 2, Addis Ababa.

Leulseged Demelash, Girma Balcha.1999. Labouratory Tests for Forest Seeds. Ethiopian Agricultural Research Organization, National Tree seed Project, Addis Ababa.

Mebrate Mihretu, Alemu Gezahegne, Belachew Gizachew. 2004. Early survival and height performance of some Australian species in field trials at Didessa, western Ethiopia. Ethiopian Journal of Natural Resources, Vol.6 No. 2: 253-263.

Mebrate Mihretu, Belachew Gizachew, Mesfin Mulugeta. 2002. Survival and growth performance of some *Eucalyptus* species/provenances in elimination trial at Aman, southwestern Ethiopia. Ethiopian Journal of Natural Resources, Vol. 4 No.1: 97-106.

Mebrate Mihretu, Belay Gebre. 2005. The effect of planting site preparations on the establishment of *Casuarina equisetifolia, Eucalyptus camaldulensis* and *Melia azedarach* in the semi-arid area, at Meki. Ethiopian Journal of Natural Resources, Vol. 7 No.2: 2005.

Nambiar EKS, R Sand. 1990. Understanding and managing competition foe water and nutrients in forest. CSIRO Division of Forestry, School of Forestry, Melbourne University, Australia. pp. 1-15.

Pukkala T, V Pohjonen. 1989, Yield models for Ethiopian highland *Eucalyptus,* United Nations Sudano-Sahelian Office, Addis Ababa, Ethiopia 53 p.

Tesfaye Hunde Belachew Gizachew, Chris Harwood. 2007. Genetic variation in survival and growth of *Eucalyptus globulus* ssp. globulus in Ethiopia. Australian Forestry 2007, Vol. 70, No.1, pp 48-52.

Tesfaye Hunde, Dagne Duguma, Belachew Gizachew, Dawit Mamushet, Demel Teketay. 2006. Growth and form of *Eucalyptus grandis* provenances at Wondo Genet, Southern Ethiopia.

Tesfaye Hunde, Dawit Mamushet, Dagne Duguma, Belachew Gizachew, Demel Teketay. 2002. Growth and form of Provenances of *Eucalyptus saligna* at Wondo Genet, Southern Ethiopia.

Tesfaye Hunde. 1999. Effect of different site preparation methods on growth and survival of *Eucalyptus globulus* Labill at Gefersa, Ethiopia. Ethiopian Journal of Natural Resources, Vol.1 No. 2: 251-258.

Webb DB, PJ Wood, JP Smith, GS Henman. 1984. A guide to species selection for tropical and sub-tropical plantation. Unit of tropical silviculture. Commonwealth Forestry Institute. University of Oxford. Tropical forestry papers No. 15. 2nd edition, Revised, 84-256 pp.

Chapter IV

Plantation Management: Silviculture and Harvesting

The Effect and Phytoaccumulation of Chromium at Seedling Stage of *Eucalyptus camaldulensis* in Ethiopia

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Abstract

Cleaning of chromium-contaminated sites using chemical and physical techniques is the most challenging task. Then alternative remediation and cleaning up techniques such as phytoremidiation should be outsourced. A pot culture experiment was conducted in the glasshouse at Holetta Research Centre; Ethiopia. The aim of the trail was to study the impact of Cr on seed germination, seedling quality and growth of *Eucalyptus camaldulensis* species and to establish in which parts of the plant the metal is stored for an eventual use of phyto-stabilization and/or phytoextraction purpose to remediate tannery effluent contaminated site. Both biologically stable oxidation state of Cr (trivalent) as $Cr_2(SO_4)_3.6H_2O$ and hexavalent as ($K_2Cr_2O_7$) at four concentration levels (0, 10,100, 1000 ppm) were used as treatment. The growing media was prepared by mixing 3:3:1:1, forest soil, local soil, manure, and sand respectively. Before sowing, the media were mixed in appropriate proportion, moistened, sterilised and finally filled into polythene bags of 16 x 20 cm diameter/height, respectively. The pots were taken into the greenhouse and laid out in completely randomised design (CRD) with three replications, and then the seeds were directly sown onto polythene bags.Among the concentration levels used, the highest germination value (18.1) was recorded at 10 ppm of hexavalent chromium followed by (14.4) in the control of the same species. However, the lowest germination value (3.6) was recorded at 1000 ppm of hexavalent chromium followed by (8.1) of 1000 ppm for trivalent Cr species respectively. Seed germination of *Eucalyptus camaldulensis* was also reduced to 22.9 % at 1000 ppm hexavalent Cr as compared to 97.92 % at the control. Besides, concentrated Cr (VI) application at 1000 ppm was too severe and resulted in complete failure of germination. Similarly, shoot length; root length and root collar diameter was statistically significant ($P \leq 0.05$) among different Cr concentrations. *Eucalyptus camaldulensis* accumulated 154.78 µg g^{-1}DM of Cr (tot) in trivalent treated soil and 26.45 µg g^{-1}DM of Cr (tot) in Cr (VI) treated soil this showed that the species has a moderate chromium phytoaccumulation potential.With regardless of plant parts the species roots accumulate (42.70 µg, g^{-1}) and shoots (55.60 µg, g^{-1}) of the species more or less accumulate nearly the same amount of Cr.Besides, chromium accumulation factor CAF of roots (0.78) is more or less similar to shoots (0.74). The species also accumulated 154.78 µg g^{-1}DM of Cr (tot) in trivalent treated soil and 26.45 µg g^{-1}DM of Cr (tot) in Cr (VI) treated soil. Thus, *Eucalyptus camaldulensis* can be used as a potential phytoremediator species where Cr contamination levels are low to moderate.

Key words: *Eucalyptus camaldulensis*, hexavalent chromium, trivalent chromium

Introduction

Industrial development is a recent phenomenon in Ethiopia and many industries discharge harmful wastes into the rivers and land. Most of our industries are at the infant stage and cannot afford enormous investment in pollution control due to low profit margin. Heavy metals such as lead, mercury, arsenic, and cadmium, other heavy metals, including copper, zinc, and chromium are the main toxic pollutant discharged by industries and cause a great threat to the health of surrounding people and near by biota. Among the industries, tanning industries constitute a major portion of industrial growth since there is high quality of hide from the native livestock population. On the other hand, the leather industry is the major reason for the environmental influx of chromium, which is a potential carcinogen for human beings.

The effluent and sludge disposed from these industries into rivers and land has led to extensive degradation of productive land (Ramasamy, 1997). Therefore, the probability of chromium migration and bioavailability to arable activities poses a potential threat in the surrounding areas. Chromium is one of the major heavy metal discharged from tanneries in Ethiopia. Cleaning of chromium-contaminated site as one of the challenging tasks because remediation of sites contaminated with toxic heavy metal chromium is particularly the most challenging one. Unlike organic compounds, the heavy metal chromium cannot be degraded and the clean up technology requires removal.

The heavy metal removing process from contaminated sites often employs, physiochemical agents, which can dramatically inhibit soil fertility with subsequent negative impacts on the ecosystem.Phytoremediation is an emerging new and recent technology that can be considered in remediation the contaminated sites because of its cost effectiveness, aesthetic advantages, and long-term applicability. It refers to the use of metal accumulating plants that can translocate and concentrate metals from soil in roots to above ground shoots or leaves (Cunningham and OW, 1996). Many research findings indicated that plants have the genetic potential to remove many toxic heavy metals from the soil.

The present study was under taken to investigate phytoremediation potential of *Eucalyptus camaldulensis* species in Ethiopia at seedling stage. Research results stated that *E.camaldulensais*s tolerates high level of soil salinity and periodic flooding (Hills and Brown, 1975). It also grows in areas receiving less than 200 mm rainfall per annum (Hills and Brown, 1975). A study conducted by Grant, *et al* (2002) a site polluted by Cr, and finally he found that Cr could be remediate-using *E.camaldulensis.* The tree species was also fast growing nature, ease of establishment, locally adaptable, environmentally sound, economically important, and socially attractive. Top of all, the pollutant transformation in the food chain is eliminated since the end use of the species is for timber and fuel wood. This research will help to understand the role of *Eucalyptus camaldulensis* in remediation of Cr contaminated sites. Besides, the study tried to understand the accumulation of Cr in the stem as well as in the root parts of the plant at seedling stage. Therefore, it helps to screen the species to select them for reclamation of contaminated land with different objective.

Methodology

Study site description

The research was carried out at Holetta Agricultural Research Center, Ethiopia. The center is located 28 km west of Addis Ababa, with an altitude of 2400 m above sea level. Geographically, the center is located between 9^{o} 06` N latitude and $38^{o}$ 08` E longitude

Treatments and experimental design

The treatments were applied in split plot design with CRD with 3 replications, *Eucalyptus camaldulensis* with four levels of two Cr concentrations were used as a treatment. Trivalent Cr was applied as $Cr_2 (SO_4)_{3.}6H_2O$ and Cr (VI) as $K_2Cr_2O_7$ with Cr (III), Cr (VI) 0, 10,100 and 1000 ppm.

Media and chemical preparation

Forest soil, manure, sand and local soil were collected, pretreated and mixed, with a proportion of 3:3:1:1 i.e. forest soil, local soil, sand and manure respectively. The media were then filled into 16 x 20 cm diameter/depth of polythene bags and transferred to the glasshouse. Polybags totalled 16 and 48 per plot and treatment. Watering was carried out for 3 consecutive days before planting. Seeds were thoroughly mixed, randomized, and sown directly on each polybag. Watering was done daily from planting up to transplanting stage of the seedlings. Weeding was done when needed.

Data collection

Germination data were recorded every day during emergence of the radical from the soil. Data on the number of seeds germinated each day and date of germination were recorded. After seedling reached plantable size, the four inner best seedlings were assessed for data collection to avoid bordering effect. Shoot length, root collar diameter and crown depth were measured before and after seedlings uprooted using a ruler. The shoot and roots were separated into two parts using a sharp knife, preserved in plastic bags, and finally taken to the labouratory for leaf area measurement. The shoot and root samples were oven-dried at 100 ˚C for 24 hours. The samples were grinded using grinding mill, at a mesh size of 2 mm for further chromium analysis. A soil sample was also collected before and after the experiment using a labeled plastic bag. Then the samples were sun dried until the water in the soil was completely removed grinded using mortars and piestel and sieved using a seiver. For the sake of accuracy, sieves of 2 mm mesh size were used to sieve 1 mm soil size.

Soil sample analysis

Ten ml of concentrated HNO_3 was added to 0.5 g of soil samples in a 50 ml digestion tube and allowed to stand over night at room temperature. The digestion tubes were placed in a heating block for 1 hr at 150 ºC, tubes were then removed allowed to cool for 1 hr and 2ml of 30 % H_2O_2 was added. The contents were mixed by swirling and then allowed the solution for heating at 150 ºC until digestion was completed. Digested soil samples were analyzed for Cr in Atomic Absorption Spectrophotometer (Varian Spectra AA-220) with air acethylene flame at 358 ηm with 0.2 spectral slit width .The procedures was modified from (Arun K. Shanker, *et al*., 2004).

Plant sample analysis

Five ml of concentrated HNO_3 was added to 0.25 g of dried plant sample in a 50 ml digestion tubes and allowed to stand over night at room temprature.The digestion tubes were placed in a heating block for 4 hr at 150 ºC.Color change was observed during digestion from orange color to pale yellow and finally changed into colorless.Digestion samples were analysed for Cr in Atomic Absorption Spectophotometer (Varian spectra AA-220) with air acethylene flame at 358 ηm with 0.2 spectra slit width.The procedure used was modified from (Arun,K.Shanker,*et al*.,2004)

Data analysis

All data were analyzed using SAS 1999-2000 Version 8.2 with GLM (General Linear Model) procedure and means were separated using DMRT (Duncan's Multiple Range Test).

Results and Discussion

Mean germination of *Eucalyptus camaldulensis*

The species was germinated after 13 days from sowing. However, partial delay in germination has been observed in some treatments. Cr application at the highest concentration levels brought delayed in germination by 14 day when compared to the control. Besides, death of the seedlings was observed after emergence at 1000 ppm of Cr (VI). Similarly, Karunyal, *et al.* (1994) it was observed that germination study on *Paddy, Luceana* and *Acacia* species with 10 % concentration of tannery effluent resulted in complete inhibition of germination. On another study by Stanberg, *et al.* (1984c) reported that delayed in germination and stunting growth were apparent in the corn on soils that received the tannery wastes. These facts were reflected on *E. camaldulensis.*The date acquired from sowing to germination was statistically not significant among the treatments. The result revealed that date of germination of the treatments is similar along the treatments. Besides, the germination percentage of most treatments was not significant among each other. The highest germination percentage (95.83 %) was recorded at 10 ppm of trivalent chromium species however; the lowest germination percentage (22.92 %) was recorded at hexavalent chromium species of 1000 ppm (Table, 1).

Table 1 Least square means for the germination data (*Eucalyptus camaldulensis*)

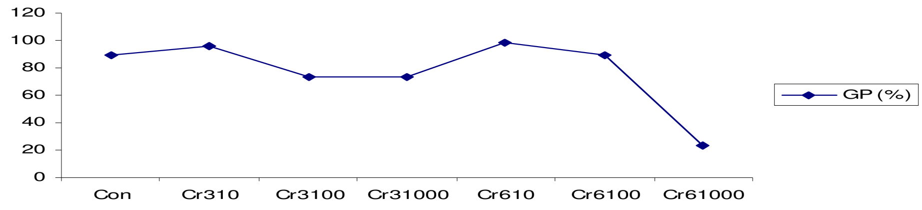
Treatments	NO	Ddiff	GP (%)	PVG	MDG	GV
Control	8	43^{a}	89.58^{a}	11.17^{a}	1.38^{abc}	14.35^{abc}
$Cr^{3}10$	8	43^{a}	95.83^{a}	9.33^{a}	1.09^{a}	10.27^{c}
$Cr^{3}100$	8	43^{a}	72.92^{a}	9.00^{a}	0.83^{bc}	9.34^{bc}
$Cr^{3}1000$	8	43^{a}	72.92^{a}	10^{a}	0.82^{c}	8.10^{b}
$Cr^{6}10$	8	43^{a}	97.92^{a}	12.67^{a}	1.40^{a}	18.10^{a}
$Cr^{6}100$	8	43^{a}	89.56^{a}	9.67^{a}	1.27^{a}	11.60^{bcd}
$Cr^{6}1000$	8	43^{a}	22.92^{b}	3.67^{b}	0.97^{a}	3.56^{d}
SE ±		2.61	8.86	1.58	2.21	2.1

Note: Letters with the same superscript are not statistically significant at($P \leq 0.05$) .

Germination value of *Eucalyptus camaldulensis*

The mean germination value of the treatments for *Eucalyptus camaldulensis* was significantly differed among each other. The highest germination value (18.10) was recorded at 10 ppm of hexavalent chromium followed by (14.35) the control chromium respectively. However, the lowest germination value (3.56) (Table, 1) was recorded at 1000 ppm of hexavalent chromium followed by (8.10) of 1000 ppm for trivalent Cr species respectively. From (figure, 1) below it was observed that the control of chromium has the highest germination. However, the total germination value was recorded at 1000 ppm of hexavalent Cr; this was due to lower in peak value of germination and mean daily germination percentage as compared to the other species.

Figure 1 Germination values of the *Eucalyptus camaldulensis*



Interaction effect of two Cr species on tree species

Since germination is the first physiological process affected by Cr, the ability of a seed to germinate in a growing media containing Cr would be indicative of its level of tolerance to this metal Peralta *et al.* (2001). Seed germination of the *Eucalyptus camaldulensis* was reduced to (22.92 %) (Table, 2) with 1000 ppm of hexavalent Cr and this result was supported by (Rout, *et al.*, 2000, Peralta, *et.al*. 2001).Another study by Jain,*et.al*.(2000) found that a reduction of 32-57 % in sugarcane bud germination was observed with 20 and 80 ppm Cr, respectively. The reduced germination of seeds under Cr stress could be depressive effect of Cr on the activity of amylases and on the subsequent transport of sugars to the embryo axes (Zeid, 2001). Protease activity, on the other hand, increase with the Cr treatment, which could also contribute to the reduction in germination of Cr-treated seeds (Zeid, 2001).

Table 2 Least square means for germination data with interaction

Treatments	Ddiff	GP (%)	PVG	MDG	GV
ECco	33^{b}	89.58^{a}	11.17^{a}	1.38^{a}	14.35^{a}
$Cr^{3}EC10$	23^{c}	95.83^{a}	9.33^{a}	1.09a	10.27^{b}
$Cr^{3}EC100$	23^{c}	72.92^{b}	9.00^{a}	0.83^{a}	9.34^{b}
$Cr^{3}EC1000$	23^{c}	72.92^{b}	10.00^{a}	0.82^{b}	8.10^{c}
$Cr^{6}EC10$	43^{a}	97.92^{a}	12.67^{a}	1.40^{a}	18.10^{a}
$Cr^{6}EC100$	43^{a}	89.58^{a}	9.67^{a}	1.27^{a}	11.60^{b}
$Cr^{6}EC1000$	43^{a}	22.92^{c}	3.67^{b}	1.10^{a}	3.56^{c}
SE±	2.61	8.86	1.58	0.21	2.10

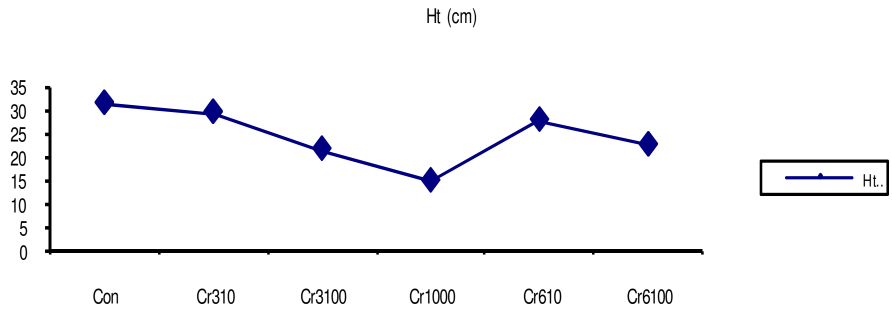
Note: Letters with the same superscript in the column are not statistically significant at (P≤0.05) level of significant.

Seedling growth parameters

Shoot length

There was significant difference in shoot length of *Eucalyptus camaldulensis* among the treatments at ($p \leq 0.05$).The maximum (32.17 cm) shoot length was recorded at the control of chromium (figure, 2). However, the lowest value (15 cm) was recorded at 1000 ppm of trivalent Cr followed by (22.67 cm) (figure, 2) of 100 ppm for hexavalent chromium species respectively. The above result was inline with the study done by Anderson, *et al.* (1972) who observed 11 %, 22 % and 41 % reduction in plant height, respectively over control, when Cr (VI) was applied at 2, 10, and 25 ppm to nutrient solutions in sand cultures in oats. Besides, reduction in plant height due to Cr (VI) was recorded on *Curcumas sativus*, *Lactuca sativa* and *Panicum miliaceum* was reported by (Joseph, *et al*., 1995). Baron, *et al.* (2000) observed that Cr (III) addition inhibited shoot growth in Lucerne cultures. Sharma and Sharma (1993) reported that after 32 and 96 days, plant height reduced significantly in wheat Cv.UP 2003 in a glasshouse trial when sown in sand with 0.5 µM sodium dichromate. Adverse effects of Cr on plant height and shoot growth have been reported (Rout, *et al*., 1997). The reduction in plant height might be due to the reduced root growth and consequent lesser nutrients and water transport to the aerial part of the plant. Besides, Cr transport to the aerial part of the plant can have a direct impact on cellular metabolism of shoots contributing to the reduction in plant height.

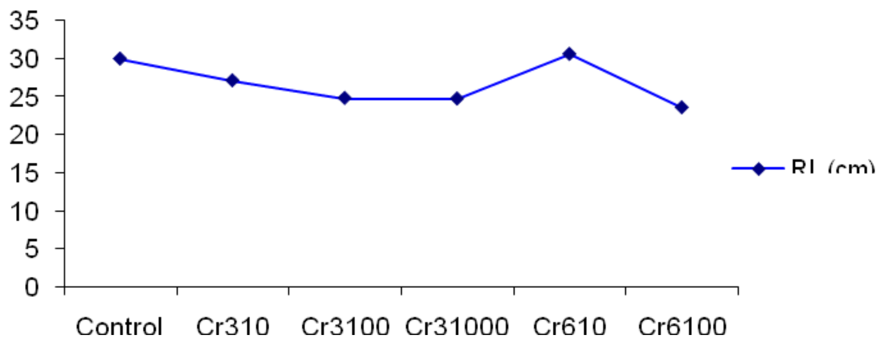
Figure 2 shoot length of *Eucalyptus camaldulensis*



Root length

The treatments of root length of *Eucalyptus camaldulensis* were not significantly differed among the treatments at ($p \leq 0.05$). The highest root length (31.75 cm) was recorded at the control of chromium followed by (30.67 cm) 10 ppm for hexavalent chromium species. However, the lowest value (23.58 cm) was recorded at 1000 ppm of hexavalent chromium followed by (24.75 cm) of 1000 ppm for trivalent Cr species (Figure 3). At the highest concentration level, trivalent chromium species has brought an impact in root length. In line with this result, studies by Panda and Patra (2000) found that 1μM of Cr increased the root length in seedlings grown under nitrogen (N) nutrient levels. However, higher Cr concentration decreases root length in all the nitrogen treatments. Another study by Samnteray, *et al.* (1999), with chromites mine spoil soil in five cultivars of mungabean, noted that, root growth was significantly affected in 28 days after emergence.

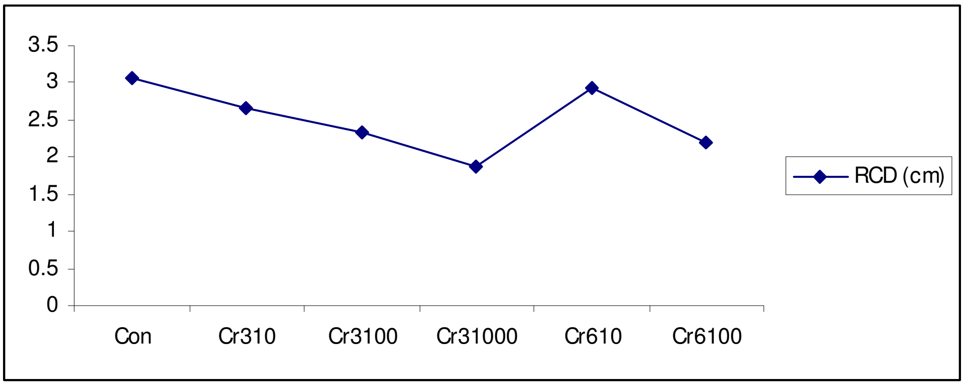
Figure 3 Root lengths (cm) for *Eucalyptus camaldulensis*



Root collar diameter

In most of the treatments of *Eucalyptus camaldulensis,* the root collar diameter was not significant. The maximum root collar diameter (3.07 mm) was observed at the control chromium followed by (2.92 cm) (figure, 4) 10 ppm for hexavalent Cr species. However, the lowest (1.87 mm) root collar diameter was recorded at 1000 ppm of trivalent chromium followed by (2.21 mm) (figure, 4) for hexavalent chromium species. The above result was supported by several authors; a decrease in root growth is well-documented effect due to heavy metals in trees and crops (Breckle, 1991) reported that at a very low Cr content of 1 to 2 ppm (DW) inhibited the growth of plant species. General response of decreased root growth due to Cr toxicity could be due to inhibition of root cell division/ root elongation or root extension of cell cycle in the roots. Under high concentrations of both the Cr speciation combination, the reduction in root growth could be due to the direct contact of seedlings roots with Cr in the medium causing a collapse and subsequent inability of the roots to absorb water from the medium (Barcelo, *et al*., 1986).

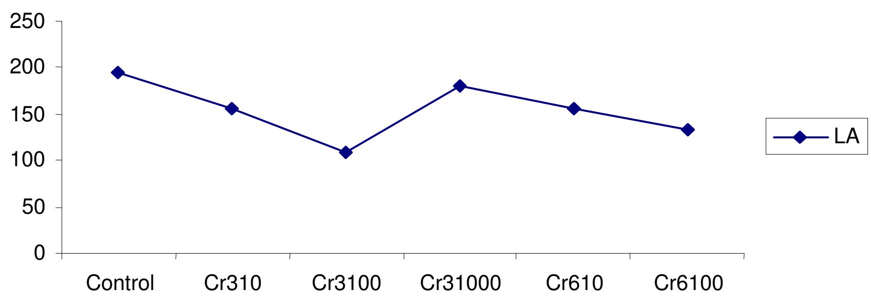
Figure 4 Root collar diameter growth (mm) *Eucalyptus camaldulensis*



Leaf area (LA)

Most of the treatments of leaf area of *Eucalyptus camaldulensis* were not significantly differed among each other. From (figure 5) below the highest value of leaf area (195.65 cm^2) was recorded at the control of chromium followed by (156.69 cm^2) of the 10 ppm for hexavalent and trivalent chromium species. However, the lowest leaf area (109.58 cm^2) was recorded at 100 ppm of trivalent chromium followed by (133.41 cm^2) of 100 ppm for hexavalent chromium species (figure 5). In a study on the effect of Cr (III) and Cr (VI) on spinach, Singh (2001) reported that Cr (VI) applied at 60 mg kg^{-1} and higher levels reduced the leaf size, caused burning of leaf tips or margin, and reduced leaf growth rate. Jain, *et al.* (2000) observed leaf chlorosis at 40 ppm Cr (VI) that turned to necrosis at 80 ppm Cr (VI). In a study with several heavy metals, Pedreno, *et al.* (1997) found that Cr had a pronounced effect on leaf growth and preferably affected young leaves in tomato plants. Reduction in leaf biomass was correlated with the oxalate acid extractable Cr in *P.vulgaris* by Poschenrieder, *et al*. (1993). Canopy photosynthesis appears to be increase symmetrically with increase in LAI; on the other hand LAI is directly proportional to leaf area.

Figure 5 Leaf areas of *Eucalyptus camaldulensis*



Uptake and phytoaccumulation of chromium

Shoots

There was no significant difference in the uptake of chromium for trivalent Cr species uptake between controls up to 100 ppm and vice versa. The maximum trivalent Cr accumulation in shoots (163.60 µg g^{-1}DW) (table, 3) was recorded at 1000 ppm of trivalent Cr species followed by (90.31 µg g^{-1}DW) 100 ppm for the same Cr species respectively. However, the maximum hexavalent Cr accumulation (22.27 µg g^{-1}DW) was recorded at 100 ppm of hexavalent chromium species followed by (17.60 µg g^{-1}DW) 10 ppm for the same chromium species. Besides, shoots of *Eucalyptus camldulensis* accumulated on average more of trivalent chromium species (73.94 µg g^{-1} DW) than that of hexavalent chromium (13.94 µg g^{-1} DW). Nevertheless, Cr accumulation capacity of the shoots was linearly correlated to Cr application in the soil growing media. Corresponding accumulation of total Cr with regards to control, 10 ppm, 100 ppm and 1000 ppm were 3.94<26.77<56.29<163.60, µg g^{-1}DW (table, 3) respectively.

Roots

The total uptake of Cr was 64.88 and 62.65 µg g^{-1}DW for the roots and shoots, respectively (Table 3). Significance difference in total Cr accumulation of the roots was recorded among the treatments at ($P \leq 0.05$).The maximum Cr accumulation (158.20 and 114.89 µg g^{-1}DW) (table, 3) was recorded at 1000 ppm and 100 ppm of trivalent Cr species respectively. Roots of *Eucalyptus camldulensis* accumulated on average more of trivalent chromium (80.84 µg g^{-1} DW) than that of hexavalent chromium (12.51 µg g^{-1} DW). Nevertheless, Cr accumulation capacity of the roots was linearly correlated to Cr application in the soil growing media. Corresponding accumulation of total Cr with regards to control, 10 ppm, 100 ppm and 1000 ppm were, (4.68< 29.56< 67.11 < 158.2 µg g^{-1} DW (table,3) respectively. In general at the maximum chromium concentration level, the Cr content in shoots and roots were (163.60 and 158.20 µg g^{-1}DW) (table, 3) respectively. Hence the Cr accumulation capacity of roots and shoots are directly correlated, the highest Cr accumulation value recorded in the roots was also recorded in the same treatments where the Cr accumulation capacity in the shoot was also maximum and vice versa.

Chromium accumulation factor (CAF) for *Eucalyptus camaldulensis*

The Cr accumulation factor is the ratio of Cr accumulated in plant parts (shoots and roots) divided by Cr content in the soil media.CAF of *Eucalyptus camaldulensis* was similar trend with Cr accumulation in the roots and shoots .Cr accumulation factor of *Eucalyptus camaldulensis* was not significantly differed among the treatments at ($P \leq 0.05$) both in the shoots and roots as well as the two Cr species. The highest root CAF of trivalent chromium (1.76) was recorded at 1000 ppm of trivalent Cr species followed by (1.20) (table, 3) of 100 ppm for the same Cr species respectively. Besides, the highest total CAF (1.76) was recorded at 1000 ppm of hexavalent chromium species followed by (1.34) of 100 ppm of trivalent chromium species at Cr (III) however the highest total CAF of hexavalent chromium (0.25) was recorded at 100 ppm of hexavalent chromium species respectively(Table 3). Between the two chromium species, CAF of trivalent chromium (1.02) was higher than CAF of hexavalent (0.24) chromium. A study conducted by Grant, *et al* (2002) a site polluted by Cr, and finally he found that Cr could be remediate-using *E.camaldulensis.*

Table 3 *Eucalyptus,* average chromium concentration (µg g^{-1} DM) of the plant parts

Cr added to the soil (ppm)	Cr (tot) parts of the plant (µg, g^{-1})		CAF		
	Shoots	Roots	Shoots	Roots	Root+shoot
$Cr^3$10	35.93^b	42.63^b	0.75^a	0.75^a	0.75^a
$Cr^3$100	90.31^{ab}	114.89^{ab}	1.20^a	1.49^a	1.34^a
$Cr^3$1000	163.60^a	158.20^a	1.76^a	1.76^a	1.76^a
$Cr^6$10	17.60^b	16.49^{bc}	0.25^a	0.19^a	0.22^a
$Cr^6$100	22.27^b	19.33^b	0.27^a	0.22^a	0.25^a
Control	3.94^b	4.68^c	0.21^a	0.27^a	0.24^a
Mean	55.60	42.70	0.74	0.78	0.76
SE+-	30.91	30.91	0.69	0.69	0.69

Note: Letters with the same superscript in the column are not statistically significant at ($P \leq 0.05$).

Chromium concentration in the soil media

The Cr concentration in the soil growing media between the two Cr species was not significantly differed. To control leaching effect the pots were put under plastic sheets lay down on the ground. The Cr content in the soil growing media of Cr^6 (62.28 µg g^{-1}) per dry soil was lower than Cr^3 (67.43 µg g^{-1}) per dry soil (table, 4). The chromium concentration value for *Eucalyptus camaldulenisis* in the soil media is (76.26 µg g^{-1}) per dry soil (table, 4).Nevertheless, the Cr concentration in the soil growing media was linearly correlated to the Cr concentration applied in the soil. Corresponding concentration of total Cr with regards to control, 10 ppm, 100 ppm and 1000 ppm were 35.36<58.15<71.62< 94.28 µg g^{-1} of dry soil (table, 4) respectively. This result showed that increasing Cr application to the soil growing media increases its concentration and increase availability of Cr to the plants. The highest concentration of hexavalent Cr (98.71 µg g^{-1}) per dry soil was recorded at 1000 ppm of hexavalent chromium species for *Eucalyptus camaldulensis.* Besides, the Cr accumulation of trivalent Cr (113.47 µg g^{-1}) per dry soil was recorded at 1000 ppm of trivalent chromium *Eucalyptus camaldulensis*. However, the lowest value of Cr concentration of (32.17 µg g^{-1}) per dry soil of the control for *Eucalyptus camaldulensis* respectively (Table 4).

Table 4 Cr (total) (µg g-1) of dry soil in the soil growing media

Treatments Cr (tot)	(µg g^{-1} of dry soil)
ECcontrol)	36.75^{cd}
EC ($Cr^3$10 ppm)	69.65^{bc}
EC ($Cr^3$100 ppm)	81.73^{bc}
EC ($Cr^3$1000 ppm)	113.47^{a}
ECCr^{6}10 ppm	83.26^{b}
ECCr^6 100 ppm	89.77^{ab}
ECCr61000 ppm	98.71^{ab}

Note: letters with the same superscript are not statistically significant at (P≤0.05)

Discussion

Eucalyptus camaldulensis seedlings accumulated significantly more Cr (III) applied to the soil in tissue in comparison to Cr (VI) application. The species accumulated in average (154.78 µg g^{-1}DM) of Cr (III) and (26.45 µg g^{-1}DM) of Cr (VI) treated treatment the CAF was also showed similar trend to the chromium accumulated. The possibility of modification of the Cr form after it is supplied to the soil growing media either Cr (III) or Cr (VI) for the species was also magnified in the experiment. This may occurred because of the action of root exudates with the capacity for reduced or oxidized form of chromium in the soil nutrient solution. The reason for the high accumulation of Cr in both shoots and roots parts of the plant could be because of transformation (detoxification) of Cr (VI) to Cr (III) in the roots environment and changed into non-toxic form of trivalent chromium species then translocated into the shoots. Since both Cr (VI) and Cr (III) must cross the endodermis symplast, the Cr (VI) in cells is readily reduced to Cr (III) and the Cr (III) is retained in the root cortex cells (Zayed, *et al.,* 1998). Another important reason for the potential of transport of Cr from roots to shoots could be because of the plants may have their own specific mechanism transport of Cr. The accumulation factor for both Cr speciation valued derived in the present study in the tree species revealed that the capacity of the species and confirmation with the reports of Khan (2001).This could be because the uptake pattern of Cr from soil depends on the tree species and with in the tree species the concentration largely differed between different parts of the trees (Pulford, *et al.*, 2001). In general it is possible that the comparative accumulation of Cr to the shoots and roots is more in Cr accumulator nature of the species' (VI) is actively taken up and is a metabolically driven process in contrast to Cr (III), which is passively taken up and retained by cation exchange sites of the cell wall (Shanker, *et al*., 2004).The more probability of good transfer of Cr from roots to shoots means that the prospect for using these trees as phytoremediation potential on chromium-contaminated sites is high. It should be noted that Cr is very poorly translocated in all the higher vascular plants (Zayed, *et al.*, 1998). Hence, *Eucalyptus camaldulensis* can be used as a potential for phytoremediattion of Cr in areas where Cr contamination level was low to moderate.

Conclusions and Recommendations

Higher application of chromium resulted in poor quality and poor growth of the *Eucalyptus camaldulensis* seedlings. Hence trivalent and hexavalent Cr at higher and medium concentration levels caused a reduction in shoot length, root collar diameter, root length and leaf area, but the impact recorded at lower concentration levels was minimal. Besides, hexavalent chromium at the highest concentration applied to the soil growing media caused delay in germination, reduction in shoot length, root length, leaf area, and abnormal morphology of the seedlings. Even death of seedlings was also recoded at highest level. In general, the total chromium concentration was found to be higher in trivalent Cr treated soil when compared to hexavalent Cr treated soil. The dosage of Cr in soil had a positive correlation with the measured amount of total Cr concentration. Generally, the species is found to be sensitive to high levels of Cr especially the hexavalent species that, in this study, failed to survive and tried in low to moderate Cr contaminated soils.

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References

Anderson AJ, DR Meyer, FK Mayer. 1972. Heavy metal toxicities: levels of nickel, cobalt and chromium in the soil and plants associated with visual symptoms and variation in growth of an oat crop. Australian Journal Agriculture Pest 89:47-53.

Arun Shanker K. 2004. Uptake and Phytoaccumulation of Chromium by Selected Tree species. Tamilnadu Agricultural University; *Department of Physiology Coimbarture:* 641003.India.

Barcelo J, C Poschenrieder, B Gunse. 1986. Water Relations of Chromium VI Treated Bush Bean Plants (*Phaseolus vulgaris* L) (cv Contender) *Under both Normal and Water Stress Conditions: J Exp Bot*; 37:178-87.

Breckle SW. 1991. Growth under Stress; *Heavy Metals: In: Waisely, Y.Eshel A, Kafkaf*: U.editors.Plant Root: The Hidden Half, NY, USA; Marcel Dekker: pp.351-73.

Cunningham SD. 1996. Promises and prospects of phytoremediation. *Journal of Plant Physiology* 110:715-719.

Grant CD, CJ Campbell, NR Charnock. 2002. Selection of species for phytoremediation of Cr contaminated site. *Journal of Water, Air and Soil Pollution* 139: 215-235.

Hills WE, AG Brown. 1978. *Eucalyptus* for Wood Production, Division of Building Research, CSIRO, Melbourne, *Division of Forest Research*, Melbourne Australia.

Jain R, S Srivastava, UK Madam, R Jain.2000. Influence of Chromium on Growth and Cell Division of Sugarcane. *Indian J Plant Physio:* l; 5:228-31.

Joseph GW, RA Merrilee, E Raymond. 1995. Comparative Toxicities of Six Heavy Metals Using Root Elongation and Shoot Growth in Three-Plant Species. *The Symposium on Environmental Toxicology and Risk Assessment Atlanta* GA, USA; PP.26-9.

Karunyal S, G Renuga, K Paliwal. 1994. Effects of tannery effluent on seed Germination leaf area, biomass and mineral content of some plants Bioresources Technology 26:417-423.

Khan AG. 2001. Relationships between chromium magnification ratios, accumulation factor and mycorrhizae in plants growing on tannery effluent- polluted soil. *Environment International* 6: 417-423.

Panda SK, HK Patra. 2000. Nitrate and Ammonium Ions Effect on the chromium Toxicity in Developing Wheat Seedlings *natn Acad Sci*.Indian B; 70:75-80.

Pedreno NJI, R Gomez, G Moral, J Palacio, J Mataix. 1997. Heavy Metals and Plant Nutrition and Development: *Recent Res Dev Phytochem*: 1:173-9.

Peralta JR, JL Gadea Torresdey, KJ Tiemann, E Gomez, Arteaga, S Rascan. 2001. Uptake and Effects of Five Heavy Metals on Seed Germination and Plant Growth in Alfalfa (*Medicaso sativa*) L B.*Environ Contam Toxicol*: 66(6): 727-34.

Poschenrieder C, B Gunse, J Barcelo. 1993. Chromium -Induced Inhibition of Ethylene Evolution in Bean (*Phaseolus vulgaris*) Leaves-Physiolo Plant: 89:404-8.

Pulford ID, C Watson, SD McGregor. 2001. Uptake of chromium by trees: Prospects for phytoremediation. *Environmental Geochemistry Health* 23: 307-311.

Ramasamy K. 1997. Tannery Effluent Related Pollution on Land and Water Ecosystems in India." Fourth International Conference on the Biogeochemistry of Trace Elements". University of California Berkley, USA.June 23-26: pp.771-772.

Rout GR, S Samantary, P Das. 1997.Differential Chromium Tolerance among Eight Mung bean Cultivars Grown in Nutrient Culture *Plant Nutr.*:20:473-83.

Rout GR, S Sangahamitra, SP Das. 2000. Effects of Chromium and Nickel on Germination and Growth in Tolerant and Non-tolerant Populations of *Echinochloa colona* (L); chemosphere; 40:855-9.

Samantaray S, GR Rout, P Das. 1999.Studies on Differential Tolerance of Mugabean Cultivars to Metalliferous Minewastes.*Agribiol Res*, 52:193-201

Sharma DC, P Sharma. 1993. Chromium Uptake and its Effect on Growth and Biological Yield of Wheat: Cetreal Res Commun; 21:317-21.

Singh, AK. 2001. Effect of Trivalent and Hexavalent Chromium on Spinach (*Spinacea Oleracea* L): *Environ Eco*l, 19:807-10.

Stanberg AL, DD Hemphilli, VV Volk. 1984.Yield and Elemental Concentration of Sweet Corn Grown on Tannery Wastes Amended Soil.*J.Environ.Qual*.13:162-166.

Zayed A, CM Lytle, N Qian-Jinhong, JH Terry. 1998. Chromium accumulation, translocation, and chemical speciation in vegetable crops". *Planta* 206: 293-299.

Aboveground Biomass Equations for Selected *Eucalyptus species* in Ethiopia

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Abstract

In Ethiopia, plantations of fast-growing species are being established to increase the supply of wood, especially for biomass fuel. For proper planning of such plantation development accurate methods of aboveground biomass (AGB) production, need to be developed. The objectives of this study were to i) to develop regression equations for different tree components of three selected eucalypt species, and ii) determine the biomass distribution in the above-ground components of the selected three species. The selected eucalypt species were *Eucalyptus globulus, Eucalyptus grandis,* and *Eucalyptus saligna*. For each species, 24 sample trees (20 for regression and 4 for validation test) were randomly selected from respective forest stands located in the central part of Ethiopia. Biometrical data were obtained by felling the sample trees. The sample trees were further stratified into three diameter groups based on measured diameter at breast height (DBH). ANOVA and prediction equations were computed by using base-10 log-transformed dry weights (kg) of above-ground biomass (AGB) components and their corresponding log-transformed DBH, squared DBH (DBH^2) and DBH^2*height (H). The data were analysed with statistical software SPSS 11.5. The allometric equation with DBH^2 as predictor variable showed better results (higher R^2 and lower SE) than other growth parameters. Since DBH can be easily measured with higher accuracy and provide better estimates, it was recommended as an adequate growth parameter for AGB estimation. The study showed that there were considerable variations in biomass distribution in the aboveground in the respective forest stands. This resulted due to variability of individual trees in size structure. For all size groups, stem wood accounted for high proportion (82.4 to 85.9%) of total tree in three *Eucalyptus* species.

Keywords: biomass, biometrical data, breast height diameter, predictor variable, growth parameter

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Introduction

Ethiopia has a long history and experience in plantation forestry. The origins date to the last decade of the 1800's when *Eucalyptus* species were introduced into the country to alleviate the acute shortage of wood for fuel and construction around the capital. The introduction was a success. Soon after the turn of the century, planting of eucalypts for fuel, especially *E.globulus* and *E.camaldulensis* expanded in areas surrounding the capital. In the late 1930s, the estimated size of *Eucalyptus* forest was 4000 to 5000 ha (Giordano, 1938).

Existing forest plantations include industrial plantations and peri-urban plantations, established and operated by the government, as well as community woodlots and catchments/protection plantations. According to the reports by Ministry of Agriculture (Anon. 1990b), *Eucalyptus* spp. such as *E. globulus*, *E. saligna*, *E.grandis*, *E. camaldulensis* and *Cupressus lustanica* are the main trees in industrial plantation (58% and 29% respectively), followed by *Juniperus procera* (4%) *Pinus patula* and *Pinus radiata* (2%) and others (7%). Peri-urban plantations, established to supply urban centers with poles and fuel wood are located around Addis Ababa and other major towns. Community woodlots are plantations established and managed by groups of farmers or community. The community woodlots, similar to peri-urban plantations, consist mainly of *Eucalyptus* spp.

In Ethiopia and elsewhere, forest assessment is largely dependent on the conventional forest inventory methods, which mainly estimate the merchantable volume of a tree. Only species, which are considered economically important from lumber, veneer or plywood point of view, are well treated. As a result, the so called "wastes" that are trees thinned out of commercial forests, non-commercial tree species, dead and crooked trees, branches, slashes trimmed from merchantable bole, twigs, leaves and many forms of "wastes" and forest products are left unestimated. Since the so-called "wastes" lack definite geometric figure, these resources are best estimated by weight rather than volume. The knowledge that will be gained from this study will help to estimate the above-mentioned forest products.

The establishment of forest plantations of fast-growing species for industrial and energy use in Ethiopia is being accelerated. The reason is the limited supply of wood from natural forests and woodlands. The most numerously planted *Eucalyptus* species are *E.globulus* and *E. camaldulensis.* They cover about 250,000 ha (Tsegaye Bekele, 1996; Turnbull, 1999). Towards this end, however, accurate methods for estimating biomass of aboveground components of existing plantations for effective management and rational utilisation would become a necessity. Now, since the aim is 100 percent use of every tree cut, reliable estimation of different biomass components is of paramount concern.

In recent years, aboveground biomass functions of *E.globulus* and *E.saligna* have been developed by Solomon et al (2003); Gebre Kidan (1998) and Emiyayu (1997) in plantations from seedling and coppice origin, respectively. However, many more aboveground biomass studies are required to clarify our existing knowledge of biomass accumulation and allometric relations of growth parameters in plantations from different origin and growing sites. This study provides (1) dry weight predictive allometric equation for three *Eucalyptus* species (*E. globulus*, *E. grandis,* and *E.saligna*) relating aboveground tree components to diameter at breast height (DBH) and height (H), (2) allometric relations, and biomass distribution in aboveground components of three *Eucalyptus* species.

Materials and Methods

Description of the study areas

The study was conducted in one of the country's largest plantation estate- Aris Forest Enteprise; Degaga and Kofele districts. The geographic location of the study sites is $7^0$09' N latitude and 38^0 61' E longitudes for *E. globulus*, 7^0 25' N latitude, and 38^0 73' E longitudes for *E. saligna* and *E. grandis*. The mean annual rainfall at the study sites for the 10-year period (1993-2002) ranged from 1099.9 -1260 mm. Mean maximum and mean minimum temperature for *E. globulus* site ranged from 19.0 to 27.7 ^{0}C and 7.1 to 8.7 ^{0}C, respectively, whereas for *E. saligna* and *E. grandis,* it was ranged from 23.2 to 26.2 ^{0}C and 4.2 to 11.1 ^{0}C, respectively (Anonymous, 2003). According to FAO soil classification, the soils of the site growing *E. globulus* are orthic Luvisols and those of *E. saligna* and *E. grandis* are dystric Fluvisols (FAO, 1988).

Selection and marking of trees for destructive sampling

For the study stands of *E. globulus*, *E. saligna* and *E. grandis* were selected in plantations of seedling origin. At the time of sampling, the stands were 15, 17 and 14 years old, respectively, while the density of trees in the selected stands was 544, 788 and 656 trees/ha, respectively. Sample plots were selected through delineation of plantation compartment and dividing the compartment into equal plots using grid squares on the compartment map. Selection of one plot was accomplished randomly from already partitioned plots within the compartment. The selected plot was divided into many 1-ha plots. Then 1ha plot was selected by simple random sampling and partitioned into 16 equal plots (25 x25 m) from which eight sample plots were selected randomly. DBH of all standing and alive trees in selected plots were measured and the trees were stratified into three DBH classes; referring to their minimum and maximum DBH to ensure that different ranges of DBH are included in the sampling unit. Trees with broken tops and other clear defects were excluded from sampling units. Three trees in the target plot (one tree from each size group) were marked and the height was measured before felling.

Biomass measurement

Field measurements for developing biomass allometric equations were conducted as suggested by Brown (1997).The selected trees from the DBH class were felled. During felling, the stump height was kept low to the ground level. After felling, the trees were arranged into components as described by Young (1976), i.e. stem, branch, and foliages. Twigs less than one cm were considered as foliage biomass. After delimbing all branches, the stem was measured up to seven cm top diameter and this was considered as stem wood with bark. The fresh weight (FW) of components (stem wood, branch, foliage, and bark) was obtained on the site by weighing with a balance (capacity of 300 kg) to the nearest 0.5g. Results from measurements were recorded on a special form prepared for the purpose.

After measuring the fresh weight (FW) of the components, sub-samples were collected in three replications to obtain oven-dry (OD) weight at 105^0 C until constant weight was obtained. The fresh weight (FW) of the sub-samples was determined with Triple Beam Balance (capacity of 2.61 kg) to the nearest 0.1 g. The sub-samples were oven dried to obtain their respective over dry weight (OD). The average of the ratio of OD weight to FW of the three replicated samples was determined. The ratio (F) for each sample was calculated as follows:

$$OD/FW = F \quad (1)$$

Where: OD - oven-dry weight of samples;
FW - fresh weight of samples;
F - ratio of OD and FW.

The averaged ratio (*F*) of the components was multiplied with the fresh weight of the respective component to calculate the dry weight (*DW*) of aboveground components.

$$DW = FW \times F \quad (2)$$

Data analysis

Prior to analysis, the data were explored and checked for measurement errors, outliers and conformance to normality and other irregularities using statistical tools such as box plot, normality plot and Kolmogorov-Smirov's tests. Dry aboveground biomass (AGB) of sample trees was obtained by summing up dry weight of stem wood, stem bark, branches and foliages. Regression equations for the above-ground biomass components were developed by using base-10 log transformed dry weights (kg) of the different components and log-transformed DBH, squared DBH, and squared DBH*H. The relationships between DBH, DBH^2 and DBH^2*H and dry weight of components (stem wood, branch, foliage and bark) of the three species were determined using linear regression procedures. Microsoft Excel 2002 and SPSS version 11.5 were employed.

After analyzing the input data through log transformed linear regression, independent variables with higher R^2 ($R^2 \geq 0.9$) were selected for further refining. Statistics used for further selection of the "best-fit" allometric equations were R^2, SE, and SSRR. The highest R^2 and the lowest SE and SSRR were the basic criteria for the selection of the model (Schlaegel, 1982, Michael and Beck, 1993; Ter-Mikaelian and Korzukhin, 1997). In addition to R^2, SE and SSRR as criteria for model selection, the underlying regression assumptions were checked for fitted models (homogeneity of variance and normality of residuals) by plotting the residuals against predicted values. Furthermore, values of predicted versus observed log-transformed dry weight of aboveground components were plotted and examined. Generally, the graphs revealed that all the points were closely distributed along the mean. The selected models met the equality of variance and assumption of normality.

Results and Discussion

Regression Outputs and Selection of the Best Fit Models

The regression output of prediction data is shown in Table 1 and the prediction equations that were tested and proved the best are shown in Table 2. The graphs revealing the equality and normality of the variance of selected models are shown in Fig. 1. The selected allometric equations for aboveground biomass components are as follows:

E. globulus

I. Total tree $\log Y = -1.189 + 1.391(\log DBH^2)$ (3)

II. Stem wood $\log Y = -1.478 + 1.465 (\log DBH^2)$ (4)

III. Bark $\log Y = -2.048 + 1.32 (\log DBH^2)$ (5)

E. grandis

I. Total tree $\log Y = -1.381+2.893 (\log DBH)$ (6)

II. Stem wood $\log Y = -1.457+1.467 (\log DBH^2)$ (7)

III. Bark $\log Y = -2.286+1.365 (\log DBH^2)$ (8)

E. saligna

I. Total tree $\log Y = -1.062+1.337 (\log DBH^2)$ (9)

II. Stem wood $\log Y = -0.840+2.488 (\log DBH)$ (10)

III. Bark $\log Y = -2.333+1.384 (\log DBH^2)$ (11)

Table 1. Regression outputs for estimating above ground biomass of the three selected eucalypt species (N = 20).

		R^2					SE				
Species	Predictor variable	St. wood	Branch	Foliage	Bark	Total tree	St. wood	Branch	Foliage	Bark	Total tree
E.globulus	logDBH	0.90	0.69	0.68	0.89	0.92	0.114	0.124	0.149	0.108	0.094
	$logDBH^2$	0.90	0.69	0.68	0.90	0.93	0.112	0.126	0.150	0.105	0.092
	$logDBH^2*H$	0.94	0.56	0.59	0.85	0.94	0.086	0.145	0.167	0.121	0.079
E. grandis	logDBH	0.97	0.83	0.75	0.96	0.98	0.094	0.126	0.188	0.103	0.072
	$logDBH^2$	0.97	0.83	0.74	0.96	0.98	0.097	0.127	0.191	0.104	0.076
	$logDBH^2*H$	0.98	0.77	0.69	0.94	0.98	0.073	0.148	0.216	0.115	0.071
E. saligna	logDBH	0.83	0.13	0.44	0.87	0.91	0.132	0.266	0.181	0.117	0.097
	$logDBH^2$	0.79	0.12	0.50	0.92	0.94	0.143	0.274	0.171	0.092	0.081
	$logDBH^2*H$	0.84	0.16	0.53	0.92	0.97	0.128	0.268	0.167	0.091	0.057

Table 2. Prediction and validation statistics for the selected regression models to estimate the above ground biomass for three eucalypt species.

Species	Component	Predictor variable (X)	Coefficients		CF	Prediction Data			Validation Data			
			A	b		R^2	SE	SSRR	R^2	SE	SSRR	Bias
E.globulus	Total tree	$logDBH^2$	-1.189	1.391	1.000	0.93	0.0920	0.0229	0.91	0.0670	0.0006	0.0000
	St. wood	$logDBH^2$	-1.478	1.465	1.014	0.90	0.1119	0.0394	0.91	0.0662	0.0001	0.0025
	Bark	$logDBH^2$	-2.048	1.320	1.014	0.90	0.1047	0.0953	0.65	0.0873	0.0100	0.0075
E.grandis	Total tree	logDBH	-1.381	2.893	1.006	0.98	0.0723	0.0186	0.99	0.0491	0.0013	0.0025
	St. wood	$logDBH^2$	-1.457	1.467	1.010	0.97	0.0969	0.0081	0.98	0.0835	0.0055	0.0000
	Bark	$logDBH^2$	-2.286	1.365	1.013	0.96	0.1043	0.1076	0.97	0.0935	0.0038	0.0000
E.saligna	Total tree	$logDBH^2$	-1.062	1.337	1.020	0.94	0.076	0.0201	0.96	0.0773	0.0100	0.0100
	St. wood	logDBH	-0.840	2.488	1.020	0.82	0.1366	0.0783	0.96	0.0756	0.0020	0.0100

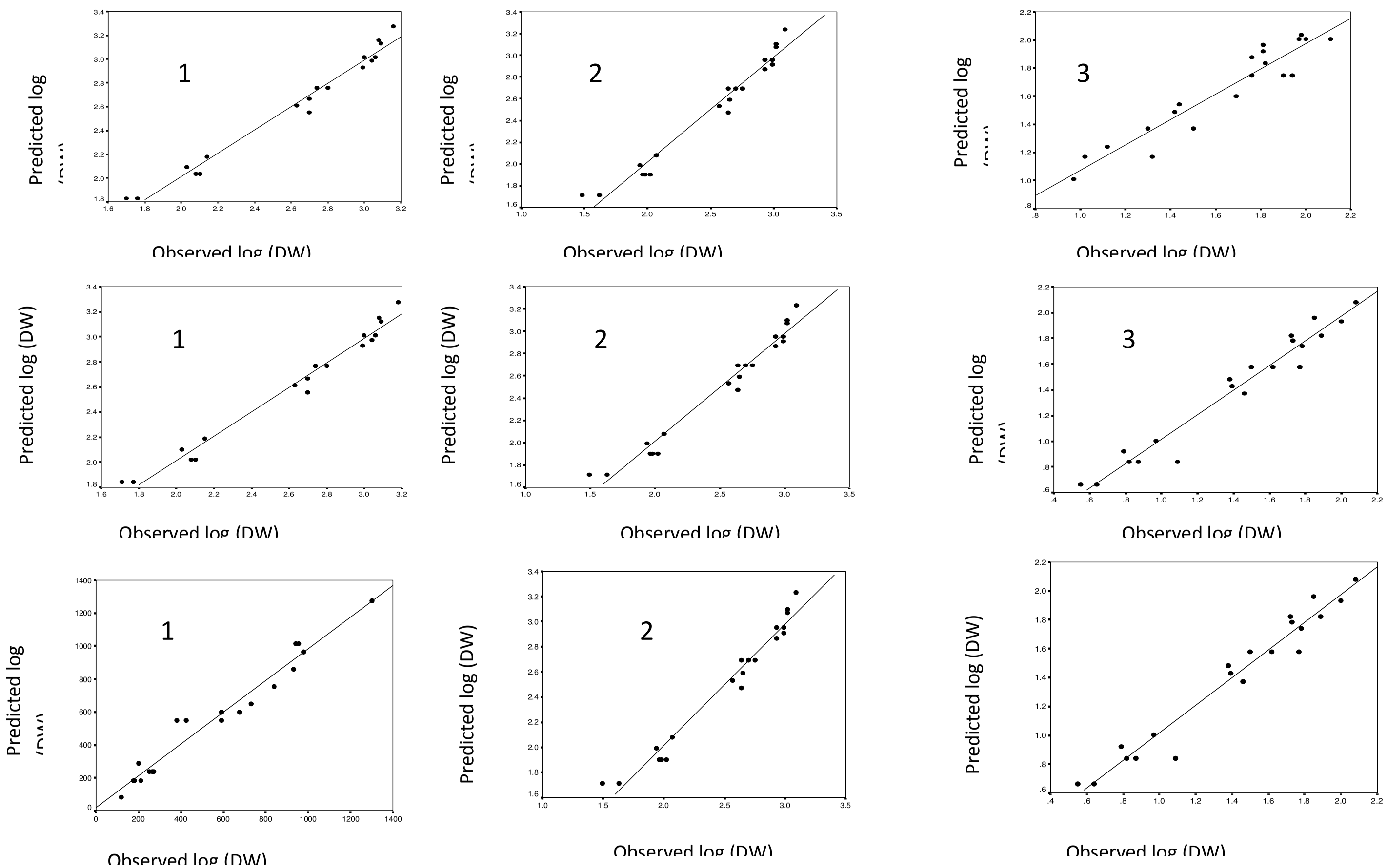

Fig. 1. Predicted versus observed log (DW) of total tree (1), stem wood (2), and bark (3) of *E.globulus* (a), *E.grandis* (b) and *E.saligna* (c) at the age of 15, 14, and 17 years,

Eucalyptus globulus

Dry weight of total tree and stem wood showed better relationship when H was included as independent variable. However, the significance of including H in the independent variable was very little. R^2 improved only by 2 and 4%, respectively (Table 1). Given the significant increase for work required to obtain H, it is probably not cost-effective to add this variable to the model.

For total tree and stem wood, R^2 varied from 0.90 to 0.95; indicating that over 90% of the proportion of variation in dry weight of total tree and stem wood was accounted by DBH, DBH^2 or DBH^2*H. Statistically significant relationship existed between independent variables and dry weight of total tree and stem wood ($P<0.001$) (Table 1).

The allometric relationship between bark and DBH was also high. All the three independent variables; DBH, DBH^2 and DBH^2*H have very clearly explained the relationship. R^2 varied from 0.85 to 0.90; indicating that 85-90% of the variability in dry biomass was accounted by DBH and H (Table 1).

The allometric relationship between independent variables and dry weights of branch and foliage was low. R^2 varied from 0.56 to 0.69. This indicated that only 56-69% of the proportion of variability in dry biomass was accounted by independent variable; DBH, DBH^2, or DBH^2*H, leaving 30-40% of the variation for other factors. The variation of the SE around the mean was also high (12-17%) (Table1). Regression with low R^2 is considered inappropriate for indirect determination of tree component dry weight (Senelwa and Sims, 1998). Therefore, no prediction model was selected for branch and foliage components.

The prediction ability of the selected equations was tested by comparing predicted with observed dry weight of aboveground components. For total tree, trees with bigger DBH (≥33 cm) showed a tendency of overestimating the dry matter. However, this was stabilised by trees of medium DBH groups. The difference between observed and estimated dry biomass for all sampled trees was 0.4%. The predicted dry weight of aboveground components of sample trees was less by 0.4% from the observed ones. This showed that the prediction ability of the selected regression equation performed well and is in good agreement with validation data.

The prediction ability of the equation for stem wood did not show underestimation or overestimation trend in small and medium DBH groups; but for trees >30 cm DBH, the equation overestimated the dry biomass. The selected equation overestimated stems wood dry matter of sample trees by 1.2%. The variation between observed and predicted dry biomass of bark was also little. It showed a tendency of overestimation by 0.77%.

In all cases, there was a high correlation between DBH and dry weight of aboveground components of *E. globulus*. The high correlation between aboveground components and DBH showed that tree biomass is a function of DBH; as has been postulated by several earlier researchers (Whittaker and Woodwell, 1968; Crow, 1978; Wang et al., 1991; Shiver and Brister, 1992; Tietema, 1993).

E. globulus at the age of 15 year with stand density of 544 trees/ha at the time of sampling, the dry weight of total tree was estimated as being 333.7 t/ha MAI being 27.8 t/ha/yr. Negi and Sharma (1984) reported that 13-year-old *E. globulus* plantation in Tamil Nadu (India), produced 162 t/ha aboveground dry matter. For bole, branch, foliage, and bark, the reported dry weight was 58.8, 6.3, 7.3, and 9.3%, respectively.

Eucalyptus grandis

The allometric relationship between dependent variables (dry weight of total tree, stem wood, bark) and independent variables (DBH, DBH^2 and DBH^2*H) was very high. The inclusion of H in the independent variable did not show any significant influence in the relationship (R^2 for stem wood improved by 1%). R^2 varied from 0.94 to 0.98 for total tree, stem wood and bark; indicating that over 94% of the proportion of variation of dry weight of total tree, stem wood and bark was accounted by DBH, DBH^2, DBH^2*H (Table 1).

Statistically significant relationship existed between independent and dependent variables (total tree, stem wood, bark) ($P<0.001$). The observed and predicted values were adequately comparable; the SE was low and varied from 0.071 to 0.115; indicating that ≥90% of the error variance was around the mean (Table 1).

Eucalyptus saligna

The allometric relationship between total tree and independent variables (DBH, DBH^2 and DBH^2*H) was very high. The inclusion of H in the independent variable has improved R^2 by 6%. R^2 varied from 0.91 to 0.97 indicating that over 91% of the proportion of the variation in dry weight of total tree was accounted by DBH, DBH^2, or DBH^2*H. The highest R^2 was obtained for total tree when the independent variable was DBH^2*H (Table 1). Statistically significant relationship existed between independent variables and dry weight of total tree ($P<0.001$). The observed and predicted values were comparable.

The allometric relationship between dependent variables (branch and foliage dry biomass) and independent variables (DBH and H) was poor. R^2 varied in the range of 0.12-0.53; indicating that only 12-53% of the proportion of the variability in dry biomass was accounted by the independent variables; DBH, DBH^2 or DBH^2*H (Table 1). The poorest relationship existed between branch and predictor variables. The deviation of SE from the mean was also high, varying in the range of 16.7-27.4%; the highest percent of deviation observed for branch component (Table 4).

Therefore, it was recognised that branch and foliage dry biomass of *E.saligna* cannot be estimated accurately by easily measurable dimensions like DBH and H because the relationship of the dry biomass of branch and foliage was very poorly explained by easily measurable independent variables. Branch and foliage dry weight can be estimated with low accuracy up to 53%.

In the current study, the aboveground dry matter for *E. saligna* at age of 17 year with stands density of 788 trees/ha was estimated at 420.8 t/ha. The MAI was estimated at 28.05 t/ha/yr. The average across sampled trees dry biomass allocated in stem wood, branch, foliage and bark in relation to total tree was 86.0, 3.9, 2.8 and 7.3%, respectively. Biomass production of over 40 t/ha/yr for tropical plantations has been reported by Lugo et al. (1988); Evans (1992); and Binkley and Giardina (1997). The current results of *E. saligna* plantation in Ethiopia indicate that it is among those highly productive tropical plantations reported elsewhere.

Biomass distribution in components and total tree

Eucalyptus globulus

The dry weight of the aboveground components of *E. globulus* showed a large variation between the sampled trees. The average values of dry weight for total tree, stem wood, branch, foliage and bark were 613.0±339.9, 513.2±299.5, 23.7±12.3, 21.0±11.8 and 52.5±28.1 kg, respectively. Based on the above values, dry matter allocation in stem wood, branch, foliage and bark in relation to total tree dry weight were 82.4, 4.8, 3.9 and 8.8%, respectively. On a hectare base, the AGB dry weight of all the components is about 337.7 tons.

Eucalyptus grandis

For *E. grandis* of age of 14, DBH and H ranged from 12 to 40 cm and 13.9 to 47.1 m, respectively. The average dry weight for total tree, stem wood, branch, foliage, and bark were 600.2±467.2, 515.0±404.0, 27.8±19.4, and 17.6±15.2 and 39.8±34.0 kg, respectively. The dry weight allocation between stem wood, branch, foliage, and bark in relation to total tree were 82.9, 6.8, 3.6, and 6.7%, respectively. The estimated AGB per hectare is estimated to be 389.0 tons/ha.

Eucalyptus saligna

For *E. saligna* of age of 17, DBH and H ranged from 16 to 39 cm and 27.3 to 48.0 m, respectively. The average values of dry matter for total tree, stem wood, branch, foliage and bark were 550.7±351.0, 481.2±317.3, 16.6±6.6, 12.5±6.6 and 40.4±26.9 kg, respectively. The dry weight allocation between in stem wood, branch, foliage, and bark in relation to total tree were 85.9, 4.1, 2.6, and 7.3%, respectively. The estimated AGB per hectare was estimated to be 420.8 tons/ha.

Conclusions

In the current study, allometric equations for aboveground components of *E.globulus, E.grandis, and E.saligna* were derived in the form of logarithmically transformed linear allometric equations. The logarithmic transformation of dependent variables showed a good ability to stabilise the variance. From the results, it became clear that no single independent variable consistently produced the most reliable fit for all components. However, this study confirmed the existence of strong allometric relationship between aboveground components and easily measurable parameter, DBH. In general, the allometric equations with DBH^2 as an independent variable over-weighed other variables in dry biomass estimation of tree components.

The study showed that variations in biomass distribution in the aboveground components were considerable within sampled trees in the respective forest stands. This resulted due to variability of individual trees in size structure. For all size ranges, stem wood accounted for high proportion (82.4 to 85.9%) in relation to dry AGB in three *Eucalyptus* species.

Some differences were observed between predicted and observed dry weight of aboveground components, calculated using the developed models. The observed differences were either underestimations (for smaller diameters) or overestimations (for bigger diameters), which were in the range of 0.4-7%. Even though the differences investigated were small, further studies using stands growing at several sites will provide a better understanding of factors that influence the magnitude of deviations between predicted and observed biomass values.

In conclusion, this study has produced useful allometric equations that allow prediction of biomass of total tree, stem wood, branches, foliage, and bark for three *Eucalyptus* species in Shashemane-Munessa plantation forest. The equations are useful tools in predicting stand productivity. The work adds to the scant, but growing number of studies; which demonstrated good relationship between aboveground components and easily measurable dimension, DBH.

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References

Anonymous. 2003. Rainfall and temperature data of Ethiopia. National Meteorology Service Agency, Addis Ababa, Ethiopia. (unpublished)

Binkley D, C Giardina. 1997. Biological nitrogen fixation in plantations. *In:* Nambiar EKS, Brown A (eds.), Management of soil, water and nutrients in tropical plantation forests. ACIAR Monograph 43, Canberra, pp. 297-337.

Brown S. 1997. Estimating biomass and biomass change of tropical forests - A Primer. FAO, Rome, Italy.

Crow TR. 1978. Common regression to estimate biomass in tropical stands. Forest Science, 24(1): 110-114.

Evans J. 1992. Plantation Forestry in the Tropics, 2nd ed. Oxford Science, Oxford, 403p.

FAO. 1988. Soil Map of the World. Revised legend. Reprinted with corrections, World Soil Resources Report 60. FAO, Rome.

Jagger P. J Pender. 2000. The role of trees for sustainable management of less-favoured lands: the case of *Eucalyptus* in Ethiopia. Environment and Production Technology Division, International Food Policy Research Institute, EPDT Discussion Paper No.65. Washington, DC.

Lugo AE, S Brown, J Chapman. 1988. An analytical review of production rates and stem wood biomass of tropical forest plantations. Forest Ecology and Management, 23: 179-200.

Michael S, L Beck. 1993. Regression analysis. International Handbooks of Quantitative Applications in Social Sciences, University of IOWA. SAGE Publications, Toppan Publishing. USA.Volume 2.

Negi JD, DC Sharma. 1984. Distribution of nutrient in an age series of *Eucalyptus globulus* in Tamil Nadu. Indian Forester 110(8): 944-953.

Pohjonen, V, T Pukkala. 1991. Which *Eucalyptus* grows best in Ethiopia? *Biomass and Bioenergy* 1: 193-195.

Pohjonen, V. T Pukkala. 1990. *Eucalyptus globulus* in Ethiopian forestry. Forest Ecology and Management. pp 36:19-31.

Schlaegel BE. 1982. Testing, reporting and using biomass estimation models. *In:* Gresham CA, W Belle, SBaruch (eds). Proceedings of the Third Annual Southern Forest Biomass Workshop, Forest Science Institute, Clemson University, Clemson

Senelwa K, REH Sims. 1998. Tree biomass equations for short rotation *Eucalyptus* grown in New Zealand. Biomass and Bioenergy 13(3): 133-140.

Shiver BD, GH Brister. 1992. Tree and stand volume functions for *Eucalyptus saligna*. Forest Ecology and Management, 47:211-223.

Ter- Mikaelian MT, MD Korzukhin. 1997. Biomass equation for sixty-five North American tree species. Forest Ecology and Management, 97: 1-24.

Tietema T. 1993. Biomass determination of fuel wood trees and bushes of Botswana, Southern Africa. Forest Ecology and Management, 60: 257-269.

Wang YP, PJ Jarvis, CMA Taylor. 1991. Par absorption and its relation to aboveground dry matter production of Sitka spruce, Journal of Applied Ecology, 28:247-260.

Whittaker RH, GM Woodwell. 1968. Dimension and production relations and shrubs in Brookhaven forest, New York. Journal of Ecology, 1-25.

Young HE. 1976. A summary and analysis of weight tables studies. In: Oslo Biomass Studies, College of Life Sciences and Agriculture, Univ. of Maine at Orono. pp. 251-281.

Zerfu H, 2002. Ecological impact evaluation of *Eucalyptus* plantation in comparison with agricultural and grazing land-use types in the Highlands of Ethiopia. Ph.D. dissertation. Institute of Forest Ecology, Vienna, Austria. pp1-81.

Impacts of *Eucalyptus globulus* Labill. Plantation on Regeneration of Woody Species at Entoto Mountain, Addis Ababa

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Abstract

This study was carried out in the *Eucalyptus globulus* plantation of the Entoto Mountain near Addis Ababa, Ethiopia to assess the impact of *Eucalyptus globulus* plantation on the naturally regenerated woody species. A total of sixty plots with a size of 400 m ^{2} (20 m X 20 m) were established along transect lines at every 300 m distance between each plot. Transects were laid in the north–south directions at 500 m distance interval from each other. Seedlings, herbaceous species, and soil samples were colleted from five sub-plots with a size of 2 m X 2 m each within each major plot. A total of 68 plant species belonging to 55 genera and 32 families were identified. Asteraceae (8 species) was the most dominant family. Out of the total 68 plant species, 41 of them were naturally regenerated woody species. They represented 33 genera and 25 families. The remaining plant species are not woody species. For the analysis of vegetation diversity, woody species density, and soil environmental factors, the individual *E. globulus* plantation stands were used to classify the plots into three categories. These are C1 (plots with less than 154 *E. globulus* stands or < 64 stems/ha), C2 (plots consisting of 154 to 199 *E. globulus* stands or ≥ 64 to 83 stems/ha) and C3 (plots with greater than 199 *E. globulus* stands or > 83 stems/ha). Twenty plots were identified for each category. There was significant difference ($P < 0.05$) in the species diversity (H') between C1 and C2, as well as C1 and C3 while there was no significant difference between C2 and C3. The species richness was also significantly different ($P < 0.05$) for the three density categories of *E. globulus* stands. The species diversity and species richness increased with the decrease in *E. globulus* stem density and vice versa. Sorenson similarity index showed highest similarity between C1 and C2 while C2 and C3 were dissimilar. The density of naturally regenerated woody species showed a decreasing trend with the increase in the density of *E. globulus* plantation and vice versa. Therefore, the density of *E. globulus* plantation was negatively correlated with density of naturally regenerated woody species. There was no significant difference between the three density categories of *E. globulus* plantations in their major soil nutrient contents. Generally, the less dens stands of *E. globulus* plantations harbor more naturally regenerated woody species than the more dens stands of *E. globulus* plantation or vice versa.

Key words: Density, Entoto Mountain, *Eucalyptus globulus*, natural regeneration, plantation, woody species

Introduction

Ethiopia is an important regional centre of biological diversity, and the flora and fauna have a rich endemic element (Sayer *et al*., 1992; WCMC, 1992). The country has the fifth largest flora in tropical Africa. The flora of Ethiopia is very heterogeneous and is estimated to include about 6000 species of higher plants, and about 10% of these are endemic (Vivero *et al*., 2005).

The natural forests of the country, particularly the *Juniperus procera*, *Olea europea* subsp. *cuspidata*, and *Podocarpus falcatus* stands around the capital city were depleted long ago due to deforestation for fuel and construction material. The scarcity of fuel wood and construction material was what forced Menilek II to introduce fast growing exotic species for plantation development in 1895 (Breitenbach, 1961; Davidson, 1995). The introduction of *Eucalyptus* species was a great success. The planting of *Eucalyptus* species particularly, *Eucalyptus globulus* and *Eucalyptus camaldulensis* for fuel was expanding near Addis and other small towns in the country. *E. globulus* was the most successful of the introduced *Eucalyptus* species and was quickly adopted by farmers. The reason for the widespread early popularity and success of the blue gum can be attributed to its fast growth, coppicing ability, the unpalatability of its leaves, and its adaptability to a wide range of site conditions (FAO, 1981). However, this is true for most *Eucalyptus* species. Although plantations have such, and many other benefits, they are widely perceived negatively in relation to biological diversity conservation and other environmental impacts (Shiva and Bandyopadhyay, 1983; Poore and Fries, 1985; Bhaskar and Dasappa, 1986; Florence, 1986; Carnus *et al*., 2003).

One of the criticisms associated with *Eucalyptus* species plantation is the impediment of the establishment of other plants in their understory by out-competing for moisture and nutrients, as well as by direct inhibition through phytotoxic exudates from leaves and litter (Shiva and Bandyopadhyay, 1983; Poore and Fries, 1985; Florence, 1986). In contrast to this view, many plantations of *Eucalyptus* species have been found to host high herbaceous species richness and foster natural regeneration of woody species (Holgen and Svensson, 1990; Pohjonen and Pukkala, 1990; Michelsen *et al.*, 1996; Feyera and Demel, 2001; Eshetu Yirdaw, 2002; Mulugeta Lemenih, 2004). Plantations in general and *Eucalyptus* plantation in particular can have a catalytic effect on the regeneration of native species and can be used as a management tool for restoration of degraded forest lands (Lugo, 1997; Yitebtu Moges, 1998; Engelmark, 2001; Eshetu Yirdaw, 2002; Feyera Senbeta *et al*., 2002; Mulugeta Lemenih and Demel Teketay, 2004; Mulugeta Lemenih *et al*., 2004).

However, the controversy over the impacts of *Eucalyptus* plantation persisted (Jagger and Ponder, 2000), and has been a serious barrier to take advantage of the positive fostering effect of the genus on for biodiversity management. In this study data is collected on naturally regenerated species under coppice stands of *Eucalyptus globulus* to generate valuable information on its effect on native species. Furthermore, the current plantation management system deserves a close scrutiny. In view of this, the present study was carried out with the main objective to assess the impact of *E. globulus* plantations on the regeneration of woody species, and the following specific objectives in mind to (a) identify the vegetation composition of the study area, (b) assess species diversity, species richness and evenness under various categories of *E. globulus* plantations of the study area, (c) assess the current regeneration status of woody species under *E. globulus* plantation, and (d) determine the correlation between species with environmental factors.

Materials and Methods

The study area

The study was conducted in Entoto-mountain range that surrounds the city Addis Ababa between latitudes 9º 04' to 9º 05' N and longitudes 38º 43' to 38º 47' E. The altitude range of the study area is between 2596 and 2956 m a.s.l. The soil catena (topo-sequence) of Entoto Mountain includes Nitisols at higher altitude and Cambisols in the middle of the hill. Down the mountain, Vertisols have been formed from the finest erosion material (Tobias, 2004). All these soils are considered fertile. The color is blackish brown due to a high content of basalt, a rock type that generally has a considerable weathering potential (Tobias, 2004). Analysis of the meteorological data show that the mean annual temperature of the study area is 13.1 ^{0}C, ranging from a mean minimum of 8.2 ^{0}C to a mean maximum of 18 ^{0}C. The hottest month is May (mean maximum temperature of 20.1 ^{0}C), while the coldest month is December (mean minimum temperature of 7.0 ^{0}C). The mean annual rainfall of the area is 1233.1 mm. Generally, the study area has a bimodal type of rainfall pattern. The short rainy season extends from March to May, and the long rainy season ranges from July to September. Most of the rain comes in July and August. The original vegetation of Entoto belongs to the dry tropical Afromontane forest common to the central highlands of Ethiopia. *Juniperus procera*, *Olea europea* subsp. *cuspidata*, and *Podocarpus falcatus* forest, which were once abundant on the Entoto Mountain, vanished due to over exploitation (Pohjonen, 1989).

Vegetation Sampling

In this study, a systematic sampling design was used to collect data on vegetation and environmental variables. A total of 60 plots of size 20 m x 20 m (400 m^2) were systematically laid in north–south directions using Compass. The distance between consecutive plots along the transect line was 300 m. Thirteen transects were laid at 500 m distance from each other. For the collection of herbaceous species, subplots of 2 m x 2 m (4 m^2) at the four corners and the center of the large plots were laid.

These subplots were also used for collection of composite soil samples. The cover abundance of plant species in each plot was estimated. Plant specimens were collected, pressed, dried, checked, and identified at the National Herbarium (ETH), Biology Department of the Addis Ababa University. In each major plot, altitude and geographical positions in degrees and UTM were taken using GPS (Global Position System).

Soil sampling and analyses

Soil samples were collected with a soil auger from the top 1-30 cm depth in each of the subplots and mixed to make a composite and representative sample for each plot independently. Soil samples were air-dried and sieved with 0.2 mm wire mesh for labouratory analysis. Soil chemical analysis was made in the Soil Labouratory of Water Works Design and Supervision Enterprise (WWDSE). The Soil pH was determined in 1:2.5 pH-H_2O using pH meter; soil moisture using hygrometer method; exchangeable bases (Ca and Mg) using Volumetric method; K, Na and CEC using Instrumental Finishing method; Nitrogen following Kjeldahl method; organic carbon following Walkey and Black's titration method; available K following ammonium acetate extraction method, and available phosphorus following Olsen *et al.,* 1954.

Data analysis

For the analysis of vegetation diversity, woody species density, and soil variables in the *E. globulus* plantation stands were used to classify the plots into three density categories. These are C1 (plots with less than 154 *E. globulus* stands or < 64 stems/ha), C2 (plots consists of 154 to 199 *E. globulus* stands or ≥ 64 to 83 stems/ha) and C3 (plots with greater than 199 *E. globulus* stands or > 83 stems/ha). Twenty plots were identified for each category. Shannon and Wiener (1949) index of species diversity was computed to describe species diversity and richness for the three categories aforementioned. The Shannon-Wiener Diversity Index (H') was computed and the result was crosschecked by using PC-ORD Version 4.20 Statistical Software Package (McCune and Mefford, 1999). Moreover, One-way ANOVA and LSD (Least Significant Difference) test was run to compare the species diversity (H') and species richness of the three density categories. Similarity in species composition among the *E. globulus* plantation categories was computed using Sorensen similarity index (Kent and Coker, 1992). SPSS (2007) Version 15.0 software was used to calculate Pearson Correlation Coefficient among species diversity, species richness, environmental factors, and to see the correlation between the density of *E. globulus* plantation and density of naturally regenerated woody species. Soil data were also analyzed using statistical SPSS (2007) Version 15.0 software program. One-way ANOVA was used. Mean differences were compared by LSD test at the same level of probability.

Results and Discussion

Vegetation Composition

A total of 68 plant species were recorded belonging to 55 genera and 32 families. Out of the 68 identified species, 36.8% were herbs, 1.5% climbers, 4.4% liana, 36.8% shrubs, 8.8% trees/shrubs and 11.8% were trees.

Diversity and Similarity of regeneration under *Eucalyptus globulus* plantations

Shannon-Wiener diversity index, species richness, and species evenness, under the three density categories of *E. globulus* plantation stands in Entoto showed considerable variation (Table 1). The low-density *E. globulus* stands (C1) exhibited the highest mean values of Shannon species diversity (3.129), species richness (61) and evenness (0.761), followed by C2 with 2.872 species diversity, species richness (58) and evenness (0.701), while the high density stands (C3) exhibited the lowest mean values of Shannon species diversity (2.653), species richness (45) and evenness (0.697). The difference in the species diversity (H') between C1 and C2, C1 and C3 was significant ($P < 0.05$), while there was no significance difference between C2 and C3. The species richness was also significantly different ($P < 0.05$) among the three density categories of *E. globulus* plantations.

E. globulus plantation stands that had high Shannon-Wiener diversity indices contained high mean species richness. Therefore, the less dense stands of *E. globulus* harbors more regenerated plant species than the high dense stands. This result agrees with the study by Mulugeta Lemenih (2004) who demonstrated the inverse relationship between canopy cover density and diversity of naturally regenerating species in central Ethiopian highlands. This implies that factors such as photosynthetically active radiation (PAR) reaching forest floor seem to have a substantial impact on the regeneration and recolonization of native flora in forest plantations. Relatively highest species similarity index was observed between the C1 and C2 categories (0.47). On the other hand, C2 and C3 categories showed relatively weak similarity (0.44) (Table 2).

Table 1: Shannon-Wiener diversity index (H'), species richness and species evenness, under the three categories of *E. globulus* plantation in Entoto

Stem density category	Shannon index (H)	Species richness (S)	Evenness (E)
C1	3.129	61	0.761
C2	2.872	58	0.701
C3	2.653	45	0.697

Table 2: Sorensen similarity index among the *E. globulus* plantations in Entoto

Stem density category	C1	C2	C3
C1	1.00		
C2	0.47	1.00	
C3	0.46	0.44	1.00

Variation in density of regenerated woody species in *E. globulus* plantations

In total, 41 naturally regenerated woody species were recorded in Entoto *E. globulus* plantation. In the total density of stems ha^{-1} C1, C2 and C3 of *E. globulus* plantation; 1291 stems ha^{-1} in C1, 1259 stems ha^{-1} in C2 and 1066 stems ha^{-1} in C3 of naturally regenerated woody species density were recorded in that order (Fig 1). The trend shows a decrease in the density of naturally regenerated woody species with an increase in the density of *E. globulus*. Pearson's correlation showed a strong negative relationship (r = - 0.967 at $P < 0.05$) between the density of *E. globulus* plantation and density of naturally regenerated woody species. The number of naturally regenerated woody species recorded under *E. globulus* plantation in this study was relatively higher than the number of species recorded under some of the exotic plantation species in Ethiopia. For example, Feyera Senbeta and Demel Teketay (2001) recorded 37 species under *E. globulus, E. saligna, Pinus patula,* and *Cupressus lusitanica* on the central highlands of Ethiopia. The number of woody species recorded in the *Eucalyptus* plantations at Chancho and Menagesha were 20 and 22, respectively (Eshetu Yirdaw, 2001). The total number of regenerated woody species at the present study site (41 species) is very close to previous reports from Jirren forest, South-Western Ethiopia (40 species) (Getachew Tesfaye and Abiyot Berhanu, 2006), but lower than the one recorded in Munessa-Shashemene (55 species) (Feyera Senbeta *et al*., 2002).

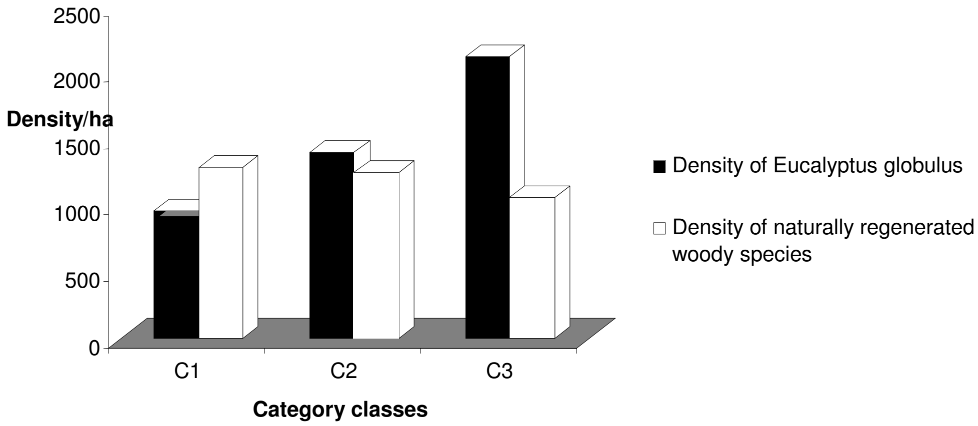

Figure 1: Density distribution of naturally regenerated woody species and *E. globulus* in three density categories.

Soil properties

The three density categories of *E. globulus* plantations did not show statistically significant difference with respect to their soil chemical properties such as moisture content, pH, exchangeable Na, exchangeable K, exchangeable Ca, exchangeable Mg, cation exchange capacity, organic carbon, total nitrogen, available P and available K.

Environmental factors vis-à-vis species diversity and richness

The output of pearson`s correlation coefficient showed that the trend of correlation of species diversity, species richness and environmental factors under the three categories of *E. globulus* plantations. Species diversity has a significant ($P < 0.05$) positive correlation with altitude ($r = 0.558$) in C1, while in C2 and C3, species diversity has a no significant correlation with altitude. Similarly, species richness has no positive correlation with altitude in C1, but showed a negative correlation in C2, and C3. Nitrogen (N), Phosphorus (P), Potassium (K), Calcium (Ca) and Magnesium (Mg) contents have no significant correlation with species diversity and species richness in the three density categories of *E. globulus* plantations.

Conclusion and Recommendations

The results of this study indicated that the species diversity, density, and species richness increased with decreasing *E. globulus* stems ha^{-1} or vice versa at Entoto Mountain, Addis Ababa, Ethiopia. Thus, the less dens stands of *Eucalyptus globulus* plantations harbor more naturally regenerated woody species than the more dens stands of *Eucalyptus globulus* plantation or vice versa. Generally, in degraded high rainfall areas, *E. globulus* plantations may play a role in fostering the regeneration of native plant species.

The results in this research provide an important indication that *Eucalyptus* plantations play a significant role in fostering regeneration of indigenous species. However, further investigation needs to be done to generate more in depth knowledge on the interaction between *E. globulus* and naturally regenerated woody species. Therefore, to conserve naturally regenerated woody species in *E. globulus* plantations, appropriate management strategy is vital. For example, less dens *E. globulus* plantations stands harbor more naturally regenerated woody species than more dense *E. globulus* plantation stands. Thus, less plantation density should be practiced to encourage natural regeneration of woody species. It would be advisable to initiate further research related to the allelopathic effects of more and less dense *E. globulus* plantations on the naturally regenerated woody species. For an optimum number of *E. globulus* plantation per unit area, spacing research has to be initiated. In addition, the status of soil seed bank has to be investigated to determine the sources of regeneration other than seedlings and saplings stocks.

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References

Bhaskar V, V Dasappa. 1986. Ground flora in *Eucalyptus* plantations of differentages. In: Sharma J.K., Nair C.T.S., Kedharnath S. and Kondas S. (eds). *Eucalyptus* in India: Past, Present and Future. Kerala Forest Research Institute, Peechi, Kerala, India, pp. 213–224.

Breitenbach F. 1961. Exotic forest trees in Ethiopia. A.A. Ethiopia Forestry Association; *Ethiopian Forestry Review*. 2:19-39.

Carnus JM, J Parotta, E Brockerhoff, M Arbez, H Jactel, A Kremer, D Lamb, K O'Hara, B Walters. 2006. Planted forests and biodiversity. Journal of Forestry 104: 65-77.

Davidson J. 1995. Eucalypts Tree Improvement and Breeding. Ministry of Natural Resources Development and Environmental Protection, Addis Ababa.

Engelmark O. 2001. Ecological Effects and Management Aspects of an Exotic Tree Species: The Case of Lodgepole Pine in Sweden. Forest Ecology and Management 141: 3-13.

Eshetu Yirdaw. 2001. Diversity of Naturally Regenerated Native Woody Species in Forest Plantations in the Ethiopian Highlands. New Forests 22: 159-177.

Eshetu Yirdaw. 2002. Restoration of the Native Woody Species Diversity Using Plantation Species as Foster Trees in the Degraded Highlands of Ethiopia: Academic Dissertation. University of Helsinki, Finland.

FAO. 1981. Eucalypts for Planting. FAO Forestry and Forest Products Studies 11. FAO, Rome.

Feyera Senbeta, Demel Teketay. 2001. Regeneration of Indigenous Woody Species Under the Canopy of Tree Plantations in Central Ethiopia. *Tropical Ecology* 42: 175-185.

Feyera Senbeta, Demel Teketay, N Bert-Ake. 2002. Native Woody Species Regeneration in Exotic Tree Plantations at Munessa-Shashemene Forest, Southern Ethiopia. New Forests 24: 131-145.

Florence RG. 1986. Cultural problems of *Eucalyptus* as exotics. *Commonwealth Forest Review* 65: 141–163.

Getachew Tesfaye, Abyot Berhanu. 2006. Regeneration of indigenous woody species in the understory of exotic tree species plantations in southwestern Ethiopia. *Ethiop. J. Biol. Sci*., 5 (1): 31-43.

Holgen P, M Svensson. 1990. Loss of Inorganic Nutrients by Whole Tree Utilization for Firewood in Ethiopia. Working paper 150. Swedish University of Agricultural Sciences, International Rural Development Centre, Uppsala, Sweden.

Jagger P, J Pender. 2000. The role of trees for sustainable management of less-favored lands: the case of *Eucalyptus* in Ethiopia. EPTD Discussion Paper No. 65. International Food Policy Research Institute, Washington D.C., USA.

Kent M, P Coker. 1992. Vegetation Description and Analysis: A practical Approach. Belhaven Press, London, 263pp.

Lugo AE. 1997. The apparent paradox of reestablishing species richness on Degraded lands with tree monocultures. Forest Ecology and Management: 99: 9-19.

McCune B, MJ Mefford. 1999. PC-ORD. Multivariate Analysis of Ecological Data, Version 4.20. MjM Software Design Gleneden Beach, OR 97388 USA.

Michelsen A, Lisanework Nigatu, I Friis, N Holst. 1996. Comparisons of Understory Vegetation and Soil Fertility in Plantations and Adjacent Natural Forests in Ethiopian Highlands. Journal of Applied Ecology 33: 627-642. Mulugeta Lemenih (2004). Effects of land use change on soil quality and native flora degradation and restoration in the highlands of Ethiopia. PhD dissertation. ISSN 1401-6230, ISBN 91-576-6540-0, Swedish University of Agricultural Sciences, Department of Forest Soils, Uppsala. 1-64.

Mulugeta Lemenih, Demel Teketay. 2004. Restoration of Native Forest Flora in the Degraded High Lands of Ethiopia: Constraints and opportunities. SINET: Ethiopian Journal of Science. 27: 75-90.

Mulugeta Lemenih, Taye Gidyelew, Demel Teketay. 2004. Effects of Canopy Cover and Understory Environment of Tree Plantations on Species Richness, Density and Sizes of Colonizing Woody Species in Southern Ethiopia. Forest Ecology and Management 194: 1-10.

Olsen SR., CV Cole, S Watanabe, LA Dean. 1954. Estimation of Available Phosphorus in Soils by Extraction with Sodium Bicarbonate: Circular No. 939. U.S Department of Agriculture, Washington DC.

Pohjonen V. 1989. Establishment of fuel wood plantations in Ethiopia. University of Joensuu, Finland, 7-387.

Pohjonen V, T Pukkala. 1990. *Eucalyptus globulus* in Ethiopian forestry. *Forest Ecology and Management* 36: 19–31.

Poore MED, C Fries. 1985. The Ecological Effects of *Eucalyptus.* Forestry Paper 59. FAO, Rome.

Sayer AJ, SC Harcourt, MN Collins. 1992. The conservation atlas of tropical forests Africa. IUCN, Cambridge, UK. 288 p.

Shannon, C.E. and Wiener, W. (1949). The Mathematical Theory of Communication. University of Illinois, Chicago, USA.

Shiva V, J Bandyopadhyay. 1983. *Eucalyptus*–a disastrous tree for India. *The Ecologist* 13: 184–187.

SPSS. 2007. Windows Version: 15. Vista HOTFIX. exe.

Tobias O. 2004. Social and environmental issues on the removal of fuel-wood and Litter from *Eucalyptus* stands around Addis Ababa, Ethiopia. Swedish University of Agricultural Sciences, SLU External Relations, Uppsala, 27pp.

Vivero JL, Ensermu Kelbessa, Sebsebe Demissew .2005. Progress on the Red List of plants of Ethiopia and Eritrea: Conservation and biogeography of Endemic flowering taxa. *In:* Ghazanfar SA, HJ Beentje (eds). *Biodiversity, Ecology, Taxonomy and Phytogeography of African plants*. Proceedings of the 17th AETFAT Congress. Royal Botanic Gardens, Kew, London and National Herbarium, Addis Ababa University, Ethiopia.

World Conservation Monitoring Centre. 1992. Global biodiversity. Status of the earth's living resources. Chapman and Hall, London.

Yitebtu Moges. 1998. The Role of Exotic Plantation Forests in Fostering the Regeneration of Native Trees in an Afromontane Forest Area in Ethiopia. MSc Thesis, Wageningen Agricultural University, Wageningen.

Appendix: List of all plant species, family, and growth habit recorded from Entoto Mountain.

Botanical name	Family	Habit
Acacia abyssinica Hochst. ex Benth	Fabaceae	Tree
Alchemilla pedata A. Rich.	Rosaceae	Herb
Asparagus africanus Lam.	Asparagaceae	Shrub
Asparagus setaceus (Kunth) Jessop	Asparagaceae	Shrub
Bersama abyssinica Fresen.	Melianthaceae	T/S
Carduus schimperi Sch. Bip. ex A.Rich.	Asteraceae	Herb
Carissa spinarum L.	Apocynaceae	Shrub
Clerododendrum sp.	Verbenaceae	Shrub
Clutia lanceolata Forssk	Euphorbiaceae	Shrub
Conyza pedunculata (Oliv.) Wild.	Asteraceae	Herb
Conyza pyrrhopappa Sch. Bip. ex A. Rich	Asteraceae	Herb
Crepis rueppllii Sch. Bip	Asteraceae	Herb
Cynodon sp.	Poaceae	Herb
Dichondra repens J. R. and G. Forst.	Convolvulaceae	Herb
Digitaria velutina (Forssk.) P. Beauv.	Poaceae	Herb
Dovyalis abyssinica (A. Rich.) Warb	Flacourtiaceae	Shrub
Dovyalis verrucosa (Hochst.) Warb.	Flacourtiaceae	Shrub
Dyschoriste radicans Nees	Acanthaceae	Herb
Ekebergia capensis Sparrm.	Meliaceae	Tree
Erica arborea L.	Ericaceae	Shrub
Eucalyptus globulus Labill.	Myrtaceae	Tree
Exotheca sp.	Poaceae	Herb
Helichrysum glumaceum Dc.	Asteraceae	Herb
Hypoestes forskaolii (Vahl) R. Br.	Acanthaceae	Herb
Jasminum abyssinicum Hochest. ex Dc.	Oleaceae	Liana
Jasminum grandiflorum L. subsp. *floribundum* (R. Br. ex Fresen.) P. S. Green	Oleaceae	Liana
Jasminum stans Pax	Oleaceae	Shrub
Juniperus procera Endl.	Cupressaceae	Tree
Lactuca inermis Forssk.	Asteraceae	Herb
Laggera tomentosa (Sch. Bip. ex A. Rich.) Oliv. and Hiern	Asteraceae	Shrub
Linum trigynum L.	Linaceae	Herb
Lippia adoensis Hochst. ex Walp.	Verbenaceae	Shrub
Lotus corniculatus L.	Fabaceae	Herb
Maesa lanceolata Forssk.	Myrsinaceae	T/S
Maytenus arbutifolia (A. Rich.) Wilczek	Celastraceae	T/S
Maytenus gracilipes (Welw. ex Oliv.) Exell	Celastraceae	Shrub

Maytenus senegalensis (Lam.) Exell	Celastraceae	Shrub
Myrsine africana L.	Myrsinaceae	Shrub
Nuxia congesta R. Br. ex Fresen	Loganiaceae	T/S
Olea europaea L. subsp. *cuspidata* (Wall. ex G. Don) Cif., L'Olivicoltore	Oleaceae	Tree
Olinia rochetiana A. Juss.	Oliniaceae	T/S
Osyris quadripartita Decn.	Santalaceae	T/S
Pennisetum squamulatum Fresen.	Poaceae	Herb
Pentas lanceolata (Forssk) Defl.	Rubiaceae	Shrub
Pentas schimperiana (A. Rich.) Vatke	Rubiaceae	Shrub
Podocarpus falcatus (Thunb) Mirb.	Podocarpaceae	Tree
Premna schimperi Engl.	Lamiaceae	Shrub
Prunus africana (Hook. f.) Kalkm.	Rosaceae	Tree
Rhamnus staddo A. Rich.	Rhamnaceae	Shrub
Rhus vulgaris Meikle	Anacardiaceae	Shrub
Rosa abyssinica Lindley	Rosaceae	Shrub
Rubia cordifolia L.	Rubiaceae	Climber
Rubus apetalus Poir.	Rosaceae	Shrub
Satureja abyssinica (Benth.) Briq.	Lamiaceae	Herb
Satureja imbricata (Forssk.) Briq.	Lamiaceae	Shrub
Satureja punctata (Benth.) Briq.	Lamiaceae	Shrub
Scabiosa columbaria L.	Dipsacaceae	Herb
Scolopia theiofolia Gilg	Flacourtiaceae	Tree
Sida tenuicarpa Vollesen	Malvaceae	Shrub
Smilax aspera L.	Smilacaceae	Liana
Sprmacoce sphaerostigma (A. Rich.) Vatke	Rubiaceae	Herb
Stephania abyssinica (Dill. and A. Rich.) Walp	Menispermaceae	Herb
Thymus schimperi Ronniger	Lamiaceae	Herb
Trifolium acaule Steud. ex A. Rich.	Fabaceae	Herb
Trifolium cryptopodium Steud. ex A. Rich.	Fabaceae	Herb
Trifolium rueppellianum Fresen.	Fabaceae	Herb
Trifolium semipilosum Fresen.	Fabaceae	Herb
Vernonia filigera Oliv. and Hiern	Asteraceae	Shrub

Stocking and Coppice Management of *Eucalyptus* Species an Implication to Landuse in Gunchire District, Gurage Zone

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Abstract

Eucalyptus camaldulensis and *E. globulus* woodlots were assessed on the farmlands of 15 households (hh) at Gunchire district of the Guraghe zone. Group discussions were held with tree growers, district forest officials, development agents, and traders. In each hh, 3 plots of 100m^2 were selected as samples for seedling and coppice stand measurement. There were different attitudes towards eucalypt planting from different stakeholders. Tree growers were considering eucalypt as the most productive and land ownership securing asset. Traders were interested in the lucrative eucalypt market that generates good income to them. District officials were against eucalypt planting as the productivity of the coppice is declining with rotations, re-establishment of stands and conversion to other land use is expensive. They also have the opinion that eucalypt woodlots are taking large area of land from annual crops, and natural forests. In their opinion, the production of eucalypt requires appropriate land use planning. We observed that local farmers are managing eucalypt poorly, and their spacing and cutting practices are highly variable. Plot measurements showed that seedling stem density (stocking) varies from 4300 to 24,700 per ha for *E. camaldulensis* (ANOVA, F=3574.6; P 0.01), and 24300 stems per ha for *E. globulus*. The spacing is irregular, uneven, and ranging 0.64m- 1.5m, at 3-4 years old stand. The maximum stem number and volume was obtained at spacing of 72 cm for seedlings stands and at 88 cm for coppicing stumps. In more than 90% of the coppice stands assessed, the cutting height is 5-6cm and on 7% it is 15cm. There are 1-6 shoots kept on the stool for 5-6 years, instead of the recommended, 1 -3 stems at 18months. Therefore, various blames such as excessive water consumption and depletion of soil nutrient could be resolved if appropriate landuse planning and silvicultural treatments like appropriate spacing, and cutting at appropriate methods are used.

Keywords: Coppicing, spacing, landuse, reestablishment, and rotation

Introduction

Eucalypt species is covering the largest proportion of plantation forests in Ethiopia. It accounts for 58% of the total plantation area in the country (EFAP 1994). *Eucalyptus* is a naturalized tree species in Ethiopia (Taddesse et.al. 2002). In Addis Ababa out of the 6000 ha forest land 80-85% is *Eucalyptus* species (Taddesse et.al. 2002). Eucalypt was introduced to Guraghe zone in the same period as it was introduced to Ethiopia, 1907, as that is an area some 150 km southwest of Addis Ababa.

In Guraghe Zone, it is hardly possible to get a farmer without eucalypt plantation or woodlots. *Eucalyptus globulus* in the highlands and *Eucalyptus camaldulensis* in the mid altitude and lowlands are commonly grown. There are small to large-scale plantations of Eucalypt in the district accounting for more than 7000 ha as of the 2004 assessment of both *E. camaldulensis* and *E. globulus* on private farmlands (personal communication with district forest department).

In spite of the good qualities of many of the species of Eucalypt such as fast growth, survival under poor soils, high calorific value and raw material supply in large quantity for subsistent and commercial purposes, a number of people expressed their objection against *Eucalyptus* planting. The main problems associated with eucalypt are high water consumption, suppression of under growth, high soil nutrient uptake, and promotion of soil erosion (Taddesse et.al. 2002).

In Ethiopia, about 90% of the annually produced wood is used for fuel (Alemayehu 1997). Nearly 85% of the total energy consumed is obtained from biomass. The fuel wood deficit in the country is predicted to be doubling in 2014 (EFAP 1994). There is no indigenous tree species that equate to the qualities of eucalypt so far (Taddesse et.al. 2002).Therefore, the long term solution to Ethiopia's rural energy problem requires small to large scale plantations (EARO 2000), with fast growing species like that of eucalypt. It is generally known that in many of eucalypt growing farmers in Gunchire district are getting no technical support to improve the productivity of eucalypt. That is identifying the means of increasing the production of eucalypt yield is highly important so to alleviate landuse competition and to halt mere expansion without productivity. As eucalypt has characteristics of a low forest (vegetative origin like coppicing) and high forest (seed or seedling origin) (Smith et.al. 1997), proper management of coppice and seedling are also important.

The objective of this study was to analyze the perception of eucalypt local actors and to identify the type of eucalypt stands' stocking and coppice management, and the problems that affect the productivity of the common species, *E.camaldulensis* and *E.globulus*,

Material and Methods

The study area

The study was conducted in Guraghe zone in Southern Nations, Nationalities, and Peoples Regional State (SNNPRS) of Ethiopia at Gunchire district (woreda) in March and June 2010. The district is located at 8˚04'03'' latitude and 37˚48' 29.0'' longitude, and the altitude is about 2024m above sea level. All the eucalypt woodlots were owned by private farmers and used for both household wood consumption and as cash crop. The people are heavily dependent on natural resources. Mixed faming is the main livelihood activities of the community. The mixed farming components include annual crop production (barley, wheat, maize, tef), root crops, perennial crops like enset (Enset ventricosum), Coffee (Coffea arabica), Khat (Catha edulis), fruit trees, livestocks such as cattle, goat, sheep, horse, mule, donkey and chicken. Nowadays eucalypt is a primary cash generating activity for the community. The area is semi arid, Weyna dega (Sub Tropical), with long dry period usually December to May, and short rainy season from June to September.

Data collection and analysis

Perception interviews of district forest experts, development agents, and eucalypt traders were assessed. Then the major problems that hinder eucalypt production and the tradeoffs among landuses were identified. A 3-4 years old seedlings stands after planting and the same age of coppice stands after first cutting were selected in 15 eucalypt growing households and measurement were conducted. In each household three circular plots ($100m^2$ radius 5.64m) of each stand type was selected. Then the number of stems per plot was counted, diameter at breast height (DBH), total height (H) and stump height was measured. The age of the stand was estimated from household's interview. DBH was measured by diameter tape and height by graduated stick.

The qualitative data was summarized. The stocking of seedling stems and coppice stumps were computed interms of number of stems per hectare (N/ha), and then volume per hectare (V/ha) was calculated using the formula (equation 1 and 2). The difference in number of stems and volume per plot of the different households were analyzed for ANOVA.

$$v = (\pi/4)\, d^2 h ff \text{ ------------------------------ (Equation 1)}$$

$$V/ha = v*100 \text{ --------------------------------- (Equation2)}$$

v=Volume of standing tree over bark, d= DBH=Diameter at Breast Height, 1.3m above the ground, h=total height, ff=form factor. A constant value of 0.51 was used for seedlings stands and 0.5 for coppice stands as a form factor.

Results and Discussion

Stakeholders perception of eucalypt

The main stakeholders also called eucalypt actors in the district are eucalypt growers (producers), traders, and development agents, and district forest experts. They have different views (opinion) towards eucalypt planting.

Producers view

The producers are considering eucalypt as the most productive asset on their land, because it is fast growing. It is used at household level and as cash crop. It is also considered as a land ownership-securing asset. Illegally obtained communal lands become private lands by planting this fast growing eucalypt species. In cases when an illegally held land is to be released, the possessors of the land claim compensation for the eucalypt planted. Therefore, many of eucalypt growers favour eucalypt and they wish to get more land for eucalypt planting. On the contrary, tree growers that have shortage of land are planned to stop eucalypt planting to use their land for other purposes. While, the rich and young farmers are searching unoccupied natural forest or communal grazing land to grow eucalypt. The producers are selling their stands as pole/ post at the traders willing to pay price. The prices are very subjective and do not satisfy the sellers.

Traders view

The traders are interested in the lucrative eucalypt market. However, the lack of appropriate measurement of standing stock, and high transaction costs (long discussions and frequent travel to farm places to agree on price) make the business less comfortable, and reduce profitability. The traders would like to have modern method of harvesting the standing stock. Eucalypt production and marketing had created a number of seasonal job opportunities. Licensed traders are also seeking land for eucalypt planting. This is because harvesting has a number of uses. The poles and posts are transported to the nearby towns, and to the capital Addis Ababa and in some cases exported to Sudan and Djibouti. The branches, leaves, and twigs are either left for the owner or sold at local market.

District forest departments and development agents view

The district was previously known for “coffee” and “Khat” production. Now all the roads to towns are occupied by eucalypt poles and eucalypt traders. Eucalypt becomes the main cash crop. The district’s forest and natural resources experts are totally against eucalypt planting. They assume that due to *Eucalyptus* plantation streams and small rivers dried out, fertility of soils reduced, remnant natural forests are cleared, biodiversity declined, food production has been reduced (land competition), pasture and other cash crops also reduced. Only few tree species such as Juniperus procera and Podocarpus falcatus are growing under eucalypt, which is a trend observed in many places of Ethiopia including Entoto Mountain around Addis Ababa city (Fekadu 2009).

Actually, the district forest department has no information about eucalypt research output with regard to water and nutrient efficiency (Davidson 1989) and its tolerance to moisture stress, low fertility and insect attack (Azene 1993). Moreover, there is limitation of information on poor capacity of eucalypt and other

monoculture plantation in controlling erosion and promoting undergrowth (Henery 1973).
The district forest department is expressing their worries because, landowners are simply planting eucalypt in most parts of their holding, and the expansion is doubling every five or so years. Some rich people in local administrative units (Kebeles) are illegally acquiring communal pasturelands for planting eucalypt that resulted in reduction of cattle population. The expansion of eucalypt is unavoidable in the near future as well. The once campaign, 2002/2003, to ban eucalypt planting was failed because of the attractive income generated to individuals and to the state. In dry seasons (October to May) the state earn more than 400 Ethiopian Birr ($40 USD) from each of the daily 10-20 loaded cars that transport eucalypt poles to Addis Ababa (personal communication). However, as eucalypt is taking over the annual crop and natural forestland, affects ecological balance. Economically, eucalypt is also not a sustainable landuse option, as the productivity of the coppice is declining after fifth or so rotation, uprooting the stump and reestablishment is an expensive task and conversion to other landuses consumes much time and labour. The haphazard planting, irregular spacing, poor management such as lack of thinning, improper cutting at either below or above the recommended level of stump is economically not profitable. This is true throughout farmers grown eucalypt plantation. The forest department concluded the opinion about eucalypt by saying the woodlots should be managed to sustain their yield and reduce their ecological impacts. Proper land allocation for eucalypt, appropriate spacing, and management, in the zone and district should be in place to make eucalypt plantation profitable and environmentally friendly.

As understood from the forest department, the district needs a diverse forest tree species. The attitude of the district forest department to eucalypt is a barrier for close collabouration on management and improving the productivity of eucalypt. Within eucalypt, there are best provenances that are more productive. Therefore, in order to improve productivity within small area, study results like Mebrate, et al. (2003), Tesfaye, and Belachew (2003) on selection of northern Australian provenance over southern provenances are timely needed.

Quantitative measures

Stocking management

In the studied district, the stocking of eucalypt was variable among farmers (households to households) and within a farmers stand. As shown in figure 1, there are 4300stupms to 24700 seedlings stems per hectare. A preliminary survey conducted at Debre Birhan, Northern Ethiopia on *E.globulus* stocking also counted as 24300 seedlings stems per hectare. This variation is highly significant among different farming households (ANOVA, F=3574.573; p<0.01 for seedling stands, F=5915.660; p<0.01for coppice stands of *E. camaldulensis*).

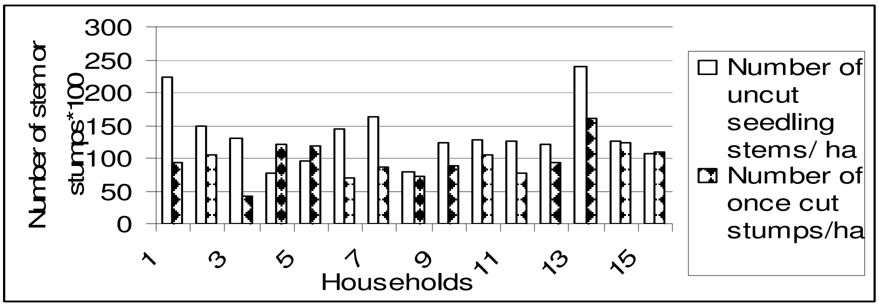

Figure 1. Stocking of a 3 to 4 year old *Eucalypt camaldulensis* stand

The spacing among households also varies from 0.64m -1.5m. Moreover, the planting is not in line and the stocking is irregular. The farmers are planting eucalypt in narrow spacing without targeting for fuel wood, pole, or saw log production. However, studies such as Mebrate et.al (2003), explained that the stocking of stands (number of stems per unit area) depends on the spacing between trees. The spacing between trees depends on the fertility of the site and the objective of planting such as poles, post, saw logs for firewood, pulp production, or lumber. For fuel wood production an initial spacing of 1mx1m, for pulpwood, miner timber, light posts 2mx2m, and for saw logs 3mx3m spacing are commonly used.

At the district, it was observed that plantation plots with wider spacing resulted in bigger size diameter poles while those with narrow spacing resulted in smaller diameter. The diameter difference has a different volume production as shown in Figure 2 and 3. For seedling stands, the highest volume of wood was obtained at nearly 72cm spacing as shown in figure 2. For coppice stands, the highest volume was obtained at 88 cm of stumps after the first cut of seedling stands (figure3). That is 72 cm and 88cm spacing is the best spacing to plan thinning (creating a gap in the usual dense planting practice of farmers) at 3-4 years seedling stands. However, the total volume production did not show a statistically significant difference.

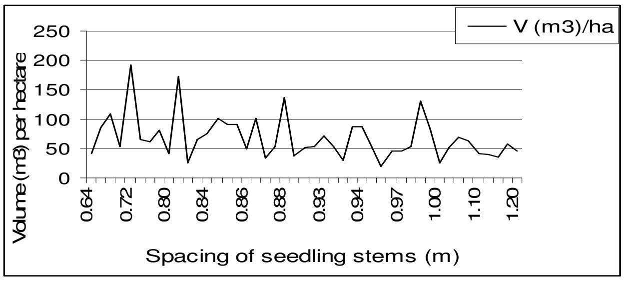

Figure 2. The effect of spacing on *E.camaldulensis* seedling volume

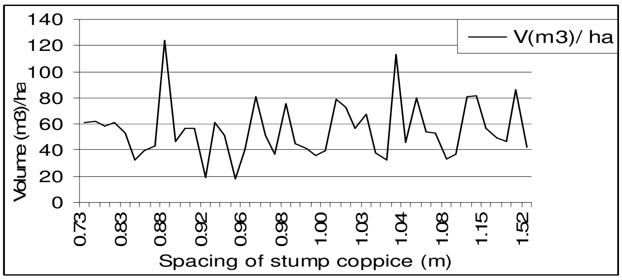

Figure 3. The effect of spacing on *E.camaldulensis* coppice volume

This may be because the 3-4years age is very young to decide the best spacing for volume production. In 3-4years time, the nearly similar volume production is attributed to the larger number of stems and smaller diameters in narrower spacing compensated by the lesser number and the larger diameter in wider spacing. However, further studies need to verify the volume difference at 5-6 years of commonly used rotation period.

Tesfaye (1996) confirmed that wider spacing provides fast growth. The average merchantable volume per tree for saw log increases with increasing spacing. However, the merchantable volume production per hectare for spacing has compared on *Cupressus lusitanica* in Shashemene, Ethiopia, 2.1m*2.1m, 2.5m*2.5m and 3.2m*3.2m, narrower spacing was higher than wider spacing. In closer spacing getting bigger construction, material takes longer time.

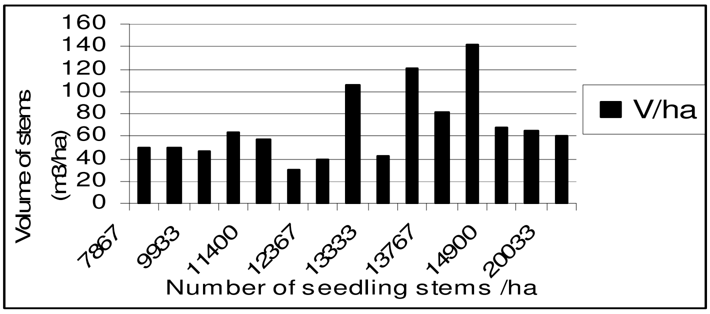

Figure 4. The effects of seedling stem number on volume production of *E.camaldulensis*

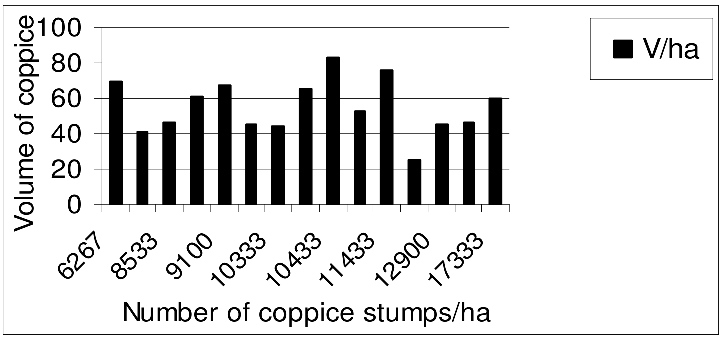

Figure 5. The effect of coppice stump number on volume production *E.camaldulensis*

As can be seen in seedling stand (figure 4), the highest mean volume production of 142.064 m^3 per hectare was obtained by 14333 stems per hecatre and the lowest mean volume production of 30.242 m^3 per hectare by 12200 stems per hecatre. In actively growing coppice stems (figure 5) the highest mean volume of wood, 83.106 m^3 per hectare was produced by 10433 coppice stems per hectare and the lowest mean of 25.140 m^3 per hectare by 12267 stems per hectare. That is the volume production was not directly related the number of stems. The irregularity in volume production is attributed to the lack of irregular stocking within a stand. This volume production provides a hint to the farmers that in their usual planting, thinning be required to maintain larger volume producing number of stems at 3-4 years age. In addition to figure 2 and 3, the point of intersection (Philip 1994).of seedling stems or coppice stumps and volume production in figures 6 and 7 confirm the 72 cm and 88 cm spacings are the maximum for the 3-4 years aged *E. camaldulensis* stands within the management level of local farmers.

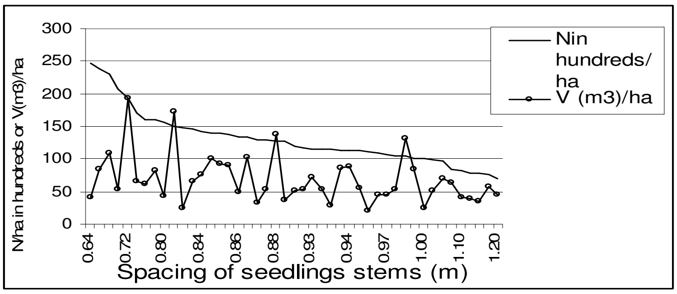

Figure 6. The effect of spacing on number of seedling stems and volume production

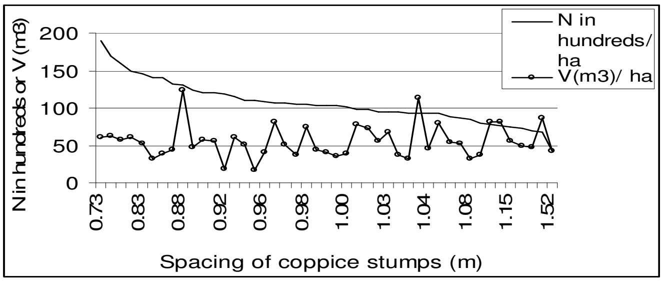

Figure 7. The effect of spacing on number of coppice stumps and volume production

Coppice management of eucalypt

Sometimes a young eucalypt is broken by animals or storms. If these are cut close to the ground, in effect coppiced, a strong new shoot develops which is much more suited to the object of management than the damaged shoot (FAO 1981; Smith et.al 1997). Production of vigorous coppice shoots is determined by felling (cutting) season, felling tools, felling height (felling level), felling age and stump diameter, frequency of feeling, thinning practices and many other environmental and anthropogenic factors (Haney 1962; Wilson 1968; Kramer and Kozlowski 1979; FAO 1981; Lamson 1983; Johnson and Rogers 1984; Lowell et al. 1989; Smith et.al 1997; Johnson et al. 2002).

In the studied district, the felling is done during dry season when there is accessibility of transport to market. However, FAO (1981) stated that the felling period adjustment is just to avoid dry periods, heavy frost, and selecting dormant growth. The best times are in cold areas the early growing period after the heavy frost and in very dry areas at the beginning of the rainy season to ensure enough moisture in the ground. The present study showed that, in the district most of the standing trees are sold at pole/post stage, and trees for household construction are obtained by leaving few scattered trees on felled stands. However, other studies explained that trees of the same species in a single stand are often interconnected by root graft (Smith et.al 1997). Leaving behind scattered trees may draw on food supply of the newly growing coppice by common root system or contribute hormonal inhibitors and hinder sunlight for sprouting and vigorousity. Therefore, to renew a stand by coppicing, all the trees of the species to be reproduced should be cut in one operation for the utmost stimulation of sprouting. As shown in figure 8, the cutting in the studied wood lots is done by axe. Using axe causes looseness of the bark, debarking and deformed coppice. When the stump is damaged, the coppice emerges as sucker on the side of the stump and faces a great risk of damage by grazing animals. Moreover, experiences of eucalypt growing countries like Australia and South Africa state that during cutting, the cut surface is required to be as smooth and slanted as possible to facilitate water runoff. The accumulation of water on the stump may facilitate fungus attack.

Figure 8. The damaged cut surface of stumps and growth of week coppice

FAO (1981) also recommends, better results in coppicing and growth of the coppice are obtained by using chain saw than axes. The uses of bow and chain saws reduce the degree of bark damage and allow the rapid formation of protective callus tissue. The bow saw and two-man cross cut saw can also be used as these have reported to give better results than the chain saw. The coppice shoots shown in figure 8 are not firm because of inappropriate cutting too and felling level (height). The ultimate aim of the traders that purchase the standing eucalypt plantation is to get wood. The farmers want to cut standing tree as easily and fast as possible. The cutting height the first seedling grown stand ranges from 5-15 cm. More than 90% of the households' sampled plot, the cutting stump height of the first seedling stem is 5-6cm; nearly 7% of the seedling stands is cut at 15cm stump height that creates wastage of wood. Figure 9 also shows increase in stump height (>50cm) that result in loss of wood to the owner and defective coppice. If the stump is too high from the ground, the chances of survival of coppice shoots are too low (Smith et.al 1997). If the cut is at the ground level, the bark may loosen. FAO (1981) recommend 10-12 cm height as an appropriate cutting level. All *Eucalyptus* trunks have numerous dormant buds on every decimeter of their length. Shoots from all of these will develop when the trunk is felled and the upper ones will tend to develop more quickly than the lower ones and soon suppress the lower ones. The upper shoots are much less stable than shoots from stumps cut to the recommended height of 12cm or less. The callus developing at some distance up the stem is weaker and cannot give good support to a new trunk as callus from a low cut (Smith et.al1997). There is also a need to avoid the tendency for the stool height to increase with successive cuttings of the coppice. The effect of felling level on coppice shoot vigorousity becomes more damaging when there is diameter difference within the stand. Johnson et al. (2002) stated that the more uniform a plantation is and the smaller the range of stump diameters, the better the survival of the stumps and the better the volume production of the coppice crop. In most eucalypt coppice plantation, the first seedling crop is felled between the ages of 7 - 10 years. On observation in South Africa, Natal, on a seven-year-old first cutting of *E. grandis* indicated there were lower and higher stump diameter groups where stump mortality was greatest. The smaller stumps (3-10cm) and the large stumps (20-38cm) had a high mortality where as the stumps with diameter 10-20cm had a low mortality rate (FAO 1981).

Figure 9. Longer cut stumps of eucalypt stands (>50cm)

The subsistence system of eucalypt plantation, development agents state that in Gunchire district the mortality is higher as the felling diameter is usually <10cm, within the ages 5-6 years rotation (personal communication). Therefore, proper and equal spacing during seedling planting ensure future uniformity of diameters of stumps. In areas like Guraghe Zone, the inappropriate spacing of seedlings could result high range of stem diameter. Different farmers indicated the yield reduction of coppice stumps. In the district, the stands are cut at short rotation of 5-6 years. In such frequently cut coppice stump, the stool surface is unable to provide sufficient space for the shoots to grow. In Gunchire district, it was interviewed that after 30-40 years of planting eucalypt higher stool height, inappropriate spacing and lack of thinning resulted in unproductive coppice stand. The coppices are poor quality to be sold in competitive market. The eucalypt land is said to be wasted because it is producing neither good pasture, nor a quality poles/ post. Because of the old stools of *E.camaldulensis* and *E.globulus,* some farmers become hungry of land. Similarly studies (Kramer and Kozlowski 1979) in different eucalypt growing areas indicated that, in each successive coppice rotation, a percentage of stumps fail to produce another coppice crop after felling. Finally, there are too few stumps to produce a reasonable mean annual increment and it is advisable to reestablish old coppice stands by a seedling stand depending on the site conditions. In Nilgri hills of India, *E. globulus* has been coppicing on nearly 10 years rotation for 100 years giving good returns. On reasonable sites, it can be assumed that at least two satisfactory coppice crops after the original seedling crop can be obtained if the crops are on short rotations of up to 10-12 years. This applied to *E. grandis*, *E. saligna*, *E. globulus*, *E. camldulensis,* and *E. tereticornis* (FAO 1981).

In the studied district, the number of healthy and competent coppice shoots at 3-4 year age is 1-6. The interviewed farmers stated that thinning is usually done after three or more years of coppice shoot age. In most cases, fuel wood collectors simply take dried shoots. However, Lowell et.al (1989) stated that to produce straight and more valuable stems, coppice must be thinned to three to one stems per stool. FAO (1981) also indicated that thinning the coppice shoots is best at 18months of age. Stems to be kept are stems which have come from dormant buds below the top of the stump and which are giving promise that the callus developing will grip the top of the stump, and stems on the windward side of the stumps.

Farmers in Gunchire district stated that, the yield from coppice stand is better than the seedling stand usually in the second and third rotation. This requires further investigation. Therefore, coppice management is a great opportunity for better yield. FAO (1981) also states coppice stands are higher in yield than their corresponding seedling stands.

Landuse practices

Proper management of spacing and coppicing curb the expansion of eucalypt plantation. The Guraghe zone requires a eucalypt landuse policy for the benefit of the ecology and economy. Remnant riparian natural forests that are home to different wild lives, and sources of streams and rivers require a landuse plan. Decision about where to plant eucalypt is a primary question to answer with the appropriate management activities discussed. Keeping the interest of large and small-scale eucalypt growers, the protection of communal grazing lands, natural riparian forest, and biodiversity of the area is the responsibility of the public at large for balanced ecosystem and species diversity. The government should control the expansion of plantations that include tea, coffee, and eucalypt.

Although fast growing and relatively sure to survive concern exists that eucalypt may not adequately supply forest benefits such as quality wood, watershed and soils conservation, wildlife habitat and even recreation and esthetic values (Demel 2001). Landuse competition as of coffee and Khat in different parts of the country, the issue of wilderness and natural forest preservation requires to be considered (Getahun and Krikorian 1973). In SNNPRS, the Ministry of Agriculture and Rural Development (MoARD) has orally stated the place of planting eucalypt. Although official document was not obtained the district officials stated that, eucalypt planting was restricted to be 150m radius away from streams and rivers and 50meter from farmlands. Moreover, the officials in the forest department emphasized the immediate need of practical and implemental landuse policy on eucalypt, natural forest, and topographic natural landscapes in the district.

Conclusion and Recommendation

Eucalyptus is one of the most important cash crops in Gunchire district. The dependence of the local people on eucalypt for the future is unavoidable because the natural forest cover is declined and reliable and foreseeable alternative income source is not visible. To compromise eucalypt use and to curb unplanned expansion of eucalypt, appropriate management of eucalypt is highly important. Making the lines of trees regular and straight and the spacing between the trees even leads to the achievement of uniform growth and facilitate mechanical tending and harvesting. The spacing 0.72m and 0.88m are best to produce more number of stems and volume of poles in seedling and coppice stands respectively in Gunchire district. Many of the eucalypt management practices are unknown to the Gunchire district tree growers. Therefore, they should be trained about appropriate spacing during planting, time of felling, felling tools, felling level, effect of stump diameter on mortality, thinning, determining rotation and reestablishment of old coppice stands. Having appropriate spacing enables reestablishment of old stands and removing poor stands by leaving a space for new planting. As the trade of between immediate food and wood, eucalypt planting is taking over other landuses, therefore, the government should put appropriate landuse policy on the allocation of different farming activities on the appropriate topographic and natural landscapes.

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References

Alemayehu G. 1997. Fuel wood as a source of urban household energy in Ethiopia: A supply perspective. Using biomass residues for energy. Issue 39 (1997).

Davidson J. 1989. The *Eucalyptus* dilemma. Arguments for and against *Eucalyptus* planting in Ethiopia. The Forestry Research Centre Seminar Note Series No. 1. A. A.

Demel T. 2001. Published works of Demel Teketay V.1, Parts 2. 1987-2000. Ethiopian Agricultural Research Organization. Addis Ababa, Ethiopia.

FAO, 1981. *Eucalyptus* for planting. Rome, Italy.

Fekadu DH. 2009. Impact of *Eucalyptus globulus* Labill. (Myrtaceae) plantation on the regeneration of woody species at Entoto Mountain, Addis Ababa, Ethiopia.

Getahun A, AD Krikorian. 1973. Khat: coffee's rival from Hara, Ethiopia. I. Botany, cultivation and use. Economic Botany 27:353-377.

Haney GP. 1962. Growth of thinned white oak sprouts. Journal of Forestry 60:644-645.

Henery PW. 1973. Notes on maps of the *Eucalyptus* plantations around A. A. and the Menagesha State Forest, Ethiopia. ODA. London. Misc. Report. 150:1-10.

Johnson PS, R Rogers. 1984. Predicting 25th-year diameters of thinned stump sprouts of northern red oak. Journal of Forestry 82:616-619.

Johnson PS, SR Shifley, R Rogers. 2002. The ecology and silviculture of oaks. CABI Publishing, New York.503 p.

Kramer PJ, TT Kozlowski. 1979. Physiology of woody plants. Academic Press, NewYork.811 p.

Lamson NI. 1983. Precommercial thinning increases diameter growth of Appalachian hardwood stump sprouts. Southern Journal of Applied Forestry 7:93-97.

Lowell KE, HE Garrett, RJ Mitchell. 1989. Early thinning can improve your stand of coppice- regenerated oak. USDA Forest Service. North Central Forest Experiment Station Gen. Tech. Rep. NC-132. 6.

Mebrate M, G Alemu, G Belachew. 2003. Early survival land height performance of some Australian species in field trial at Didessa, western Ethiopia. Ethiopian Agricultural Research Organization, Forestry Research Center. Addis Ababa: Ethiopia.

Philip MS. 1994. Measuring Trees and Forests. Cab International, Oxon, UK, p. 310.

Smith MD. 1986. The practice of silviculture, 8th ed. John Wiley and Sons Inc., New York.

Smith MD, CL Bruce, JK Mathew, PMS Ashton. 1997. The practice of silviculture: Applied Forest Ecology. John Willey and Sons. Inc. New York.

Taddesse M, K Hailu, T Tesfaye, B Alemayehu, G Gebeyehu (eds). 2002. Agriculture in Addis Ababa (Amharic Version), Vol.1 Number 1. Miazia 1994. Addis Ababa, Ethiopia.Pp.40

Tesfaye H, G Belachew. 2003. Provenance trial of *E.camaldulesis* at Mankussa, research report. Northwestern Ethiopia. Ethiopia Agricultural Research Organization, Forestry Research Center, Addis Ababa, Ethiopia.

Tesfaye T. 1996. A growth and yield model for *Cupressus lusitanica* in Munessa Shashemene State Forest Project, Ethiopia. A Ph D. thesis. University of Abrdeen. Scotland, UK. 242pp.

Wilson BF. 1968. Red maple stump sprout development the first year. Harvard Forest Paper: 18.

Expansion of *Eucalyptus* Plantations by Smallholder Farmers amid Natural Forest Depletion: Case Study from Mulo District in Central Oromia

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Abstract

Natural forests are depleting at an alarming rate in Ethiopia. As a response, farmers in many parts of the country are planting trees like *Eucalyptus* to meet their wood and income needs. Farmers in Mulo district, where this study was conducted, are no exception with this regard. Farmers in the district have engaged in *Eucalyptus* tree planting particularly since the end of 1980s, although it was first introduced in the early 20^{th} Century to the area. The objectives of this study were to comparatively assess the drivers behind the expansion of *Eucalyptus* tree planting on the one hand and the depletion of natural vegetations on the other hand, and map the resulting vegetation cover change/ dynamics in the study area. Data were collected through socio-economic survey and analyses of remote sensing imageries (aerial photos and satellite image). The results of the study revealed that woodlands have been depleting mainly in the past twenty to thirty years. Drivers of such depletion are cutting of trees for fuel, timber, and construction purposes, encroachment of cropland, and institutional and political instability. On the other hand, *Eucalyptus* plantations have been increasing especially in areas with little or no natural vegetation in their vicinities and close to towns or roads over the last twenty years. Farmers develop *Eucalyptus* plantations mainly due its socio-economic benefits and other merits such as fast growth, high biomass production, and growing on land unsuitable for most other uses. The sources of motivation to plant *Eucalyptus* emanated from the demonstration effect of *Eucalyptus* trees grown by farmers who started early, personal initiative and advice from government bodies. Most farmers began planting *Eucalyptus* around homesteads, mostly in backyard, and gradually expanding to agricultural lands close to homesteads. At the same time, some farmers converted croplands that have lost crop production potential due to fertility exhaustion to *Eucalyptus* plantation located even furthest away from homes. Currently in some parts of the district, *Eucalyptus* woodlots of neighboring households are closing together to create a large continuous plantations pattern. The study concludes by pointing out that as long as the current drivers remain intact, smallholder farmers seem to continue expanding *Eucalyptus* plantations that would ease the pressure on the remaining natural vegetation in the area.

Keywords: *Eucalyptus expansion, deforestation, land cover dynamics, Mulo district. Abbreviations*

Introduction

Forests play major roles in the preservation of biodiversity, conservation of soil and water and mitigation of climate change. In addition, millions of people globally obtain their livelihoods from the use of forests (Dixon et al. 1994; Bishaw 2001; Wofsy et al. 1993). Nonetheless, the world's natural forest cover has been declining largely due to land use change and increasing demand for wood and non-wood products. Accordingly, about 13 million hectares (ha) of forests each year over the last ten years were converted mainly to agriculture land in the tropics (FAO 2010).

In Ethiopia, which is one of the tropical countries, each year about 80,000 ha of natural high forests have been converted to farmland, while 50,000 ha of woodlands removed for charcoal production and farmland expansion; and 30,000 ha of woodland, thickets, and bushes cleared for fuel wood production (UNDP/ World Bank 1988 cited in Gemechu, 2009). Moreover, about 70% of the remaining high forests of the country are heavily disturbed while most of the reminder is slightly affected (FAO 2004). Generally, as a result of dynamic interplay among various institutional, political and socio-economic (poverty and demographic pressure) factors natural forest cover of the country has been dwindling (Bishaw 2001; Rahmato 2001; Bewket 2003; Bekele 2003; FAO 2004; Gemechu and Bewket 2007).

With degradation of natural vegetations in Ethiopia, wood for various purposes including construction and fuel for domestic uses and sale have become in short supply. Planting exotic tree species, mainly *Eucalyptus* has been considered as option to overcome the wood shortage in the country (Ball 1993; Teshome 2007; Zewudie 2008). *Eucalyptus* produces high biomass that can be used as industrial wood, construction (poles and posts), and fuel wood. *Eucalyptus* plantation is believed to relieve the pressure on natural forests by serving as an alternative source of wood products, and thus enhancing the conservation and rehabilitation of indigenous forests (Pohjonen and Pukkala 1990; Zhang and Song 2006). It can also foster the restoration of degraded natural forests (Pohjonen and Pukkala 1990; Yirdaw and Luukkanen 2003). Moreover, *Eucalyptus* provide various wood products for sale that has considerable potential to alleviate poverty and food insecurity of subsistence farmers in some parts of Ethiopia and elsewhere in Africa (Jagger and Pender 2003; Munishi 2007; Teshome 2007).

In Ethiopia, the size of community and state *Eucalyptus* plantations, where *Eucalyptus* trees species widely used since its introduction to the country, increased from 3500 ha in 1964 to 148,000 ha in 2000 (FAO, 1979, 2000). In addition, existing meager literatures revealed that subsistence farmers in many parts of the country have been planting *Eucalyptus* with an increasing intensity over the years, to meet their wood and income needs (Mekonnen 2006; Jenbere 2009). Jenbere (2009) reported that some farmers converted their farmland either to get more income or due to reduced soil fertility. In addition, Wirtu (1998) found out that the financial return of growing *Eucalyptus* in highlands of Oromia is much higher than crop cultivation.

Likewise in Mulo District, which is found in Finfine Zuria Special Zone of Oromia Regional State in Central Ethiopia, smallholder farmers *Eucalyptus* plantations are increasingly observable in recent years. On the other hand, the remaining patches of natural vegetations (mainly *Acacia abysinica* and *Juniperus procera* woodlands) have been depleting from time to time. Thus, the objectives of this study were to assess the drivers behind the expansion of smallholder farmers' *Eucalyptus* plantations and depletion of patches of woodlands; and to map the resulting vegetation cover change/ dynamics in Mulo district to contribute to the body of knowledge on smallholder farmers' *Eucalyptus* plantation establishment trends and drivers in tropics that have implications on the future forestry practices in that part of the world.

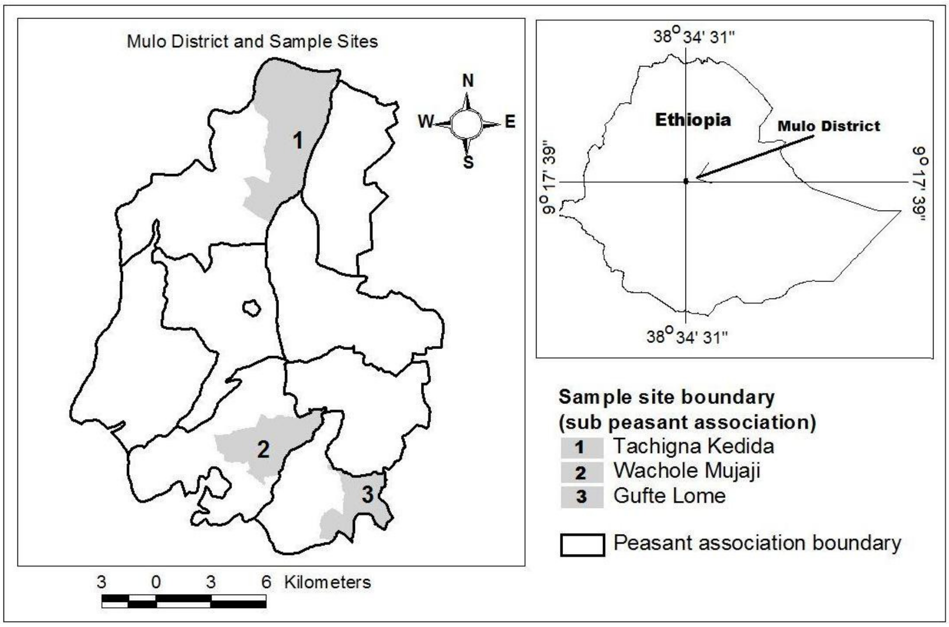
Materials and Methods

Study site description

Mulo District is one of the districts of Finfine Zuria Special Zone of Oromia Region. It is situated at about 73 kilometers (km) to the northwest of Addis Ababa. Ada'a Berga and Welmera districts border the study area in west and south directions. In addition, Sululta district surrounds it in the north and east. The prominent topographic feature of the district is plateaus followed by hills, valleys, and gorges[17]. The agro-climatic zones of the district are *bada* (temperate), *bada-daree (*sub-tropical) and gamoji (tropical) (NSZPEDO 1998). The district supports a total of 35,130 people with a crude population density of 123 persons per square kilometer (km^2) which is much higher than the entire Oromia Region (70 P/km^2) (CSA 2008).

[17] *The Socio-economic Profile of Mulo District, Unpublished Document.*

Figure 1 Location of the study sites.



Sampling technique, data collection and analysis

The district has eight Peasant Associations (PAs) and a town. Using the dominant vegetation cover as criteria[18], these PAs were grouped into three categories, namely, depleted *Juniperus* woodland, degraded *Acacia* woodland, and recently developed private *Eucalyptus* plantations that comprise of 4, 2 and 2 PAs, respectively. Mulo Silo, Mulo Falle, and Kure Kemele PAs were selected randomly as sample from PAs representing depleted *Juniperus* woodland, degraded *Acacia* woodland, and recently developed *Eucalyptus* plantations, respectively. The PAs in the study area are generally vast and thus, organized into *goti* (Sub-PAs). Mulo Silo and Kura Kemele PAs had three *goti* each while there were four *goti* in Mulo Falle. Gufte Lome and Tachigna Kedida sub-PAs were purposively selected from the sub-PAs of Kura Kemele and Mulo Falle, respectively because they had more land under the dominant vegetation types the respective PAs' represent. Nevertheless, Wachole Mujaji was selected from Mulo Silo PA through simple random sampling technique as the remaining sub-PAs can also equally represent the dominant vegetation type of the PA. Then after, the list of household heads were obtained from administrators of the three sample *goti* and checked for completeness. Through simple random sampling technique, 15% (109) of the total households were proportionally selected as sample from the three sub-PAs (38, 41, and 30 from G.Lome, T. Kedida, and W.Mujaji, respectively). Data on socioeconomic characteristics, deforestation, and *Eucalyptus* planting practices

[18] *This criteria was set based on the consultation with some staffs of Mulo District Agricultural Office and researcher's observation.*

were collected from the sample households using semi-structured questionnaire in May 2009 for three consecutive weeks. Furthermore, six key informant interviews (two in each sub PAs) were conducted with elderly people, who were recognized as knowledgeable about their locality, to capture detail information on deforestation and expansion of *Eucalyptus* plantations. Various published and unpublished materials were also reviewed. Information collected from key informant interviews and group discussions were organized, interpreted, and presented qualitatively. Statistical Package for Social Sciences (SPSS 13.0) was used to analyze information gathered through questionnaire survey.

The assessment of land cover dynamics was carried out using aerial photographs, satellite imagery, ground surveying data, information from key informants and topographic maps. The geo-referenced topographic maps were used to create baseline data for each sample site. The boundary data for each sample site was created using ground surveying data, maps from district office, and topographic maps. Aerial photographs taken in 1980 for Tachigna Kedida and Wachole Mujaji and in 1971 for Gufte Lome were obtained from Ethiopian Mapping Authority. For the assessment of the history of the land cover, stereo pair of photographs was mounted for each study area for visual interpretation. The scanned aerial photographs were geo-referenced using ground control points from topographic map. The geo-referenced aerial photographs were used for digitizing the major land cover types for each study area, supplemented by the information from the stereo interpretation of the photographs. High-resolution satellite imageries available on Google Earth (2006) were used for the collection of the recent land cover types' distribution in each sample site. Using the tools offered by Google Earth, the major land cover types were digitized. This land cover data was imported via the data conversion program developed in the GIS unit of Wondo Genet College of Forestry and Natural Resource (WGCF-NR). The data collected applying different sources was projected and/transformed to similar coordinate system (UTM with the datum Adindan). The geo-processing activities were further performed with GRASS GIS. The information from the aerial photographs and satellite imageries were verified during the field survey and by the information from the key informants. The field survey data and the information from the key informants were further used for improving the data.

Results

Characteristics of sample households

Eighty-three percent of the interviewed households were male-headed while the remaining households were female-headed. Most of the respondents were illiterate (56%) followed by those who could only read and write (36.7%) and attended primary education (7.3%).The average household size of the interviewed households was 6.27 persons. Ninety-eight percent of the respondents were born in the study area.

Mixed agriculture was reported as the major occupation for 82.6% of the respondents followed by crop cultivation (7.3%) and sell of fuel wood (4.6%). The remaining households obtained their livelihoods mainly from trade of agricultural product, livestock production, and daily labour. Most households produce various kinds of crops mainly to meet their diverse needs. On average households, cultivate 3.9 different cereals, pulses, and oil seed crops in a year. Ninety percent of the interviewed households possess livestock though the number and types of livestock owned vary significantly among households and sub-PAs. Eighty-four percent of interviewed households own land of different sizes, which they allocated to various uses mainly for crop cultivations and grazing. Seventeen percent of the respondents inherited land from their ancestors. Many problems, however, were constrained the agricultural activity in the area. The major constraints were soil erosion, expensiveness of agricultural inputs, lack of grazing land and rainfall variability. For instance, about 75% of the respondents who own livestock reported a decreasing trend in the number and type of livestock they hold mainly due to shortage of grazing land and sale of livestock during drought. In addition, forty-six percent of the interviewed households reported that the amount of crops they produced in a year does not last them for the whole year. On average, the respondents subsisted only for 10.21 months on their own annual produce. The food insecure households employ different coping strategies to secure food or income that include livestock sell, borrowing crops, and fuel wood sell and land rent.

Cattle dung, firewood and crop residue are the three major sources of energy for the interviewed households. Thirty-one percent of the respondents indicated that their energy demands were not met to varying degree and as a result, they were forced either to roam long distance to collect firewood or resort to purchase.

Depletion of natural vegetation

There have been patches of natural vegetations, which mainly comprised of *Acacia abbysinica and Juniperus procera,* and owned by communities/government in many parts of Mulo District such as T. Kedida and W. Mujaji sub-PAs. Nonetheless, the patches of woodlands in these sub-PAs have been depleting with time. Accordingly, results from the analyses of aerial photos and satellite images showed that in T. Kedida closed and open woodland covers were decreased from 32% and 2% in 1980 to 15% and 1% in 2006, respectively. In W. Mujaji the closed and open woodland covers, which were 7% and 9% in 1980, respectively, totally disappeared in 2006. Understandably, during the same period, the shrub cover increased from 2% and 0.1% to 6% and 4% in T.Kedida and W. Mujaji, respectively (Table 1, figures 2 and 3). In G. Lome, on the other hand, the small mixed *Acacia* and *Juniperus* woodland cover was increased from 0.2% in 1971 to 0.7% in 2006 mainly due to recent strict protection from PA and increased availability of wood products from smallholder farmers' *Eucalyptus* plantations (Table 1 and Figure 4).

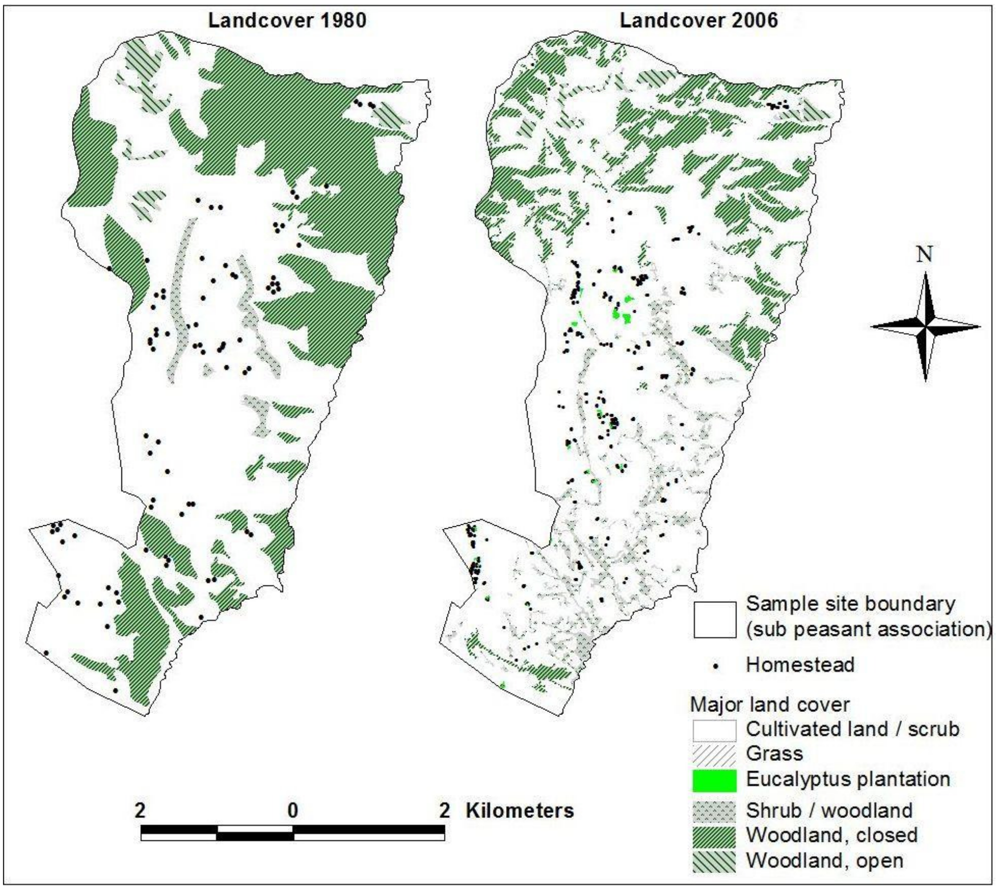
Table 1 Land cover change of the sample sites between 1971/80-2006.

Site[19]	Year	Percentage of land cover				
		Closed woodland	Open woodland	Shrubs	*Eucalyptus* plantation	Other (agriculture, settlement, grass)
T. Kedida	1980	32	2	2	0	64
	2006	15	1	6	0.1	77.9
W. Mujaji	1980	7	9	0.1	0.2	83.7
	2006	0	0	4	0.4	95.6
G. Lome	1971	0.1	0.1	0	0.3	99.5
	2006	0.4	0.3	0	2	97.3

Many factors were identified as the major causes of deforestation in the area of which institutional instability and demographic pressure were the forefront. According to the information from the key informants, woodlands were severely degraded during the transitional period in the early 1990s with the fall of the Derg government. Moreover, over the past couple of decades population has been growing rapidly in the district. For instance, the annual population growth rate increased from 1.6 in 1984-1994 to 2.4 in 1994-2007[20]. The information from key informants also confirmed that human population has been increasing significantly, which negatively affected the vegetation cover. Similarly, all the interviewed households reported that huge deforestation occurred over the last twenty to thirty years. For 63% of the interviewed households cutting trees largely for charcoal and timber production was the major cause of devegetation while the remainder put woodland conversion to cropland as the main factor for deforestation. According to the information from key informants, cutting trees for charcoal making, which was started during the Emperor time with the order from Dejezmach Zewude Asfaw Darge, the then landlord of the area, is the major factor for depletion of the *Acacia* woodland in T. Kedida. Charcoal prepared in the area was transported mainly using pack animals to Addis Ababa. In W. Mujaji, the expansion of agriculture and cutting trees for timber productions were the major culprits for devegetation. Currently, however, charcoal and timber production have showed decreasing trends mainly due to shortage of woods and strict protection from PA and district administration as well as strong punishment of people involved in such activities.

[19] *Total areas of T.Kedida, W. Mujaji and G. Lome were 26.1, 8.2, and 12.1km^2, respectively.*
[20] *These growth rates were computed using the population data of the 1984, 1994 and 2007 population censuses of Ethiopia through exponential population growth rate method.*

Figure 2. Land cover change of Tachigna Kedida Sub-Peasant Association



Expansion of *Eucalyptus* woodlots

Based on the information from key informants *Eucalyptus* was first introduced to Mulo district in the early 20th century. Until very recently, however, few *Eucalyptus* trees were planted, and these were mostly restricted to homesteads. Some fragmented *Eucalyptus* plantations, which include Hunde and Kostire plantations, were also established. These plantations were owned by the then landlords. Through 'forced mass mobilization' the Derg government in the late 1970s and early 1980s was attempted to establish community plantations mainly *Eucalyptus* in many parts of the district. However, the efforts were less successful. At the end of 1980s, the Derg government started distributing *Eucalyptus* seedlings freely to interested individuals to plant on their lands. Later on, the practice was expanded to different parts of the study area. Especially, over the last five to ten years farmers in areas like Gufte Lome and Kuye Deku have been establishing *Eucalyptus* plantations around homesteads, mostly in backyard, and gradually expanding to agricultural lands located close to homes. At the same time, some farmers converted croplands that have lost crop production potential due to fertility exhaustion to *Eucalyptus* plantation even located furthest away from homes.

Figure 3 Land cover change of Wachole Mujaji Sub-Peasant Association.

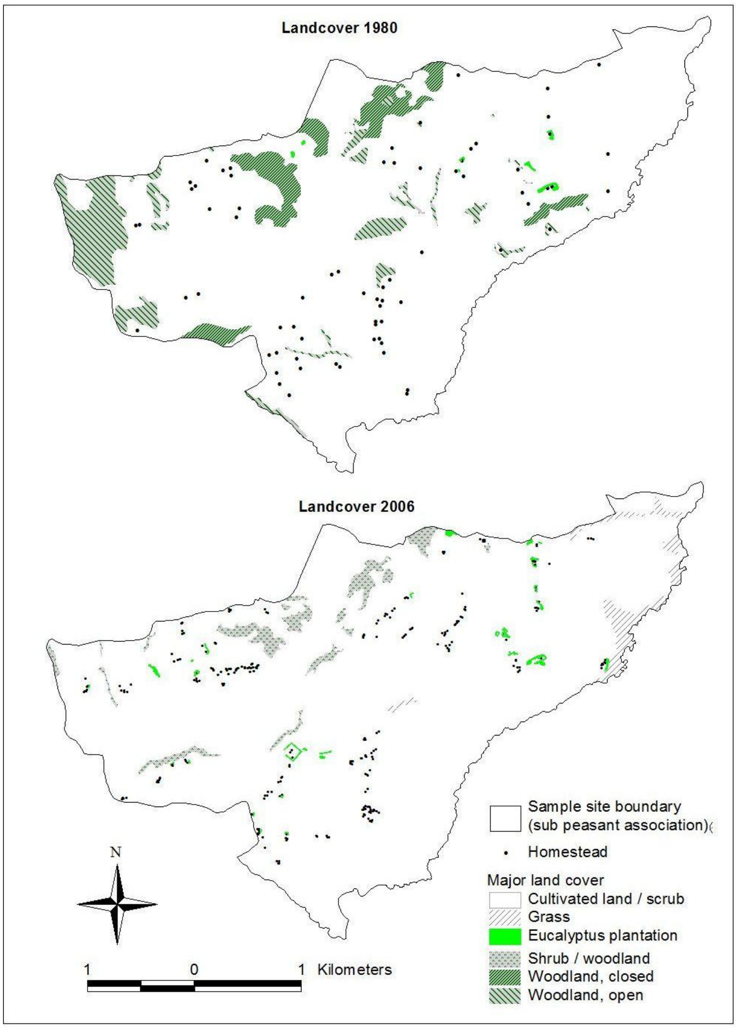
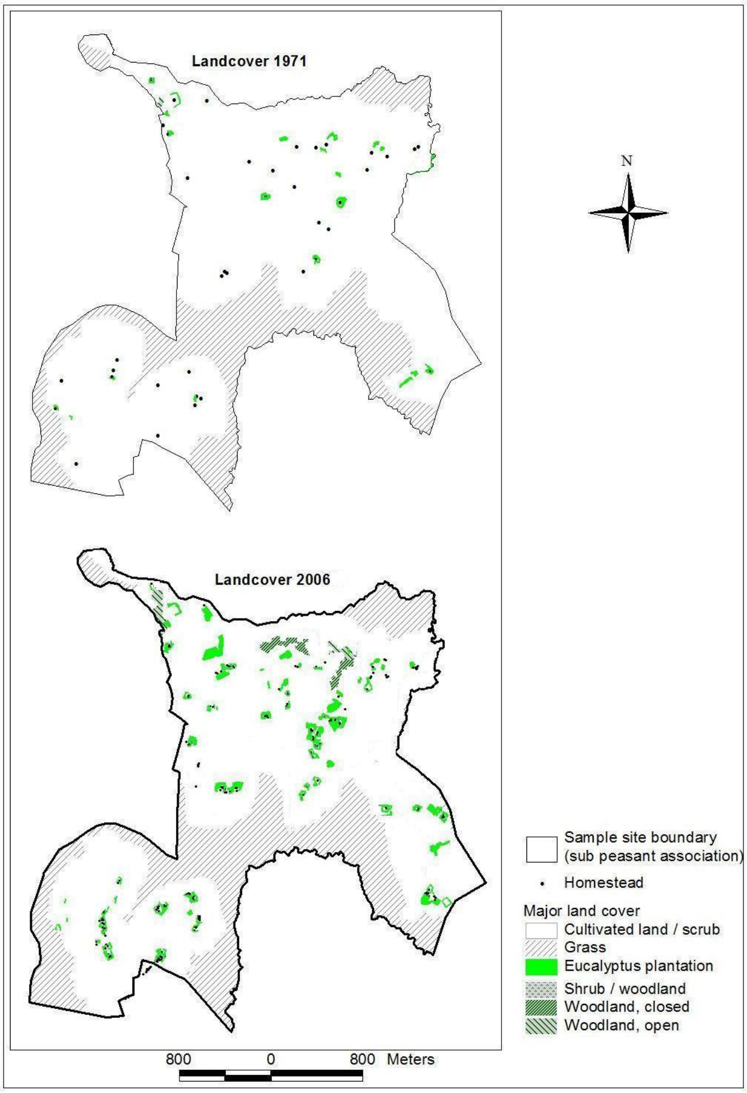


Figure 4. Land cove change of Gufte Lome Sub-Peasant Association



Now days, planting *Eucalyptus* has become a common practice in the district. Eighty-five percent of the interviewed households reported that they plant some tree species and of these households 79.6% plant *Eucalyptus globulus*. The remaining plants are either *Cupressus lusitanica* or *Juniperus procera*. As indicated in table 2, almost all the respondents from G. Lome were engaged in *Eucalyptus* planting. Similarly, in the remaining Sub-PAs, the majority of the households prefer planting *Eucalyptus.*

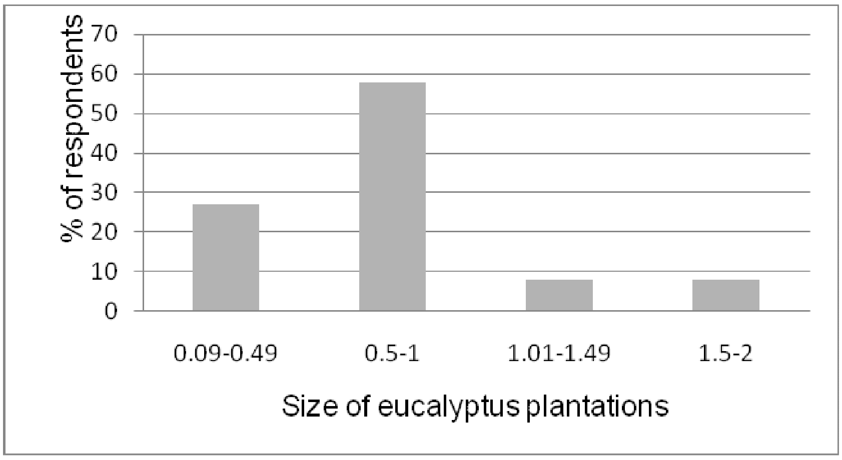
Table 2. Trees species households' prefer most to plant.

Name of Sub PA		Tree species households prefer most to plant			Total
		Eucalyptus	*Cupressus l.*	*Juniperus p.*	
G. Lome	No.	33	1	-	34
	%	97.1	2.9	-	100
W. Mujaji	No.	19	1	9	29
	%	65.5	3.5	31.0	100
T. Kedida	No.	22	8	-	30
	%	73.3	26.7	-	100
Total	No.	74	10	9	93
	%	79.6	10.8	9.7	100

The preference for *Eucalyptus* is for various reasons. The first major reason is that *Eucalyptus* is serving as cash crop. Most of the *Eucalyptus* trees grown in the area are sold on stumpage to wood merchants. These merchants prepare different wood products from the *Eucalyptus* trees and sell to nearby towns including Addis Ababa. *Eucalyptus* tree fetches high income to smallholder farmers than most other livelihood activities. As one key informant said, "We [the farmers] started to prefer planting *Eucalyptus* tree on farmland because we sell it in thousands of birr at one time, which we used to get such sum of money only from beef sale." Secondly, *Eucalyptus* grows fast and gives more biomass than other trees that can meet the wood demands of farming households for domestic use and income generation. Thirdly, farmers prefer planting *Eucalyptus,* as it can grow on land unsuitable for most other uses. Croplands that lost production potential were converted with *Eucalyptus* plantations. With little labour and financial cost compared to growing crops, *Eucalyptus* plantations established on such lands have been performing well and fetching more income.

The motivation of smallholder farmers to plant *Eucalyptus* came from three different sources. These are the demonstration effect of *Eucalyptus* trees grown by farmers who started early (60.8%), personal motivation (31.1%) and advices from previous government or Development Agent (DA) (8.1%). The pattern of sources of motivation of the respondents is similar across the three Sub PAs.

Figure 5. Reported size of *Eucalyptus* woodlot owned by households.



Ninety percent of the households who have *Eucalyptus* plantations were from G. Lome. The size of *Eucalyptus* plantations they own range between 0.09 ha and 2ha (figure 5). The size of *Eucalyptus* plantations of the majority (57.7%) of the respondents is between 0.5 and 1 ha. Similarly, the results of the analyses of aerial photos and satellite images showed that the area under *Eucalyptus* plantations in Gufte Lome was increased from 0.3 in 1971 to 2% in 2006. Most of this increase was occurred in the past ten years. There was also an increasing trend in areas under *Eucalyptus* plantations in W. Mujaji and T. Kedida. In the former sub-PA, the area under *Eucalyptus* plantations was increased from 0.2% in 1980 to 0.4% while in the latter such plantation covered 0.1% in 2006 though there was none in 1980. G. Lome, where *Eucalyptus* plantation is aggressively expanding on farmland, is dominated by flat terrain, with little natural vegetation within and in its vicinity and located at about 17 km away from Addis Ababa. On the other hand, *Eucalyptus* plantation is expanding slowly in T. Kedida and W. Mujaji, which are largely comprised of rugged terrain with relatively high woodland cover within and in their vicinities and inaccessible using road transportation.

Despite the expansion of smallholder farmers' *Eucalyptus* plantations in the district, experts and officials have been discouraging such practice as they emphasized the ecological negative effects of *Eucalyptus.* Instead, they promote the cultivation of indigenous trees species. Accordingly, the preparation *Eucalyptus* seedlings were discontinued in government nursery sites. Nonetheless, famers have continued expanding their plantations either by preparing their own *Eucalyptus* seedlings or through purchase.

Discussion

The analysis of information from different sources consistently show that in Mulo district, natural vegetation cover has been deteriorating over the past twenty to thirty years where as *Eucalyptus* planting practice has increased. Drivers of such depletion are cutting of trees for fuel, timber, and construction purposes, encroachment of cropland, and institutional and political instability. On the other hand, smallholder farmers have been developing *Eucalyptus* plantation mainly due to its socioeconomic benefits and other merits such as fast growth and high biomass production. This finding is in line with the findings of a number of researches conducted in Ethiopia and elsewhere (Davidson 1993; Sunder 1993; Jagger and Pender 2003; Teshome 2007; Munishi 2007). For instance, according to Jagger and Pender (2003) *Eucalyptus* provide various wood products for domestic use and sale, which has considerable potential to alleviate poverty and food insecurity of subsistence farmers in degraded areas of north Ethiopia.

Furthermore, smallholder farmers' *Eucalyptus* plantations are increasingly observable in parts of the district, which are close to towns or roads (market); have little or no natural vegetation within as well as in their vicinities over the last twenty years. Most of the *Eucalyptus* trees grown in the area are sold on stumpage to wood merchants, who prepare different wood products from *Eucalyptus* trees and sell to nearby towns, especially in Addis Ababa where the demand for such products is increasing from time to time, which has been encouraging farmers to continue expanding *Eucalyptus* plantations on agricultural land. This result is in accordance with Newcombe (1987) who identified reliability of market and transportation as the major determinants of *Eucalyptus* plantations. Jagger and Pender (2003) are also pointed out that reliability of market for wood products as one of the critical factors determining *Eucalyptus* plantation development.

The sources of motivation to plant *Eucalyptus* emanated from the demonstration effect of *Eucalyptus* trees grown by farmers who started early, personal initiative and advice from government bodies. The majority of farmers, however, started planting *Eucalyptus* due to the demonstration effect of *Eucalyptus* trees grown by farmers who started early. Similarly, Jenbere (2009) found out the demonstration effect of the plantation of Arsi Forest Enterprise is one of the major sources of motivation for smallholder farmers to plant *Eucalyptus.* The main motive behind own initiative to plant *Eucalyptus* was to solve wood shortage.

Most farmers began planting *Eucalyptus* around homesteads, mostly in backyard contrary to the findings of Jenbere (2009) who reported that farmers in Arsi Negelle area plant *Eucalyptus* mainly on land in front of their yard because of theft. Cognizant of its socio-economic benefits, farmers have been gradually expanding *Eucalyptus* plantations to agricultural land located close to homesteads. Simultaneous, some farmers converted croplands that have lost crop production potential due to fertility exhaustion to *Eucalyptus* plantation located even furthest away from homes.

In some parts of the district like Gufte Lome, the *Eucalyptus* plantations of neighboring households are closing together to create a large continuous plantations pattern. Furthermore, the scanty mixed woodland in this sub-PA has been rehabilitating due to expansion of private *Eucalyptus* plantations, which increased wood availability for domestic and sale among others. This finding is consistent with Zhang and Song (2006) who found out that afforestation, which increased the forest cover of China from 8.6% in 1949 to 18.21% in 2003, facilitated the rehabilitation of natural forest by becoming the major source of timber production.

Conclusion

The patches of natural vegetation cover of the district have been deteriorating over the past twenty to thirty years. Drivers of such depletion are cutting of trees for fuel, timber, and construction purposes, encroachment of cropland, and institutional and political instability Rapid population growth has been exacerbating the rate of devegetation in the district. On the other hand, smallholder farmers *Eucalyptus* plantations have been significantly increased especially in areas close towns or roads; have little or no natural vegetation within and in their vicinities; and dominated by plain terrains (accessible through vehicles during dry season) over the last twenty years. Most of the *Eucalyptus* trees grown in the area are sold on stumpage to wood merchants, who prepare different wood products from *Eucalyptus* trees and sell to nearby towns, especially in Addis Ababa. The sources of motivation to plant *Eucalyptus* emanated from the demonstration effect of *Eucalyptus* trees grown by farmers who started early, personal initiative and advice from government bodies. The majority of farmers, however, started planting *Eucalyptus* due to the demonstration effect of *Eucalyptus* trees grown by farmers who started early. Most farmers began planting *Eucalyptus* around homesteads, mostly in backyard, and gradually expanding to agricultural lands close to homesteads. Simultaneously, some farmers converted croplands that have lost crop production potential due to fertility exhaustion to *Eucalyptus* plantation located even furthest away from homes. In some parts of the district, *Eucalyptus* woodlots of neighboring households are closing together to create a large continuous plantations pattern. Furthermore, there are signs of woodland rehabilitation due to expansion of private *Eucalyptus* plantations, which increased wood availability for domestic and market uses among others.

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References

Ball JB. 1993. Development of *Eucalyptus* plantations- an overview. http://www.fao.org/docrep/005/ac777e/ac777e04.htm#bm04.1.

Bekele E. 2003. “Causes and Consequences of Environmental Degradation in Ethiopia”. *In:* Gedion Asfaw (eds.), Environment and Environmental Change in Ethiopia; Consultation Papers on Environment, No.1, Addis Ababa: Forum for Social Studies.

Bewket W. 2003. Household level tree planting and its implications for environmental management in the north-western highlands of Ethiopia: A case study in the Chemoga watershed, Blue Nile basin. *Land degradation and Development* 14. 377-388.

Bishaw B. 2001. Deforestation and Land Degradation on the Ethiopian Highlands: A Strategy for Physical Recovery. Paper presented at International Conference on Contemporary Development Issues in Ethiopia, Kalamazoo, Michigan, U.S.A. August 16-18, 2001.

CSA. 2008. Summary and Statistical Report of the 2007 Population and Housing Census: Population Size by Age and Sex. Draft. Addis Ababa.

Davidson J. 1989. The *Eucalyptus* dilemma. Arguments for and against *Eucalyptus* planting in Ethiopia. The Forestry Research Centre Seminar Note Series No. 1. A. A.

Davidson J. 1993. Ecological Aspects Of *Eucalyptus* Plantations. http://www.fao.org/docrep/005/ac777e/ac777e06.htm

Dixon RK, S Brown, RA Houghton, AM Soloman, MC Trexler, J Wies-Niewski. 1994. Carbon pools and flux of global forest ecosystems. Science 263(5144):185–190.

FAO. 2010. Global Forest Resources Assessment 2010: Key findings www.fao.org/forestry/fra2010

FAO. 2004. Ethiopia: Forests and the forestry sector http://www.fao.org/forestry/country/57478/en/eth/

FAO. 2000. Forests, food security and sustainable livelihoods. Unasylva - No. 202, An international journal of forestry and forest industries - Vol. 51- 2000/3. http://www.fao.org/DOCREP/X7273E/X7273E00.HTM

FAO. 1979. Eucalypts for planting. FAO Forestry series No. 11, Rome, Italy, PP. 75-76.

Gemechu TA. 2009. Livelihood Issues and Sustainable Natural Resource Management: A case study from Ethiopia. VDM Verlag Dr. Muller, Germany.

Gemechu TA, W Bewket. 2007. Challenges and Prospects for Sustainable Forest Management in Wondo Genet Area, Southern Ethiopia. Ethiopian Journal of Development Research 29(2).

Jagger P, J Pender . 2003. The role of trees for sustainable management of less-favored lands: the case of *Eucalyptus* in Ethiopia. Forest Policy and Economics 5 (2003) 83–95.

Jenbere D. 2009. The Expansion of *Eucalyptus* Plantation by Small holder farmers and its drivers: the case of Arsi Negelle District, Southern Oromia, Ethiopia. Unpublished MSc thesis submitted to Wondo Genet College of Forestry and Natural Resources.

Mekonnen Z. 2006. *Eucalyptus* as an Alternative to the Increasing scarcity of Wood and Income sources to Smallholders. M. Sc. Thesis, Wondo Genet College of Forestry.

Munishi PKT. 2007. The *Eucalyptus* controversy in Tanzania. Paper Presented at TAF Annual General Meeting (AGM) 23rd – 24th 2007 Dodoma Tanzania http://www.taftz.org/reports/USE%20OF%20*EUCALYPTUS*%20IN%20AFFORESTATION.doc.

Newcombe K. 1987. An economic justification for rural afforestation: The case of Ethiopia. *The Annals of Regional Science* 21, 80-90

North Shewa Zone Planning and Economic Development Office. 1998. Socio-economic Profile of Sululta and Mulo District, Fitche.

Pohjonen V, T Pukkala. 1990. *Eucalyptus globulus* in Ethiopian Forestry. Forest Ecology and Management. Volume 36, Issue 1, Pages 19-31

Rahmato D. 2001. Environmental Change and State Policy in Ethiopia: Lessons from Past Experience. FSS Monograph Series 2. Addis Ababa

Sunder SS. 1993. The ecological, economic and social effects of *Eucalyptus.* http://www.fao.org/docrep/005/ac777e/ac777e08.htm#bm08

Teshome T. 2007. Is *Eucalyptus* Ecologically Hazardous Tree Species? Ethiopian Tree Fund Foundation. http://etff.org/Articles/*Eucalyptus*.html, last visited June 2010.

Wirtu D. 1998. The economics of growing *Eucalyptus* globulus (Labill.) on the Highlands of Oromia, Ethiopia; with special reference to Intoto and Chancho areas. MSc. Thesis. Wondo Genet College of Forestry.

Wofsy SC, MI Goulden, JW Munger, S Fan, PS Bakwin, BC Daube, SI Bassow, FA Baazaz. 1993. Net exchange of CO^2 in a mid latitude forest. Science260(5112):1314 – 1317.

Yirdaw E, O Luukkanen. 2003. Indigenous woody species diversity in *Eucalyptus globulus* Labill. plantations in the Ethiopian highlands. Biodiversity Conservation. 12, 567–582.

Zewudie M. 2008. Temporal Changes of Biomass Production, Soil Properties and Ground Flora in *Eucalyptus* globulus Plantations in the Central Highlands of Ethiopia. Swedish University of Agricultural Sciences. PhD thesis Uppsala

Zhang Y, C Song. 2006. Impacts of Afforestation, Deforestation, and Reforestation on Forest Cover in China from 1949 to 2003. Journal of Forestry. October/November 2006(383-387)

Main Diseases of *Eucalyptus* Species in Ethiopia

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Abstract

Plantation of exotic tree species is widely practiced in Ethiopia in the last several decades. *Eucalyptus globulus, E. camaldulensis, E. saligna, E grandis*, and *E. citriodora* are among the introduced *Eucalyptus* species. *E. globulus* and *E. camaldulensis* are the two widely planted *Eucalyptus* species. The adoptability, growth performance, and wood quality of these tree species are influenced by biotic and abiotic agents. In this paper the occurrence, distribution and importance of diseases and insect pests on *Eucalyptus* tree species is highlighted. Stem canker caused by *Botryosphaeria parva* was commonly observed on *Eucalyptus globulus, E. saligna,* and *E. citriodora*. Another stem canker known as Coniothyrium stem canker caused by *Coniothyrium gaucheness* was frequently observed on *E. camaldulensis*. *Cytospora* is also known to cause canker on *Eucalyptus* species. Recently two new species of *Cytospora, C. abyssinica* and *C. nitschkii* were identified from Ethiopian plantations. Pink disease caused by *Erythricium salmonicolor* was recorded in some *E. camaldulensis* plantations. Leaf blotch caused by *Mycosphaerella* spp. was common on *E. globulus* in most areas where this species is planted. Three *Mycosphaerella* species, *M. nubilosa, M. parva,* and *M. merkusii* were recorded from *E. globulus* leaves. Of these diseases, Coniothyrium stem canker and Mycosphaerella, leaf blotch caused by *M. nubilosa* could be damaging in *Eucalyptus* plantations. Diseases caused by these fungi have significant impact on adaptability, growth, yield, and the quality of the wood products. Generally, studies on tree disease in Ethiopia are at infant stage. Building the research capacity and under taking organized and aggressive effort is essential to strengthen the research in areas of forest protection.

Key words: stem canker, foliage disease, *Eucalyptus* plantation, Coniothyrium, Botryosphaeria, Mycosphaerella

Introduction

Eucalyptus species that originated from Australia have been introduced and planted in many tropical and subtropical countries. Estimates indicate that plantations of *Eucalyptus* spp. cover approximately 10 million hectares of land worldwide (Eldridge *et al*. 1997). These plantations provide furniture, timber, distillates, tannins, essential oils, nectar, pollen, and fibre for the production of

paper, rayon, and viscose. They are also a valuable source of fuel wood and construction timber (Poynton 1979, Turnbull 1991).
In Ethiopia, planting of exotic trees commenced with the introduction of *Eucalyptus* spp. in approximately the 1890's. *Eucalyptus globulus, E. camaldulensis*, *E. saligna, E. grandis* and *E. citriodora* are among the early-introduced *Eucalyptus* species. Among these, *E. globulus* and *E. camaldulensis* are the most commonly planted *Eucalyptus* spp. in Ethiopia. *E. camaldulensis* is widely planted, usually at lower elevation and warmer localities, while *E. globulus* is commonly planted in the cooler highland areas. The wood from these *Eucalyptus* plantations provide wood for energy, construction material, transmission poles, and fencing material (Pohjonen and Pukkala 1990, Persson 1995).

Plantations of *Eucalyptus* spp. have showed great success in most areas where they have been planted as exotics. However, diseases pose a serious threat to these economically important plantation species. A number of important diseases have been recorded on different *Eucalyptus* species and clones. These diseases infect stems, roots, and leaves. Cryphonectria canker is caused by *Cryphonectria cubensis*, (Hodges et al. 1986, Wingfield, et al. 1989, Conradie, et al. 1990). Canker and dieback is caused by *Botryosphaeria* spp (Smith, et al. 1994). Vascular wilt of *Eucalyptus* caused by *Ceratocystis fimbriata* (Roux *et al*. 2000), pink disease caused by *Erythricium salmonicolor* (Sharma, et al 1984, Roux *et al*. 2001, Alemu, et al 2003a) and Leaf blotch caused by *Mycosphaerella* spp. (Park and Keane 1982, Crous 1998) are examples of diseases in commercial *Eucalyptus* plantations. A serious stem canker disease caused by *Coniothyrium zuluense* (Wingfield, et al 1996, Roux, et al 2002, Van Zyl *et al*. 2002) was reported from different countries. The causative agent of Coniothyrium stem canker is re-classified to belong in the genera *Kirramyces* and now the fungal species involved in causing Coniothyrium stem canker is reported to be *K. zuluence* and *K. gaucheness* (Cortinas et al. 2006, Andjic *et al*. 2007).

Diseases have had serious impacts on plantation forestry and in some cases, have resulted in the abandonment or restriction of species to specific localities. Diseases have also negatively affected the planting of *Eucalyptus* spp. in some African countries. For example, Mycosphaerella leaf blotch on *E. globulus, E. nitens,* and *E. maidenii* has resulted in reduction of planting these species (Lundquist and Purnell 1987). Likewise, *E. fastigata* and *E. fraxinoides,* which initially performed well in frost prone areas of South Africa, have been totally abandoned due to root disease caused by *Phytophthora cinnamomi* (Linde, et al. 1994).

The importance and impact of pathogens on exotic plantations in Ethiopia has yet not received adequate attention. Hence, even though tree death is common in plantations of Ethiopia, the knowledge about plantation diseases under Ethiopian condition is very limited. The deaths of trees are typically attributed to poor site-species matching, poor management and adverse climatic conditions. The role of biotic factors in tree death is underestimated, poorly understood and has not been studied in detail. Thus, a disease survey was conducted in some *Eucalyptus* plantations and wood lots in central, southern, and southwestern part of the country. The objective of the study was to determine the occurrence of diseases in *Eucalyptus* plantations, to provide a basis for further study and to high light the need to strengthen the research capacity on forest protection.

Materials and Methods

Survey areas and sample collection

Disease surveys were conducted in Central, Southern and South Western part of Ethiopia and Samples were collected from plantations and woodlots in smallholdings around Munessa Shashemene, Wondo Genet, Jima, Mizan Teferi, Bedele, Menagesha, and Addis Ababa. Samples were collected from parts of trees including bark, stems, twigs, and leaves of 10 selected symptomatic *Eucalyptus* trees. During sample collection, diseased plant tissues were kept in paper bags for transport to the laboratory (Alemu et al. 2003a).

Isolation techniques

In laboratory, isolations were made on 2% MEA growth media. Different isolation techniques were used including the transfer of pieces of mycelium or fruiting bodies from diseased plant tissue directly onto the growth medium; incubating symptomatic plant material in moist chambers; as well as inoculating segments of plant parts with disease symptoms onto growth media were used to isolate the fungus involved in causing the disease symptoms. All plates were incubated at 25 ^{o}C to induce fungal growth (Alemu et al. 2003a, Alemu 2003). For the isolation of leaf diseases discs of leaves with disease symptoms were attached beneath the cover of Petri dishes with the pseudothecia facing downward, so that spores were released onto MEA (Crous, et al. 1991). After 24 hr, ascospore germination was checked under the microscope and single germinating ascospores were transferred to MEA. Microscope slides were prepared of each isolate to determine the germination pattern of ascospores.

Identification of fungal isolates

To determine the identity of the fungus involved in causing the disease symptoms culture and spore morphology as well as molecular characterization were used (Alemu 2003).

Morphological characterisation

Isolates were initially characterized based on fungal colony growth pattern and the colour of the colony on growth media (MEA). Some isolates were inoculated on sterile pine needle placed on water agar in Petri dish and incubated for 2-3 weeks to induce sporulation. These spores were then used to analyse the size, shape septation pattern and the colour of the spores. Ten conidia were randomly selected from sample isolate and their widths and lengths were measured. Length: width ratios were calculated based on the mean length and width of each isolate. The spore germination patterns of some isolates were also used to characterise the species.

DNA extraction, PCR amplification, and sequence analysis

For molecular characterization, total genomic DNA was extracted from selected representative isolates were grown in liquid MY medium (2% Malt Extract, 0.3% Yeast Extract Agar). The DNA extraction techniques of Raeder and Broda (1985) were used to extract DNA. The concentration of the DNA in the samples was detected by running a 1% agarose gel, stained with ethidium bromide, and visualised under UV light. All molecular work was under taken at Forestry and Agricultural Biotechnology Institute (FABI), University of Pretoria, South Africa.

PCR amplification

For *Coniothyrium* isolates, the internal transcribed spacer (ITS) regions of the ribosomal RNA operon and the 5.8S gene as well as the β-tubulin gene were amplified using the polymerase chain reaction (PCR). In PCR amplification a combination of different primers were used. The primers used in the study include ITS 1 (5' TCC GTA GGT GAA CCT GCG G '3), and ITS 4 (5' TCC TCC GCT TAT TGA TAT GC 3'). To amplify ITS 1, ITS 2 and 5.8s genes of the ribosomal RNA operon (White *et al.* 1990) and the β-tubulin gene was partially amplified using the forward primer Bt2a (5' GGT AAC CAA ATC GGT GCT GCT TTC 3') and the reverse primer Bt2b (5' ACC CTC AGT GTA G TG ACC CTT GGC 3') (Glass and Donaldson 1995). Sequence of these two gene regions were used to determine the identity of the *Contiothyrium* isolates.

The internal transcribed spacer regions (ITS) and 5.8S gene of the ribosomal RNA operon and the elongation factor gene of the *Botryosphaeria* isolates used in this study were amplified using the Polymerase Chain Reaction (PCR). For the 1-α gene, forward primer EF1-728F (5'-CAT CGA GAA GTT CGA GAA GG-3') and reverse primer EFI-986R (5'-TAC TTG AAG GAA CCC TTA CC-3') was used (Carbone, et al. 1999). Comparisons of sequences of these genes were used to identify the *Botryosphaeria* isolates. Only the ITS region was amplified for *Mycospaerella* isolates (Alemu 2003, Alemu *et al*. 2005, 2006).

The PCR products were sequenced in both directions and manually aligned. The identity of the sequence of the fungus was obtained by comparing the DNA sequences of the Ethiopian isolates against sequences obtained from Gene bank [National Centre for Biotechnology Information (NCBI), US National Institute of Health Bethesda (http:/www.ncbi.nlm.nih.gov/BLAST]. Once the possible identity of the fungus was determined using blast search, more sequence data of the fungus under study were included in the study. The ITS and β-tubulin gene sequence of the *Coniothyrium* isolates as well as the ITS and elongation factor gene sequences of *Botryosphaeria* were combined and analyzed (Alemu et al. 2005).

The ITS and the β-tubulin sequence of *Coniothyriun* isolates, the ITS and the elongation factor gene sequences of *Botryosphaeria* and the ITS sequence of The *Mycosphaerella* sequences were aligned manually using PAUP 4.0 (Swofford, 1998). Gaps were inserted manually and treated as missing data. Each of these sequences was analysed using parsimony with trees generated by heuristic searches, simple addition, and Tree Bisection Reconstruction (TBR) branch swapping. Confidence intervals were determined using DNA BOOTSTRAP analysis (Bootstrap confidence intervals on DNA parsimony) (1000 replicates) (Felsenstein 1993).

Pathogenicity tests

The pathogenicity of *Botryosphaeria* and *Coniothyrium* spp was studied on an 18-month-old *E. grandis* clone (ZG 14) (approximately 1 cm diameter) in the green house where as the field pathogenicity of *Botryosphaeria* spp was conducted on *E. citodora* trees. Before inoculation, the plants were kept in the green house for a week to acclimatise them with the greenhouse conditions. Seven of the *Coniothyrium* isolates from Ethiopia were randomly selected for the inoculation study. Cultures were grown on MEA for two weeks before inoculation. A 9 mm cork borer was used to remove the bark and expose the cambium for inoculation. Mycelial plugs, of equal size, overgrown with the test cultures, were placed into each wound with the mycelium facing the wood. All the wounds were covered with parafilm (Pechiney Plastic Packaging, Chicago, U.S.A.) to prevent contamination and desiccation. Each isolate was inoculated on 10 trees and another ten trees were inoculated with sterile MEA as a control (Alemu 2003). After six weeks, development of disease was examined by measuring the lesion lengths on inoculated trees. A statistical analysis (One-way ANOVA) was conducted using Statistical for Windows to test if the lesion development of the inoculated isolates varied significantly from each other and from the control (Statsoft. Inc. 1995).

Results and Discussion

In Ethiopia, planting exotic species in plantations has been practised for more than a century. The impact of diseases on plantation development has received minimal attention. In recent years, tree deaths have been frequent observed but usually it has been attributed to extreme climatic and poor site conditions. The results of this study have shown that several well-known fungal pathogens are involved in causing considerable damage on plantations of *Eucalyptus* species. Two distinct symptoms of stem cankers were observed on several *Eucalyptus* spp. Disease symptoms included bark cracking, production of copious amounts of kino, stem discoloration and malformation, as well as the production of kino pockets in the xylem (Figs. 3, 4).

One of the Symptoms is that of Coniothyrium stem canker, which was observed in several *E. camaldulensis* growing localities in South and South Western Ethiopia. *E. camaldulensis* plantation near Jima, and *E. camaldulensis* trees planted in woodlots as well as around farms and homesteads were seriously affected by the stem canker. About 50% of *E. camaldulensis* trees growing in these localities had symptoms of the disease. Initially, small discrete lesions developed on young green bark (Figure 1a-d). When these lesions coalesced, large necrotic lesions developed on the stems, branches and twigs (Figure 1b, d). The formation of kino pockets were observed in the wood of infected trees (Figure 1c). In western Ethiopia, the disease is restricted to specific areas, and causes large-scale damage to trees in plantations, woodlots and around homesteads. It has not been found on other species of *Eucalyptus* in Ethiopia (Alemu *et al*. 2003a). In recent years it was understood that Coniothyrium stem canker seem to have wider geographic coverage and found on *E. camaldulensis* in different parts of the country where this is species is grown (personal observation). In culture, the fungi grew slowly and had olive green colonies. The colonies of most *Coniothyrium* isolates originating from different geographic sources had similar growth patterns and the colour of the colonies only showed limited variation

The result of the sequence analysis (Figure 2) revealed the *Conithyrium*-like isolate obtained from Ethiopia is closely related to *C. zuluense* identified in South Africa (Alemu 2003, Alemu *et a*l 2005). The data also depict that sequence of the *Coniothyrium* isolates used in the analysis have three distinct groups. One of these groups constituent the *Coniothyrium* isolates from Ethiopian and Uganda. All of these different groups were tentatively treated as the same species. Analysis of the two gene areas studied clearly showed the prevalence of distinct phylogenetic differences between *C. zuluense* isolates. Recently Cortinas *et al.* (2006) conducted detailed study and not only reported for the first time that two distinct species are involved in causing Coniothyrium stem canker but also recommended the name *Colletogloeopsis* be used instead of *Coniothyrium.* Hence, the causative agents were reported to be *Colletogloeopsis zuluensis* and *Colletogloeopsis gauchensis* are responsible for causing the stem canker on *Eucalyptus* species. A new species known as *C. gauchensis* was also described associated with Coniothyrim stem canker. Cortinas *et al.* (2006) confirmed that *C. gauchensis* is the fungi involved in casing Coniothyrium stem canker in Ethiopia. Later on, Andjic *et al*. (2007) argued that neither Coniothyrium nor Colletogloeopsis is appropriate placement for the fungus causing coniothyrium stem canker and recommended it should be placed in *Kirramyces.* Because of this, the two fungal species causing Coniothyrium stem canker are again renamed as *K. zuluensis* and *K. gauchensis* and the telmorphs are *Tertosphaeria zuluensis* and *T. gauchinsis*.

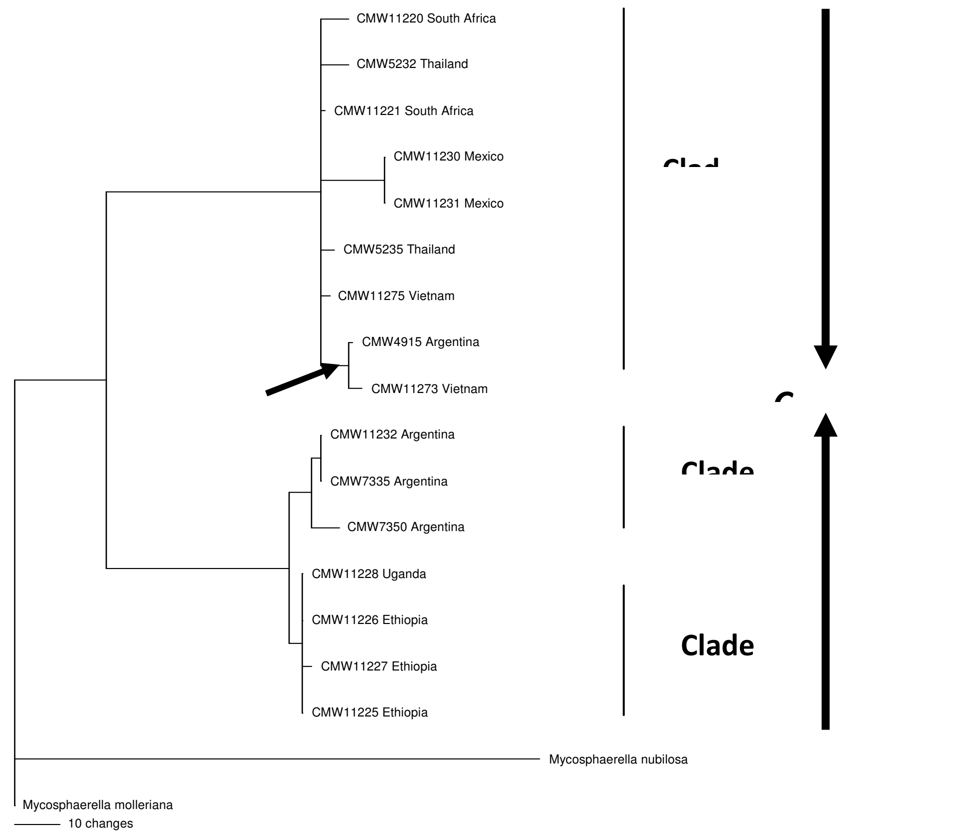

Figure 2. Phylogenetic tree of *Coniothyrium* spp. generated from the combined ITS and β-tubulin sequences. CI = 0.871 and RI = 0.837. Bootstrap values are shown at each branch.

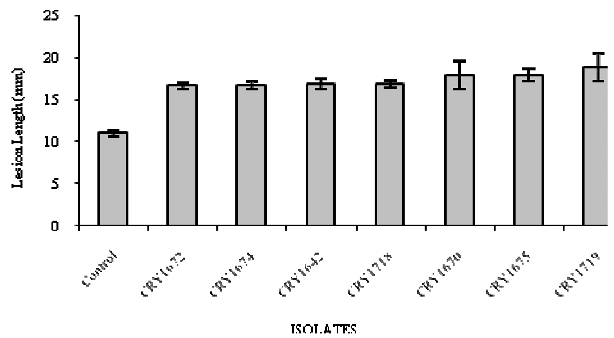

Figure 3. Mean Lesion Lengths and standard error of means of *Coniothyrium* isolates from the greenhouse inoculation trial.

The result of the pathogenicity test (Figure 3) showed the development of small lesion on inoculated plant after six weeks. Length of lesion showed significant statistical difference (P<0.0001) from the control. No significant difference in lesion development was observed between the *Coniothyrium* isolated used in the study (Alemu 2003).

In the current study it was observed that *E. camaldulensis* is highly susceptible to Coniothyrium stem canker. It is also learnt that the disease is widely spread in *E. camaldulensis* growing areas of the country. It is, therefore, essential to watch closely the progress and spread of the disease and the magnitude of damage it is inflicting. The disease situation on other *Eucalyptus* species is not known and detailed study is essential on Coniothyrium stem canker in Ethiopia. It is also of crucial importance to implement selection programmes to reduce the impact of this disease.

The other stem canker observed on *Eucalyptus* species was *Botryospharia* stem canker. Symptoms of Botryosphaeria canker were commonly found in *Eucalyptus* plantations at Munessa Shashemene, Wondo Genet, Jima, and Menagesha. Disease symptoms were found on different *Eucalyptus* species including *E. globulus, E. saligna, E. grandis,* and *E. citriodora*. Symptoms of Botryosphaeria stem canker were observed on both coppice stems and seedling stands and on trees of all ages (Fig. 4a-d). Bark cracking, production of copious amounts of kino, stem discoloration and malformation, tip dieback and death, as well as the occurrence of kino pockets in the xylem were the most common symptoms observed. When the bark was removed form symptomatic trees, well-developed kino pockets (Fig. 4b) were visible in the cambium and xylem. Of all *Eucalyptus* spp., *E. citriodora* plantations at Wondo Genet and Jima/Belete were the most severely damaged by this stem canker. Large basal cankers (Fig**.** 4a), as well as two to three layers of black kino rings (Fig. 4c) were commonly found on *E. citriodora* trees, indicating different seasons of infection. Isolates of *Botryosphaeria* associated with these stem cankers were easily collected from all samples.

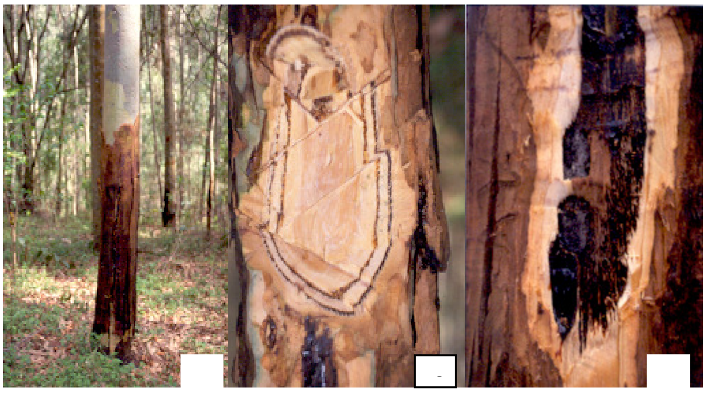

Figure 4. Disease symptoms associated with *Botryosphareia* on *Eucalyptus* spp. (a) Basal canker resulting in the cracking of the stem of *E. citriodora*, (b) Internal resin zone associated with external cankers on *E. citriodora* (c) Wood discoloration on *E. saligna* associated with stem canker.

These *Botryosphaeria* isolates when grown on MEA showed some variation in colony growth. Some of the isolates had fluffy light brown aerial mycelium, whereas others had flat colony growth with little aerial mycelium (Fig. 5D,E). Variation was observed between the conidial lengths of *Botryosphaeria* isolates obtained from Ethiopia (Table 1, Figure 5A-C). The lengths of the individual conidia ranged from 12.5 µm to 27.5 µm, whereas the average conidial length for different isolates ranged from 15.25 µm to 24.25 µm. The widths of the conidia showed limited variation and ranged from 5 µm to 7.5 µm. The conidia also showed different shapes and were categorised into three categories. They included those with long, narrow, cylindrical conidia, those with long, wide, cylindrical conidia and those with short conidia that are wide at the centre (Fig. 5a-c).

Figure 5. Culture and conidial morphology, (a) Long, narrow and cylindrical conidia, (b) Long, wide and cylindrical conidia, (c) short, and wise conidia, (d) fluffy light brown aerial mycelial growth and (e) flat light brown mycelia growth

The *Botryosphaeria* isolates used in this study showed some variation in colony growth as well as in conidial length and shape. Based on culture morphology two groups could be distinguished. When the morphology of the conidia was considered, three morphological groups emerged. The morphological variation detected in this study, was however, not consistent with the results of the DNA-based comparison (Fig. 6), which showed that the Ethiopian *Botryosphaeria* isolates represent a single species. The result of this study is consistent with the view of Sivanesan (1984), Butin (1993), Pennycook, and Samuels (1985) who reported that morphological characteristics alone are insufficient to identify many *Botryosphaeria* spp. with confidence. Hence molecular identification using analysis of the combined sequences of ITS and elongation factor genes were used to determine the identity of the Botryosphaeria isolates. Based on the sequence comparison and analysis it is now known that the *Botryosphaeria* found on *Eucalyptus* in Ethiopia is *B. Parva* (Fig. 6).

Table 1. Conidial sizes associated with *Botyosphaeria* isolates from *Eucalyptus* in Ethiopia

Isolate No	Origin	Host	Average length (µm)	Average Width (µm)	Length:width (ratio)
CMW10092	Menagesha	*E. globulus*	(15) 17.25 (20)	(5) 5.75 (7.5)	3.17
CMW11060	Jima/Belete	*E. citriodora*	(17.5) 18.25 (20)	(4.75 5 (5.5)	3.17
CMW11066	Jima/Belete	*E. citriodora*	(17.5) 20.75 (25)	(5) 5.25 (7.5)	3.95
CMW10094	Wondo Genet	*E. saligna*	(17.5) 19 (20)	(5) 5 (5.25)	3.8
CMW11072	Menagesha	*E. globulus*	(17.5) 19.75 (22.5)	(5) 5 (5.5)	3.95
CMW10093	Wondo Genet	*E. saligna*	(12.5) 15 (17.5)	(4.75) 5 (5.5)	3
CMW11068	Munessa	*E. globulus*	(15) 18.5 (22.5)	(5) 5 (5.5)	3.7
CMW11069	Menagesha	*E. globulus*	(15) 16.75 (20)	(5) 5.75 (7.5)	2.91
CMW11061	Jima/Belete	*E. citriodora*	(15) 17.75 (22.5)	(5) 5.25 (7.5)	3.38
CMW11062	Jima/ Belete	*E. citriodora*	(17.5) 19.5 (22.5)	(7) 7.5 (7.5)	2.6
CMW11059	Jima/Belete	*E. citriodora*	(15) 17.5 (20)	(5) 5 (5.5)	3.5
CMW11070	Menagesha	*E. globulus*	(17.5) 17.5 (20)	(5.25) 5 (5.5)	3.55
CMW10095	Wondo Genet	*E. grandis*	(15) 15.25 (17.5)	(5) 5 (5.5)	3.05
CMW11071	Menagesha	*E. globulus*	(17.5) 18.5 (20)	(5) 6.5 (7.5)	2.85
CMW11064	Jima/Belete	*E. citriodora*	(17.5) 21.75 (25)	(5) 5 (5.5)	4.35
CMW10088	Wondo Genet	*Eucalyptus spp.*	(15) 18.25 (22.5)	(5.25) 5 (5.5)	3.65
CMW10089	Wondo Genet	*Eucalyptus spp.*	(20) 24.25 (27.5)	(7) 7.5 (7.75)	3.23
CMW10096	Wondo Genet	*Eucalyptus spp.*	(15) 16.25 (17.25)	(5) 5 (5.25)	3.25
CMW11063	Jima/Belete	*E. citriodora*	(15) 16.5 (17.5)	(4.75 5 (5.5)	3.3

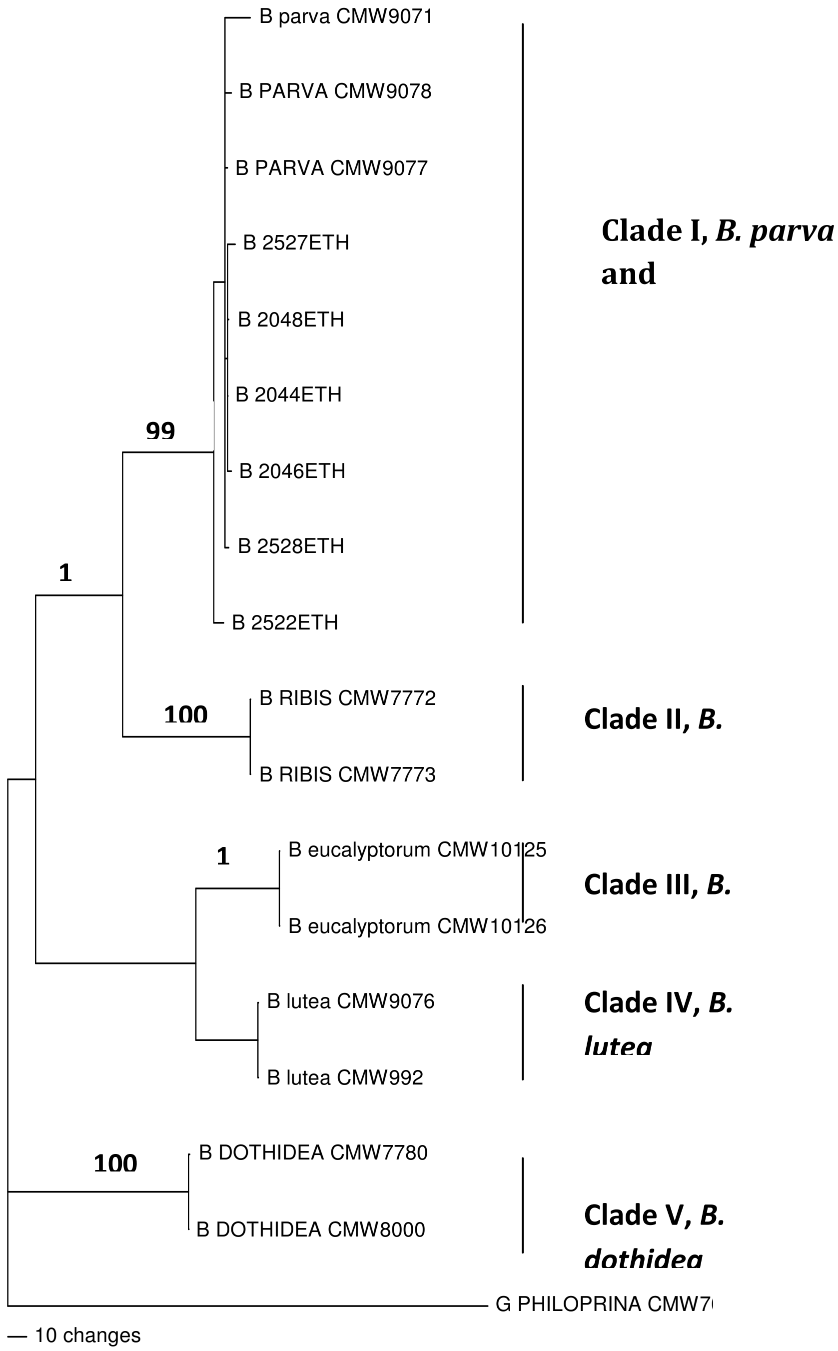

Figure 6. Phylogenetic tree for combined ITS and elongation factor sequence. CI=0.928, RI=0.905. Bootstrap values are shown on the branch.

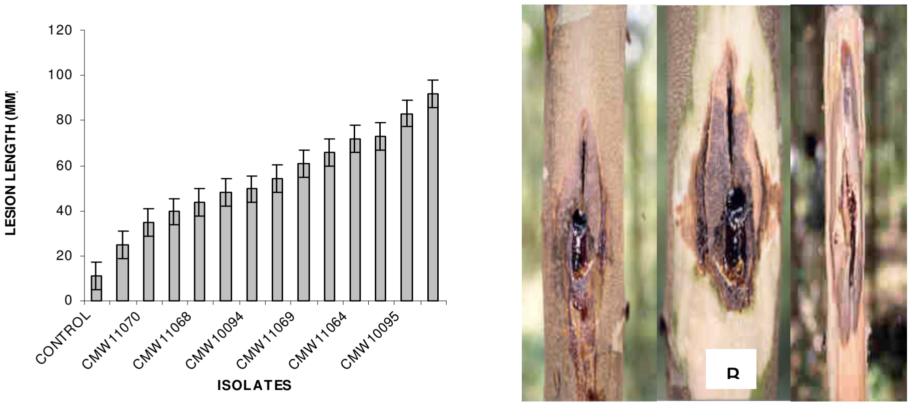

Figure 7. Results of pathogenicity tests (A) the graph show lesion developed on inoculated trees. (B) Lesion from inoculation trial

Greenhouse and field inoculation trials revealed that most *Botryosphaeria* isolates obtained from *Eucalyptus* in Ethiopia are pathogenic to *E. grandis* (clone ZG 14) (Fig. 7A-B) and to *E. citriodora*. The *B. Parva* isolates used in this study showed variation in pathogenicity in both the green house and field study. The variation in virulence of the isolates showed the same trend both in greenhouse and field inoculation studies. Jacobs (2000) showed that *B. parva* is pathogenic to Mango and it was reported that the isolates used in that study also varied from being most pathogenic to least pathogenic.

Damage due to *Botryosphaeria* spp. is more pronounced when plants are under stress caused by drought, frost, waterlogging, and insect damage (Wene and Schoenewesis 1980, Swart, et al 1987, Pusey 1989, Old *et al.* 1990). Recently, it has been recognised that *Botryosphaeria* spp. also exist as symptomless endophytes in *Eucalyptus* spp. and that they can easily be isolated from healthy tissue. For example *B. dothidea* (anamorph = *F. aesculi*) has been reported to be endophytic in *E. nitens* in England (Fisher, et al. 1993). Studies conducted in South Africa have also shown that *B. dothidea* occurs in healthy *E. grandis, E. camaldulensis, E. nitens,* and *E. smithii* as an endophyte (Smith *et al.* 1996). When trees or tree parts are affected by stress, these fungi become active and can cause dieback.

B. parva, therefore, must be considered an important pathogen in Ethiopia, where it almost certainly resides in healthy trees, but causes dieback and death of trees under stress conditions. Because, plantations in Ethiopia are commonly developed in marginal areas where moisture stress is a limiting factor and where land degradation is sever. This could favour disease development associated with *B. parva*. Moreover, the association of Botryosphaeria canker with *Eucalyptus* coppice stands is of great concern because regenerating *Eucalyptus* species by coppicing is widely practiced in Ethiopia, particularly by small hold tree growers.

In the future, efforts shall be made to match species and genotypes to sites and thus to minimise the impact of this opportunistic pathogen.

The other disease identified mainly associated with *E. globulus* was Mycosphaerella Leaf blotch (MLB) caused by *Mycosphaerella* spp. Symptoms of MLB were found on *E. globulus* from samples collected from Wondo Genet, Hosanna, Endibir, Bedele, Menagesha, Holetta, and Addis Alem. Disease symptoms, including shoot dieback and leaf blotch (were common. In some cases, nearly 100% of the leaves on a tree and nearly 100% of the leaf surfaces of these trees were affected. Lesions varied in size from small to large spots spreading over the whole leaf surface. Some lesions coalesced to form larger lesions. The lesions were light brown in colour and had raised brown margins. On some leaves, lesions were confined to the margins of the leaves. Other samples had leaf spots that extended through the leaf laminas, with lesions visible on both leaf surfaces with a light brown colour and a faint red margin.

When the growth of the fungi on MEA was considered, three culture morphologies were found. Four *Mycosphaerella* isolates obtained from *E. globulus* leaves collected from Addis Alem, Endibir and Hosanna had similar colony morphology and constituted one group (Group I) (Figure 9d). The colony colour of this group is olivaceous black. Group II comprise isolates obtained from Hosanna, Endibir, Holetta, and Bedele showed a dark olivaceous grey colour. The third group included only one isolate obtained near Hosanna. This isolate had a pale olivaceous grey colour.

Examination of the ascospore germination of these *Mycosphaerella* isolates produced three different germination patterns. These three germination patterns could be directly correlated to the group identified based on colony morphology. Isolates from morphotype I were represented by ascospore germination pattern closely resembling a Type F germination pattern. This pattern is characteristics of *M. juvenis***.** The four isolates from morphotype Group II had Type C (Crous 1998) germination patterns. This type of germination is characteristic of *M. heimii, M. gregaria, M. molleriana,* and *M. nubilosa* (Crous 1998). The isolate obtained from Hossana had a Type B germination pattern. This germination pattern has been associated with *M. gracilis* and *M. marksii* (Crous 1998). This suggested that at list three different Mycosphaerella spp. are involved in causing MLB (Alemu et al. 2006).

Gene sequence analysis of the ITS region of *Mycosphaerella* isolates confirmed the grouping made based on fungal colony growth and spore germination pattern. From the sequence analysis it was understood that three *Mycosphaerella* spp., namely *M. parva, M. nubilosa* and *M. marksii* represent the three groups of *Mycosphaerella* species (Fig. 8).

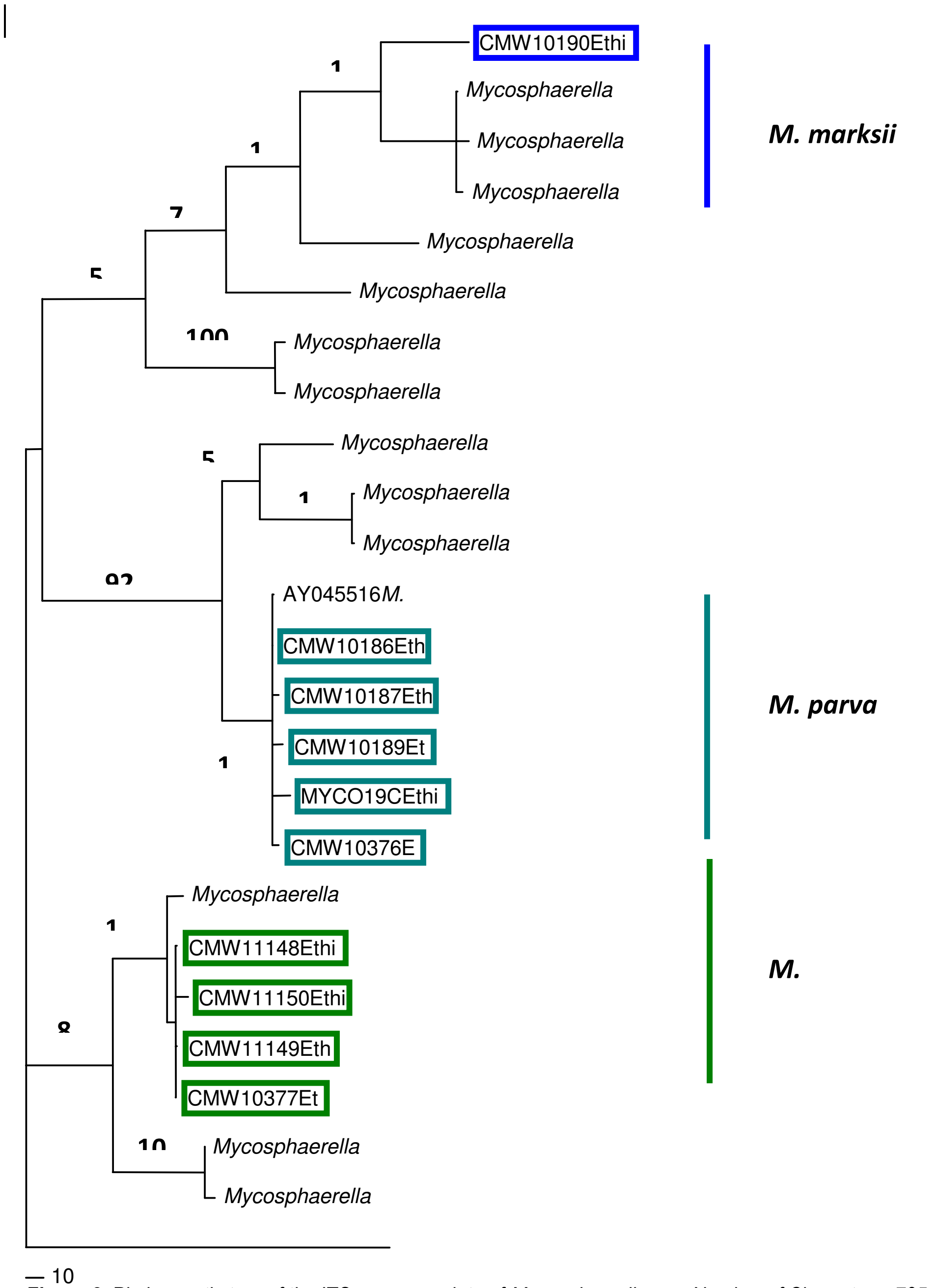

Figure 8. Phylogenetic tree of the ITS sequence data of *Mycosphaerella* spp. Number of Character = 705. CI=0.691 and RI=0.861. Bootstrap value is shown at each branch

Mycosphaerella marksii was found only from a single leaf sample collected from *E. globulus* near Hossana. Previous studies have shown that *M. marksii* occurs on several *Eucalyptus* spp., including *E. globulus, E. grandis, E. nitens,* and *E. saligna* (Carnegie *et al*. 1994). This fungus is now known to occur in South Africa, Indonesia, Portugal, and Uruguay (Carnegie *et al*. 1994, Carnegie and Keane 1997, Crous and Wingfield 1996, Crous 1998). The fungus was collected only from a single leaf; it is therefore not possible to indicate how important this disease is in *Eucalyptus* plantation in the country hence it deserves close follow up.

Mycosphaerella parva was found on samples collected from Addis Alem, Endibir, and Hosanna. This fungus was first described from Australia on *E. grandis*, *E. globulus,* and *E. nitens* (Carnegie and Keane 1994, Carnegie 2000). According to Carnegie and Keane (1994), this pathogen is a common cause of necrotic lesions at the margins of leaves. This type of symptom was common in Ethiopia, suggesting that *M. parva* is one of the more important components of MLB in the country. This is the first report of this species outside of Australia, and given its occurrence in Ethiopia, it might be found in neighbouring countries in the future.

Mycosphaerella nubilosa was found in several areas including Endibir, Holetta, Hosanna, and Bedele. This species mostly affects juvenile leaves of *E. globulus* (Park and Keane 1982a, Purnell and Lundquist 1986, Carnegie *et al*. 1994). This is also one of the most common and destructive foliage pathogens of *Eucalyptus* in many countries (Park and Keane 1982a, Dick and Gadgil 1983, Purnell and Lundquist 1986, Hunter *et al.* 2002). The presence of *M. nubilosa* in Ethiopia explains that *E. globulus* could be seriously affected by premature defoliation and this fungus should be considered as important constraints to *E. globulus* propagation in the future.

Mycosphaerella Leaf Blotch is common, wherever *E. globulus* is grown in Ethiopia. Studies conducted in other countries have shown that infection by *Mycosphaerella* spp. not only causes premature defoliation and retarded growth, but can also lead to the total abandonment of planting certain *Eucalyptus* spp. In South Africa, for example, the planting of *E. globulus* was terminated in the 1940's because of MLB (Lundquist and Purnell 1987). As *E. globulus* is a widely planted species in Ethiopia, the discovery of *M. nubilosa* is of concern, especially given the fact that plantations of this species are likely to be expanded in the future. Selection of species and provenances with tolerance to MLB might help to minimise loss of yield caused by *Mycosphaerella* species in the future. *Mycosphaerella* leaf bloch affects a range of different *Eucalyptus* species and more than 30 *Mycosphaerella* species are known to be pathogenic on different *Eucalyptus* spp. Hence, a comprehensive study is essential to study which other *Eucalyptus* spp. are affected and which other *Mycosphaerella* species are found on these tree species.

Important tree diseases are prevalent in *Eucalyptus* plantation forest of the country and most of them are reported from Ethiopia for first time. This therefore provides a foundation on which to base future studies and to develop disease management strategies. In the past, tree deaths have been ascribed to factors such as adverse climatic conditions, poor species selection, and inadequate post-planting management. This study, however, has shown that the situation is more complicated and that biotic diseases play an important role. These findings suggest that management strategies to reduce the impact of diseases, and facilities to diagnose and monitor these problems should be instituted. In addition, most of the pathogens require more detailed taxonomic study and pathogenicity tests should be conducted to understand their role in tree death. It is also equally important to follow up if the different species mentioned above have any significant impact on indigenous tree species. The identified diseases are only from sample restricted to a certain locality; hence, it is essential to continue the study to cover wider geographic range as well as to look into the prevalence of other diseases that deserve close monitoring.

In Addition to the above-mentioned diseases, two other fungal diseases were recorded on *Eucalyptus* species. One of these diseases is Pink disease that is caused by *Erythricium almonicolor* (synonym, *Corticium salmonicolor* (Alemu *et a*l. 2003b). *Cytospra* sp, the causative agent of Cytospora stem canker was found associated with twigs die back on *E. saligna.* The cytospora samples collected during this study were identified to represent two new *Cytospora* species (Alemu *et al*., 2003b). The two identified species are *Cytpspora abyssinica* and *Cytpspora nitschkii* (Gerard *et al*., 2005). The importance of these species in causing stem canker and twig dieback in Ethiopia needs further investigation.

References

Alemu Gezahgne. 2003. Diseases of exotic plantation forestry trees in Etiopía. Doctoral thesis submitted the faculty of Natural and Agricultural Sciences, Department of Microbiology and Plant Pathology, University of Pretoria, South Africa

Alemu Gezahgne, B Slippers, J Roux, MJ Wingfield. 2004. Identification of the causal agent of *Botryosphaeria* stem canker in Ethiopian *Eucalyptus* plantations South African J. Bot. 70:241-248.

Alemu Gezahgne, J Roux, MJ Wingfield. 2003. First report of pink disease on *Eucalyptus camaldulesnis* in Ethiopia. Plant Path. 53(3): 402-403.

Alemu Gezahgne, J Roux, MJ Wingfield. 2003. Diseases of exotic plantation *Eucalyptus* and *Pinus* species in Ethiopia. South African J. Sci. 99:29-33.

Alemu Gezahgne, J Roux, CG Hunter, MJ Wingfield. 2006. *Mycosphaerella* species associated with leaf disease of *Eucalyptus globulus* in Ethiopia. For. Path., 36: 253-263.

Alemu Gezahgne, Maria-Noel Cortinas, MJ Wingfield, J Roux. 2005. Characterization of the Coniothyrium stem canker pathogen on *Eucalyptus camaldulensis* in Ethiopia. Aust. Plan. Path. 34:85-90.

Alemu Gezahgne, Alemayehu Refera, Abrham Tadesse. 2009. Review of diseases and insect pests recorded on tree species in forests of Ethiopia. *In:*Abraham Tadesse (ed) Increasing crop production through improved plant protection Vol. II:. Plant Protection Society of Ethiopia (PPSE). PPSE and EIAR, Addis Ababa, Ethiopia. pp 475-500.

Andjic, V, GE Hardy, MN Cortinas, MJ Wingfield, TI Burgers. 2007. Multiple gene genealogies reveal important relationships between species of *Phaeophleospora* infecting *Eucalyptus* leaves. FEMS Micro. Lett. 268: 22-33.

Butin H. 1993. Morphological adaptation and spore pleomorphism in the form-complex *Dichomera-Camarospoium* and *Fusicoccum-Dothiorella*. *Sydowia* 45: 161-166.

Carbone I, JB Anderson, LM Kohn. 1999. A method for designing primer sets for the speciation studies in filamentous ascomycetes. *Mycologia 91*: 553-556.

Carnegie AJ, PJ Keane. 1997. A revised *Mycosphaerella gregaria* nom. nov. for *M. aggregata* on *Eucalyptus.* Mycological Research 101:843-844.

Carnegie AJ, PJ Keane, PK Ades, IW Smith. 1994. Variation in susceptibility of *Eucalyptus globulus* provenance to Mycosphaerella leaf disease. Can.J. For.y Res. 24: 1751-1757.

Conradie E, WJ Swart, MJ Wingfield .1990. Cryphonectria canker of *Eucalyptus,* an important disease in plantation forestry of South Africa. South African For. J. 152: 43-49.

Cortinas MN, T Burgess, B Dell, D Xu, PW Crous, BD Wingfield, MJ Wingfield. 2006. First record of *Colletogloeopsis zuluensis* comb. nov., causing stem canker of *Eucalyptus* in China. Myco.l Res. 110: 229–236.

Crous PW, MJ Wingfield. 1996. Species of *Mycosphaerella* and their anamorphs associated with leaf blotch disease of *Eucalyptus* in South Africa. Mycologia 88: 441-458.

Crous PW. 1998. *Mycosphaerella* spp. and their anamorphs associated with leaf spot disease of *Eucalyptus.* Myco. Memo. 21: 1-170.

Crous PW, AJL Phillips, MJ Wingfielf. 1991. The genera *Cylindrocladium* and *Cylindrocladiella* in South Africa, with special reference to forestry nurseries. South African For. *J.* 157: 68-85.

Dick M, PD Gadgil. 1983. *Eucalyptus* leaf spots. Forest Pathology in New Zealand 1: 1-7.

Eldridge K, J Davidson, C Harwood, G Van Wyk. 1997. *Eucalyptus* domestication and breading. Oxford, Science Publication, UK.

Felsentein J. 1993. DNABOOT-Bootstrap Confidence Interval on DNA parsimony 3.1. Seattle, University of Washington DC.

Fisher, PJ, O Petrini, BC Sutton. 1993. A comparative study of fungal endophytes in leaves, xylem and bark of *Eucalyptus nitens* in Australia and England. *Sydowia* 45: 1-14.

Gerard CA.MJ Wingfield, Ralph Common, J Roux. 2005. Phylogenetic relationship and morphology of Cytospora species and related telemorphs (Ascomycota, Diaporthales, Valsaceae) from *Eucalyptus.* Stud. in Myco. 52:1-144

Glass, NL, GC Donaldson. 1995. Development of primer sets designed for use with the PCR to amplify conserved genes from filamentous ascomycetes. App. Enviro. Micro. 78: 1323-1333.

Hodges CS,AC Alfenas, FA Ferreria. 1986. The conspecificity of *Cryphonetria cubensis* and *Endothia eugeniae*. Mycologia 78: 343-350.

Hunter GC, PW Crous, J Roux, TA Coutinho, BD Wingfield, MJ Wingfield. 2002. Identification of *Mycosphaerella* spp. associated with leaf disease of *Eucalyptus nitens* in South Africa. Aust. J. Patho. 33:349-355.

Jacobs R. 2002. Characterisation of *Botryosphaeria* species from mango in South Africa. M. Sc. Thesis. Faculty of Natural and Agricultural Sciences, Department of Plant Pathology and Microbiology, Forestry and Agricultural Biotechnology Institute, University of Pretoria, South Africa.

Linde C, GHJ Kemp, MJ Wingfield. 1994. *Pythium* and *Phytophthora* spp. associated with *Eucalyptus* and pines in South Africa. Euro. J. For. Patho. 24: 345-356.

Linde C, GHJ Kemp, MJ Wingfield. 1994c. Disease of *Pines* and *Eucalyptus* in South Africa associated with *Pythium* and *Phytophthora* species. South Afri. For. J. 169: 25-32.

Lundquist JE, RC Purnell. 1987. Effects of Mycosphaerella leaf spot on growth of *Eucalyptus nitens*. *Plant Disease* 71: 1025-1029.

Old KM, R Gibbs, I Craig, BJ Myers, ZQ Yaun. 1990. Effect of drought and defoliation on the susceptibility of *Eucalyptus* to canker caused by *Endothia gyrosa* and *Botryosphaeria ribis*. Aust. J. Bot. 38: 571-581.

Park RF, PJ Keane. 1982. Leaf diseases of *Eucalyptus* associated with *Mycosphaerella* spp. *Trans. Brit. Myco. Soc.* 79: 101-115.

Pennycook, SR, GJ Samuels. 1985. *Botryosphaeria* and *Fusicoccum* species associated with ripe fruit rot of *Actinidia deliciosa* (Kiwifruit) in New Zealand. *Mycotaxon* 24: 445-448.

Persson A 1995. Exotics-Prospects and risks from European and African viewpoint. Buvi. Agri. Sci. 9: 47-62.

Pohjonen V, T Pukkala. 1990. *Eucalyptus globulus* in Ethiopian forestry. For. Eco. and Manag. 36: 19-31.

Poynton RJ. 1979. Tree planting in South Africa, Vol., 2. The *Eucalyptus.* Department of Forestry. Pretoria, South Africa.

Purnell RC, JE Lundquist. 1986. Provenance variation of *Eucalyptus nitens* on the Eastern Traansvaal Highveld in South Africa*. S. Afri. for. J.* 138: 23-31.

Pusey PL. 1989. Influence of water stress on susceptibility of nonwooded peach bark to *Botryosphaeria dothidea*. *Plant Disease* 73: 1000-1003.

Raeder U, P Broda. 1985. Rapid preparation of DNA from filamentous fungi. Lett. App. Microbiology 1: 17-20.

Roux J, TA Coutinho, MJ Wingfield, JP Bouillett, P Leigh. 2000. Diseases of plantation *Eucalyptus* in the Republic of the Congo. *S. Afri. J. Sci.* 96: 454-456.

Roux J, RN Heath, A Van der Hoef, MJ Wingfield. 2001. First report of pink disease on *Eucalyptus* and *Podocarpus* in South Africa. *Phytopathology*, S78 (Abstract).

Roux J, MJ Wingfield, D Cibrián. 2002. First report of Coniothyrium stem canker of *Eucalyptus* in Mexico. Plant Patho. 51: 382.

Roux J, MJ Wingfield, BD Wingfield, JP Bouillett, AC Alfenas. 2000. A serious new disease of *Eucalyptus* caused by *Ceratocystis fimbriata* in Central Africa. Euro. J. for. Patho. 30: 175-184.

Sharma JK, C Mohanan, EJ Maria Florence. 1984. Nursery diseases of *Eucalyptus* in Kerala. Euro. J. for. Patho. 14: 77-89.

Sivanesan A. 1984. The bitunicate ascomycetes and their anamorphs. Vaduz, Germany: J. Cramer.

Smith H, MJ Wingfield, PW Crous, TA Coutinho. 1996. Sphaeropsis sapinea and Botryosphaeria dothidea endophytic in Pinus spp. and *Eucalyptus* spp. in South Africa. S. Afri. *J. Bot.* 62: 86-88.

Smith H, GHJ Kemp, MJ Wingfield. 1994. Canker and die-back of *Eucalyptus* in South Africa caused by Botryosphaeria dothidea. Plant Patho. 43: 1031-1034.

Swart WJ, MJ Wingfield, PS Knox-Davies. 1987. Factors associated with *Sphaeropsis sapinea* infection of pine trees in South Africa. *Phytophylactica* 19: 505-510.

Swofford DL. 1998 PAUP*. Phylogenetic Analysis Using Parsimony (*and other methods). Version 4.0. Beta version. Sinauer Associates. Sunderland, Massachusetts.

Turnbull JW. 1991. Future use of *Eucalyptus*: opportunities and problems. *In:* Proceedings of the IUFRO symposium on intensive forestry. The role of *Eucalyptus*: pp 2-27. 2-6 September, Durban, South Africa.

Van Zyl LM, TA Coutinho, MJ Wingfield, K Pongpanich, BD Wingfield. 2002. Morphological and molecular relatedness of geographically diverse isolates of *Coniothyrium zuluense* from South Africa and Thailand. Myco. Res. 106, 51-59.

Wene EG, DF Schoeneweiss. 1980. Localized freezing predisposition to *Botryosphaeria dothidea* canker in differentially frozen woody stems. Canadian Journal of Botany 58: 1455-1458.

White TJ,T Bruns, S Lee, J Taylor. 1990. Amplification and direct sequencing of fungal ribosomal RNA genes for phylogenetics. Innis AM, DH, Gelfand, JJ Sninsky TJ White (eds). PCR protocols: A guide to methods and applications. pp 315-322. Academic Press, San Diego.

Wingfield MJ. 1990. Current status and future prospects of forest pathology in South Africa. S. Afri. J. Sci. 86: 60-62.

Wingfield MJ, PW Crous, TA Coutinho. 1996. A serious canker disease of *Eucalyptus* in South Africa caused by a new species of *Coniothyrium*. *Mycopathologia* 136: 139-145.

Wingfield MJ, WJ Swart, BJ Abear. 1989. First record of Cryphonectria canker of *Eucalyptus* in South Africa. *Phytophylactica* 21: 311-313.

Eucalyptus Short Rotation Woody Crops for Energy: A Literature and Experiences Review with Special Reference to Industrial Trials in Spain

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Abstract

The objective of this paper is reviewing the present state of the art of the use of *Eucalyptus* biomass from short rotation woody crops for producing energy in collective or industrial scale, revising the results of published experiences regarding plantation densities, yield, etc. In Spain, the first industrial trials performed by the pulp and energy company ENCE have resulted in biomass yields over 40 tons at 30% moisture over humid basis per hectare and year. Under Mediterranean climate, 500-800 mm/year with summer drought, irrigated crops of *E. maidenii, E, dunii, E. globulus,* and *E. saligna* with short rotation periods of 20-24 months and density of 3,500 trees/ha have proved to be optimum, the preferred species depending on soil and weather conditions, while crops without irrigation – mainly *E. camaldulensis, E, maidenii, E. globulus* and other species have yielded more than 15 tons/ha· per year at consumption moisture of 30% with lower optimum density – some 3,000 trees/ha, and 3-4 years rotation ages. Total energy crops in South-Western Mediterranean Spain accounted in 2009 for 6,700 hectares. Under milder and more humid Atlantic climates – more than 1,000 mm/year, without summer drought -, main trials are performed using *E. nitens* without irrigation on sites less suitable for better pulp producer *E. globulus* because of the higher freeze risk or the less deep soils. Crops are occupying 500 hectares in 2010, ranging their rotation ages from 3 to less than 5 years. Optimum plantation density goes from 2,200 to 3,000 trees per hectare, being the yield high – estimated values over 25 tons$\cdot$ha$^{-1}\cdot$y^{-1}, at consumption moisture (30%), despite the fact that this specie's coppicing is quite poor. The above-mentioned industrial company expects to base its future energy production from biomass on *Eucalyptus* short rotation crops, at least under favourable climatic conditions, with a lesser proportion of biomass from timber harvesting residuals and stumps from plantation changes. Developing of genetically improved plants – clones more biomass-productive or with better vegetative regeneration capability in the case of *E. nitens* -, and optimization of harvesting mechanization are the main future research lines.

Keywords: *Eucalyptus,* Short Rotation Coppices, Forest biomass, Renewable energy

Introduction

In 1992, the United Nations Framework Convention on Climate Change (UNFCCC) wrote down climate change and global warming firmly on the international policy agenda. In 1997, in Kyoto, the international community agreed on binding emission targets. Most OECD and transition economy countries agreed to reduce their greenhouse gas emissions by at least 5% below the 1990 levels in the period 2008 –2012.

The energy consumed in 1990 released 22 CO_2 Gt. Properly grown woody biomass does not contribute to climatic change through CO_2 emissions. Substituting fossil fuels by renewable biomass is therefore a powerful way to reduce CO_2 emissions.

In the European case, in 2007, the European Council adopted a binding target for Renewable Sources of Energy (RES) at 20% of final consumption by 2020. The European Commission proposed for the first time a target for renewable energy, not just for electricity or biofuels from renewable sources.

Industrial and forest harvesting residuals have become objective of energy valorisation intends in developed countries. Industrial residues are already mostly used to cogenerate heat and electricity in the forest industry: black liquors from pulp industry are a main biofuel source, as well as bark and other residues. Even the sawdust and other fine materials are being pelletized to give them more added value and make their use for thermal generation easier for final consumers. Regarding forest harvesting residuals; branches, tops and small round wood that were formerly unutilized for industrial or domestic uses have problems of harvesting costs,. This is because in most cases timber and biomass supply chains should integrate, using new logistics and mechanized means, on a hand, and also because their production is seasonal, what creates supply troubles for the potential final consumer in power plants.

In order to make the supply more stable, energy crops have been suggested as a complementary biomass source. They have some problems related to the high establishing costs and difficult harvesting mechanization, but much research is being dedicated to overcome these difficulties.

Woody species have some advantages if compared to herbaceous crops. The biofuel quality of Short Rotation Woody Crops (SRWC) is better than this of herbaceous crops, the biomass production is high enough for the most fast-growing species, and the establishing costs can be reduced because cycles are longer – several years -, and in the case of coppicing species (most ot the used species are coppicing, so the SRWC are also called Short Rotation Coppices (SRC), one can maintain the same crop for several cycles without regeneration relevant costs.

Accordingly to Ortiz *et al*. (2010), most utilized species for SRWC are selected varieties of willows and poplars, densely planted, the first in Central and Northern Europe, while *Populus* clones seem to have a greater potential in Southern Europe and many American regions. In addition, *Eucalyptus* is being tried, mainly in New Zealand, North and South America and Southern Europe. *Robinia* and *Pawlonia* species, besides other trees like *Ulmus pumila*, have been tried – even in industrial experiences – in certain areas.

Facciotto (2008) evaluates the energy crop area in Europe for willow in 15,000 ha in Sweden 1,175 in U.K., 24,000 in Romania and 1,000 in Poland. In the poplar case, his estimations reach 5,350 hectares in Italy, besides 500 ha planted with *Robinia* in the same Country.

Literature on *Eucalyptus* Plantations as Forest Energy Crop

Eucalyptus species have been tried as energy crops in Europe in Italy, Greece, Portugal, and Spain (Ortiz *et a*l., 2010). Nevertheless, the published information about biomass yield from *Eucalyptus* high-density short rotation coppices is still scarce.

Dalianis *et al*. (1994, cited in Ceulemans *et al*., 1996) studied very high density plantations in Greece – 10,000 to 20,000 trees/hectare for 2 years rotations; in arable fertile lands, they obtained 25.5 green tons per hectare and year for 20,000 trees/ha density, and only 10.4 green tons ha^{-1} y^{-1} in poor soils, for 10,000 trees ha^{-1} plantation density -.

In Portugal, Pereira *et al*. (1996) obtained high yields – 16 to 21 t ha^{-1} y^{-1} for 20,000 to 40,000 trees ha^{-1} plantation densities -. In Northern Spain, several pulp or energy Companies made trials in the nineties with high or very high density *Eucalyptus* SRCs, but results are not published. Accordingly, to Ortiz *et al*. (2010), key factors such as the effect of plantation density and rotation on sprouting ability of the crops have not been studied yet.

Sochaki *et al*. (2007) in Australia, for a plantation density of 4,000 trees ha^{-1}, obtained 8.5, 9.8 and 16.6 t ha^{-1} yields, depending on the topographic position of the plantation (ridge, slope and basal plain), suggesting the strong potential of producing biomass in plantations using densities three times as much as presently common ones.

Different species and genetic improvement potential has been studied by Sims *et al*. (1999a, 1999b and 2001), showing the importance of having into account the production not only in first rotation plantations, but in further rotation periods. The results were better for 5,000 trees/ha than for 2,222 trees/ha, and the best yields for both the first and second rotations were obtained for certain varietis of *E. viminalis* (Vega et *al*., 2008; Ortiz *et al*., 2010)

There has been a strong debate around the convenience of maximizing yield by very high densities and short rotations, despite the more expensive harvesting operations using modified foragers—and the expected growing difficulties in further rotations—in front of the use of lower plantation densities with longer rotation ages, in order to make harvesting operations cheaper, even using forest machinery such as accumulative harvesting heads (Picci, 2007; Tolosana, 2009; AEBIOM, 2009). The first alternative—2 years rotation ages, plantation density higher than 3,500 trees per hectare—has been called the European model for the poplar case (Spinelli and Nati, 2007; AEBIOM, 2009; Tolosana *et al*., 2010) while the second one—rotation ages close to 5 years and plantation density lower than 3,000 trees/hectare—has been referred to as "American model" in the case of poplar energy crops.

Accordingly to Rodriguez-Soalleiro and Perez-Cruzado (2010), other relevant experiences regarding *Eucalyptus* plantations have taken place in Brazil, where more than 3.5 million hectares of *Eucalyptus* plantations have been established during the last 40 years, reaching average yields between 45 and 60 $m^3 \cdot ha^{-1} \cdot y^{-1}$, with rotation ages as short as 5 to 7 years. These plantations, which timber destinations are pulp and charcoal, occupy subtropical areas, where *Eucalyptus grandis* and *E. grandis x urophylla* – the last more resistant to plant diseases – are the best performers. In Brazilian plantation forestry, genetic improvement has been a key factor to success, besides propagation techniques.

In Northern Spain, non-industrial experiences have been carried out mostly by the Santiago de Compostela University research group UXFS (www.usc.es/uxfs). They have made simulations for both E. globulus and E. nitens, for plantation densities of 2,400 trees /ha, basing on silvicultural models from Perez-Cruzado *et al*. (2009).

The cost of plants for the present clones from the first one have proven to make more expensive the high density plantations, while the C and biomass production from the second specie is comparable with that of the first one (Rodriguez-Soalleiro and Perez-Cruzado, 2010).

In the case of *E. nitens*, economic analysis showed that, if coppicing were not the regeneration way and densities were the usual ones – close to 2,000 trees/hectare -, optimum rotation age would be similar to the adequate for panel or pulp production, making possible a combined final destination (Mendez-Perez *et al*., 2010).

Recent Industrial Experiences

Main recent experiences have been promoted by pulp industry (ENCE) This company produces more than 1 million pulp tones and more than 1 million MWh of electricity (ENCE, 2009), This enterprise has two main geographical areas of activity in the Iberian Peninsula: Huelva – South-Western Spain – and Northern Spanish coastal regions – Galicia, Asturias, Cantabria. The first area corresponds with a sub-Mediterranean climate, with smooth winters – no months below 10°C average temperature – and annual precipitation of 500 to 800 mm – with physiological drought in summer, despite oceanic influences -. In this region, tried species are shown, besides some of their observed relevant characteristics, in Table I. At the end of 2009, the *Eucalyptus* SRWC in South-Western Spain accounted for some 6,700 hectares (Soria, 2009). Productive cycle is shown in Figure 1, while plantation pattern for irrigated crops are illustrated in Figure 2. Plantation densities in irrigated crops trials have ranged from 2,300 to 3,300 trees/ha (1x3,5 m to 1x3,0 m), following designs oriented to facilitate intermediate treatments – and harvesting operations.

Table I: Irrigated *Eucalyptus* species characteristics under sub-Mediterranean conditions.

Species	Height growth	Biomass yield	Cost	Saline soils tolerant	Irrigation needs	Freezing tolerance
E. globulus (clonal)	Very high	Very high	Very high	No	High	No
E. globulus (seedling)	High	High	Moderate	No	High	No
E. maidenii.	High	Very high	Moderate	No	Moderate	No
E. dunii	Very high	Very high	Moderate	No	Very high	Yes
E.saligna	Moderate	Moderate	Moderate	Yes	High	No
E. robusta	Moderate	Moderate	Moderate	Yes	Very high	No
E. urophylla x grandis	Moderate	Moderate	High	No	High	Yes

Year 0	1	2	3	First cut	4	5	6	Second cut	7
Terrain preparation Plantation Competence control Fertilization	Competence control if needed		Harvesting Fertilization Competence control if needed		Competence control if needed		Harvesting Fertilization Competence control if needed		
	First crop cycle				Second crop cycle				3rd to nth crop cycles

Figure 1: *Eucalyptus* energy crops rotation cycles proposed for irrigated arable lands in Huelvan ENCE trials. Intermediate treatments consist of competence controls and, besides fertilization with irrigation water, there is a basal fertilization at the time of planting and after each harvesting operation (Soria, 2009).

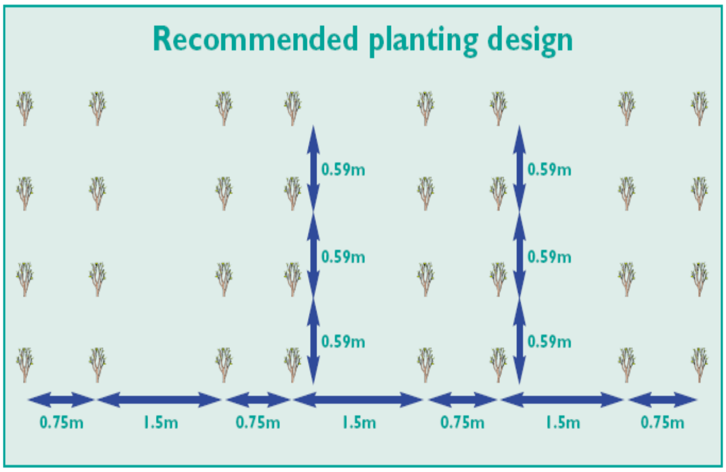

Figure 2: Recommended planted design for irrigated *Eucalyptus* crops under sub-Mediterranean conditions (ENCE Huelva trials). Represented plantation density is greater than presently recommended (Soria, 2009; adapted from a Syracuse University handbook dedicated to willow crops).

Optimum rotation age is less than two years, ranging from 20 to 22 months for the first rotation. Irrigation doses varies from a minimum of 1,600 water cubic meters per hectare per year for *E. maidenii* until no upper limit reached until now for *E. dunii*, whose biomass yield keeps on growing with increasing irrigation within the tried doses. Establishing cost has been around 2,000 €/hectare, including fertilizing and irrigation systems, and the researchers think that it could be significantly lowered in the future (Ruiz *et al*., 2009). Estimated yield for the more productive Species would be greater than 40 tons per hectare per year, for the considered consumption moisture of 30% over humid basis. Some pictures of the irrigated crops trials near Huelva are shown in Figure 3.

Figure 3: Irrigated arable land *Eucalyptus* energy crops (ENCE experiences in Huelva region), "meses" is the Spanish word for "months".

Under the same climatic conditions, non-irrigated crops require more drought tolerant *Eucalyptus* species. Depending on the drought –relative - severity, several species have been tried, from the most tolerant (*E. camaldulensis*), followed by *Eucalyptus maidenii* if drought conditions are less severe. Regarding *E. globulus*, genetic improvement developed in the last years by ENCE has lead to important advantages related to biomass production: more drought tolerance and better technological characteristics – e.g., greater basic density – (Soria, 2003). In humid areas, the trials in non-irrigated conditions are being performed using *E. dunii*, even more productive, although both *E. maidenii* and *E. dunii* have a high biomass yield per height meter.

In non-irrigated cases, plantation density trials went from 2,500 to 7,000 trees/ha. Optimum yield was found for 5,000 trees/hectare plots, but it was not significantly different from 3,000 or 7,000. Given that establishing cost is much lower for more reduced densities, it may seem logical to think about optimum densities below 3,000 trees/ha. Rotation ages for the first rotation have been fixed in 3 to 4 years depending on species and sites, and will be probably shorter in further rotations. Estimated yield – with conservative criteria – will be greater than 15 tons per hectare per year – for consumption moisture of 30%, on humid basis.

Under oceanic, more humid, weather conditions, in North-Western Spain - very short or no summer drought, annual precipitation well over 1000 mm, smooth winters with no or short freeze period - the preferred specie is *Eucalyptus nitens*, because of its bigger biomass growth – particularly regarding its early growth - and freeze tolerance, that make it complementary with the main pulp producing clones, belonging to *E. globulus*. The best performing densities have been low – 2,200 to 3,000

trees/hectare – while the proposed rotation ages ranged from 3 to less than 5 years, which makes biomass production compatible with panel roundwood production. Estimated yield varies with site index, being greater than 25 tons/hectare as an average for the same moisture (Castellanos, 2010). Some pictures of *E. nitens* plantations in Northern Spain are shown in Figure 4.

Figure 4: *Eucalyptus nitens* energy crops in Northern Spain (ENCE experiences)

Conclusions

Several experiences have proven the potential value of *Eucalyptus* species for Short Rotation Woody Crops. The trials show different *Eucalyptus*' species as most productive depending on site conditions. Anyway, the experiments show the importance of considering the yield along several rotations, as well as the genetic improvement potential, pointing out significant differences among different varieties of the same species, in the case of *E. viminalis*.

First trials showed the maximum yield in very dense plantations – more than 4,000 and up to 40,000 trees·ha^{-1} - with quite short rotation ages (equal or less than 2 years). Nowadays, the convenience of this management pattern is being discussed, because of the high establishing cost of such very dense stands plus the harvesting mechanization difficulties, particularly after coppicing. Part of the new experiments and industrial trials are choosing plantation densities closer to the commonly utilized for timber plantations – 2,000 to 3,500 trees·ha^{-1} - and rotation ages closer to 5 than to 2 years.

In Spain, ENCE industrial trials have chosen these patterns – densities from 2,000 to 3,500 trees·ha^{-1}, rotation ages between 2 years – for irrigated farmlands – and 4-5 years for non-irrigated crops. Preliminary results have shown that present high pulp-producer clones of *E. globulus* are very good performers but still expensive, so seedlings from other species are preferable, depending on the climatic conditions: *E. dunii*, *E. maidenii* and other species under particular conditions for irrigated crops in the sub-Mediterranean Southern Huelvan Spanish region, where yield could reach almost 50 t·ha^{-1}·y^{-1} (30% moisture); *E. camaldulensis*, *E. maidenii* and *E. dunii* in non irrigated crops in the same area – the species depending on drought severity -, with estimated average yield over 15 t·ha^{-1}·y^{-1}, while *E. nitens* has been the selected specie for non-irrigated crops in the Northern more humid Spanish regions, because it is complementary with the pulp producer clones of *E. globulus*, it is more freezing-tolerant and it has much greater biomass early growth (estimated productions - for rotation ages under 5 years, compatible with other productions – over 25 $t \cdot ha^{-1} \cdot y^{-1}$).

Accordingly to ENCE R &D staff, developing of genetically improved plants – clones more biomass-productive or with better vegetative regeneration capability in the case of *E. nitens* -, and optimization of harvesting mechanization are the main future research lines.

References

AEBIOM, 2009. "Energy crops in arable lands." Booklet. Coord: Francescato *et al*. (AIEL), 16 pages.

Castellanos A. 2010. Personal communications of the energy crops field trials responsible of ENCE Pulp Company in North-Western Spain. July-August 2010.

Ceulemans R, AJS McDonald, JS Pereira. 1996. A comparison among eucalypt, poplar, and willow characteristics with particular reference to a coppice, growth-modelling approach. Modelling Short Rotation Forestry Growth. Biomass and Bioenergy 11(2-3): 215-231.

Dalianis M, M Christou, C Souter, S Kyritsis, C Zafiris, G Samiotakis. 1994. Growth, yield and energy potential of densely planted *Eucalyptus globulus* in a two years short rotation. *Eucalyptus* for Biomass Production. In: Pereira JS, H Pereira (eds). Commission of the European communities, Brussels / Istituto Superior de Agronomia, Lisboa. pp. 193-201

Dopazo R, DJ Vega, R Ortiz, E Martínez-Chamorro. 2008. El aprovechamiento de biomasa residual y de cultivos energéticos: experiencias recientes y modelos de producción de biomasa forestal en montes gallegos. 5° Congreso Forestal Español. Avila, september 2009.

ENCE. 2009. Annual Report. 171 pages.

Faccioto G. 2008. Cultivos leñosos de corta rotación. Congreso Internacional de Biocarburantes de segunda generación. Pamplona.

Guo LB, REH Sims, DJ Horne. 2002. Biomass production and nutrient cycling in *Eucalyptus* short rotation energy forests in New Zealand: I. Biomass and nutrients accumulation. Bioresource technology 85, 273-283.

Guo LB, REH Sims, DJ Horne. 2006. Biomass production and nutrient cycling in *Eucalyptus* short rotation energy forests in New Zealand: II. Litter fall and nutrient return. Biomass and Bioenergy 30 (5): 393-404.

Méndez-Pérez N, C Pérez-Cruzado, R Rodríguez-Soalleiro. 2010. Evaluación y optimización económica en plantaciones energéticas de *Eucalyptus nitens*. I Congreso Ibérico de Biocombustibles. Pontevedra, June 2010.

Ortiz L, DJ Vega, R Dopazo. 2010. Manual de cultivos energéticos. Servicio de Publicaciones de la Universidad de Vigo. Escola de Enxeneria Forestal, Campus de Pontevedra. 129 pages, 2010.

Pereira H, J Pardos, AM Boudet, O Mitchell, G Mughini, S Kyritsis, C Dalianis. 1996. Eucalypt plantations for production of raw-material for industry and energy in Europe. In: Chartier, P. *et al*. Proceedings of the Ninth European Bionenergy conference on Biomass for Energy and the environment. Copenhagen (Denmark), June 1996. Ed. Pergamon, New York, pp. 84-89.

Pérez-Cruzado C, LM Rodríguez-Da Costa, E Fernández-Rivas, A Merino, R Rodríguez-Soalleiro. 2005. Diagramas de manejo de la densidad para plantaciones de *Eucalyptus nitens* Maid. en el norte de Espana con evaluación del carbono fijado en la biomasa arbórea. Actas del IV Congreso Forestal Español. Zaragoza, september 2005.

Picci G. 2007. Cultivos energéticos leñosos (SRC). Jornades sobre l'aprofitament energetic de biomassa llenyosa a Catalunya. Barcelona, november 2007.

Rodríguez-Soalleiro R,C Pérez-Cruzado. 2010. Cultivos leñosos. Situación en Europa e Iberoamérica. I Congreso Ibérico de Biocombustibles. Pontevedra, june 2010.

Rockwood DL, DR Carter, MH Langholz, JA Stricker. 2006. *Eucalyptus* and *Populus* short rotation woody crops for phosphate minelands in Florida, USA. Proceedings of the 5th Biennal meeting of the Short Rotation Woody Crops Operations Working Group in conjunction with International Energy Agency Bioenergy, Tasl 30, Short Rotation Crops for Bioenergy Systems and International Union of Forest Research Organisations (IUFRO) Unit 1.09.01, integrated Research in Temperate Short Rotation Energy Plantations. Biomass and Bioenergy 30(8-9):728-734

Rockwood DL. AW Rudie, SA Ralph, JY Zhu, JE Winandy. 2008. Energy Products Options for *Eucalyptus* species grown as short rotation woody crops. Int. J. Mol. Sci. 2008, 9, 1361-1378.

Rodríguez-Dacosta LM, A Merino, R Rodríguez-Soalleiro, C Pérez-Cruzado. 2010 Estabilidad nutricional en cultivos energéticos leñosos de *Eucalyptus nitens* y *Eucalyptus globulus*. I Congreso Ibérico de Biocombustibles. Pontevedra, june 2010.

Ruiz F, G López, F Soria. 2009. Personal communications of ENCE Research Director and other Huelvan technical staff members about the preliminary results of *Eucalyptus* energy crops trials during a visit to the field trials in June 2009.

Sims REH, K Senelwa, Maiava, BT Bullock. 1999. *Eucalyptus* species for biomass energy in New Zealand – Part I: Growth screening trials at first harvest. Biomass and Bioenergy 16(3) 199-205.

Sims REH, K Senelwa, Maiava, BT Bullock. 1999. *Eucalyptus* species for biomass energy in New Zealand – Part II: Coppice performance. Biomass and Bioenergy 17(4): 333-343.

Sims REH, K Senelwa, Maiava, Bullock BT. 2001. Short rotation coppice tree species selection for woody biomass production in New Zealand. Biomass and Bioenergy 20(5): 329-335.

Sochacki SJ, RJ Harper, KRJ Smettem. 2007. Estimation of woody biomass production from a short-rotation bio-energy system in semi-arid Australia. Biomass and Bioenergy 31(9): 608-616.

Spinelli R, C Nati . 2007. Woody Biomass Production from agricultural land in Italy. IEA Bioenergy. University of Guelph, Ontario (Canada)

Soria F. 2003. Mejora genética de *Eucalyptus globulus ssp. globulus* en áreas marginales: La experiencia clonal de ENCE. Actas del I Simposio Iberoamericano de *Eucalyptus globulus*. Montevideo (CD-Rom).

Soria F. 2009. La selvicultura de especies productoras de biomasa. VI Jornadas Forestales "El Monte Productor". Huelva, November 2009.

Tolosana E. 2009. Manual para el aprovechamiento y elabouracion de biomasa forestal. Ed. MundiPrensa and FUCOVASA. Madrid, 348 pages.

Tolosana E, R Laina, Y Ambrosio. 2010. Maquinaria y Equipamientos para el Aprovechamiento Energético de Biomasa Forestal. I Congreso Ibérico de Biocombustibles. Pontevedra, June 2010.

Vega DJ, R Dopazo, L Ortiz. 2008. Reviewing the potential of forest bioenergy plantations: woody energy crop plantations management and breeding for increasing biomass productivity. World Bioenergy 2008. Jönköping (Sweeden), may 2008.

Qualitative Analysis of Women's Participation in *Eucalyptus* Fuel Wood Supply Chain

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Abstract

The objective of this study is to understand major role of women in supplying *Eucalyptus* as fuel wood and provide alternative intervention mechanism for improving services in small scale set up of the *Eucalyptus* user society. This was done through desk study, literature review, and personal contact with some of the stakeholders. Two locations named Sululta and Sendafa were selected and assessment was done using quantitative survey method. Like many other parts of the developing countries, women in Ethiopia have limited access to and control over productive assets that determine their decision-making ability and affect their economic improvement. Women are mainly responsible for domestic activities such as food preparation, pounding, grinding, and fetching water, collecting firewood and childcare. Washing and cleaning is also the responsibility of women and girls. In the farming activity, land-tilling using animal power is usually done by men except in some cases where adult men member of the household are not available. With regard to livestock management, smaller animals are managed by women while men are responsible for larger animals. Utilization of milk and milk products (in small scale) is done by women. Preparing and providing food for the family is a direct responsibility shouldered by women, thus women usually spend their income for purchasing basic needs for their household. Hence, women are involved in different income generating activities such as sale of *Eucalyptus* to meet the demand for their needs. According to the findings of this study, *Eucalyptus* leaves and tree is used as fuel and source of income in different parts of the country. However, the infrastructure such as transport and marketing requires focused intervention with forming strong linkages among different stakeholders.

Keywords: gender role,

Introduction

This paper presents a preliminary assessment of quantitative information related to the involvement of women in the supply of *Eucalyptus* for fuel use in the urban and pre urban areas around Addis Ababa, the capital of Ethiopia. Like many other developing countries, women in Ethiopia have also multiple responsibilities in productive, reproductive, and other community management activities. In the rural areas women spend more than 13 hours of a day engaged in preparing food, fetching water, collecting fire wood, washing, cleaning, child care and farm activities such as weeding, harvesting and livestock management. Although women have equal share in maintaining family life, their roles, and responsibilities were not considered as an important component to design development measures. Providing emphasis to gender factors in research activities is relatively a recent approach in the Ethiopian agricultural research system. For example, the view of Addis Tiruneh et al (2000) is one of the foremost analyses of gender in agricultural research that refers to assessment differences in agricultural productivity between women and men headed households. In the case of gender in *Eucalyptus* production Mersha Gebrehiwot (2007) has made some analysis on gender and property rights and indicated that in spite of the existence of women's policy, the customary laws and practices have more influence in limiting women's access to productive resources. With regard to fuel wood supply, significant data were sensitized by Fikrte Haile (1991) indicating the energy consumption, pre-urban forest management, as well as socio economic characteristics of women engaged in fuel wood collection. Motuma's (2008) socio economic study of fuel wood collectors revealed that women engaged in the sector are those in the lower social status with limited access to resources and other infrastructure. Suggestion and recommendation were made particularly on the relevance of focusing on empowering fuel wood carrier women through providing alternative income generating activities (Motuma 2008).

Conventional method of biomass fuel such as charcoal, crop residue, cow dung, and forest products are the major source of energy in different parts of Ethiopia. As cited by Fikerete (1991), petroleum covers only 6.5% of estimated 205 kg of annual per capita consumption of oil equivalent. This difference is balanced by forest products, crop residue, dung collected from rural, and pre urban areas where women and children play major role in collecting and transporting.

Eucalyptus, the most planted tree in the world, has been grown in east Africa for over a century. Through this time, people in the region have accumulated important local knowledge of its management (Amare 2002). Today this tree dominates rural and urban landscapes. For smallholder growers, *Eucalyptus* suits their limited resources and yields more money than other tree crops. In addition to increasing biomass and providing ground cover, the sale of *Eucalyptus* poles and products has substantial potential to raise farm incomes. *Eucalyptus* tree plantation/wood lots are expanding and are becoming a good source of livelihood and income both in rural and peri-urban settings.

In Ethiopia, several *Eucalyptus* plantation projects were established in the 1980s with support from UNSO, DANIDA, FINNIDA, World Bank, and the African Development Bank. These plantations were established to supply fuel wood for the towns of Debre Birhan, Dessie, Gondar, Bahir Dar, Nazret, and Addis Ababa (Demel 2000). The Addis Ababa plantation is transferee to the Oromiya forest enterprise, which is the subject of this study. This paper is therefore, conducted to examine the overall participation of women in *Eucalyptus* supply chain with a specific objective of analyzing their role and looking into the contribution of *Eucalyptus* to the economic life of women in general.

Methodology

The observation was made at two different sites called “Sululta” and “Sendafa.” Sululta is located 25 km north of Addis Ababa along the main road to Gojam whereas Sendafa is about 40 km away from Addis Ababa along the main road to Dessie. Both locations are part of the Oromiya Administrative region and are known for the supply of *Eucalyptus* for a fuel wood. Both primary and secondary sources were used to collect data for the qualitative study. Primary sources include interview with key informants from wereda agricultural office, Focus Group Discussion with women fuel wood collectors, women and men traders, Oromiya forest enterprise of Sululta, and office of the Ministry of Agriculture at Sendafa. Checklist was developed to collect information from primary sources and was summarized qualitatively. Secondary sources include review of literature from relevant sources.

Major information required involves the following topic. Role of women and men in livelihood system, who among the family members are most involved in collecting *Eucalyptus* for fuel wood supply, from where (distance), travelled, time spent to collect, means of transport, where and how to sale, price of sale, any problem observed and mentioned.

Results

Overview of role of women and men in agricultural activities

Like many other parts of developing countries, women in Ethiopia have limited access to and control over productive assets that determine their decision-making ability and affect their economic improvement. Women are mainly responsible for domestic activities such as food preparation, pounding, grinding, fetching water, and collecting firewood and childcare. Washing and cleaning is also the responsibility of women and girls. In the farming activity, land-tilling using animal power is usually done by men except in some cases where adult men member of the household are not available. With regard to livestock management in general, smaller animals are managed by women while men are responsible for larger animals. Utilization of milk and milk products (in small scale) is done by women. (Yeshi and Kaleb eds.2008) Preparing and providing food for the family is a direct responsibility shouldered by women, thus women usually spend their income for purchasing basic needs for their household. Hence, women are involved in different income generating activities such as sale of *Eucalyptus* to meet the demand related to their tasks. 4.2 Description of the prevailing *Eucalyptus* fuel wood supply chain

Literature explained supply chain as a sequence of process and flows performed by community members in moving materials from source to end user in order to satisfy the customer demand (Chen,I.J., Paulraj,A 2004). *Eucalyptus* leaf and wood is therefore considered as the material, which is moved from different sources (Sululta and Sendafa) to satisfy the ever-growing demand of household energy. Household energy both in rural and urban areas are becoming a serious challenge involving substantial costs. In this regard, the fast growing nature of *Eucalyptus* has made it the best solution to address fuel wood demand in the country. The problem of fuel wood is more persistent in urban areas mainly because of limited supply of fuel wood particularly to poor urban dwellers. Limited supply in fuel wood, unavailability of well-established market and limitation to access alternative energy sources are some of the key factors that caused increasing price for fuel wood. Major constraint in the current *Eucalyptus* fuel wood supply chain includes absence of well-established market or absence of market lots, limited transport means, and declining fuel wood production. The supply chains particularly the collection and distribution involves women, men, and children, while the retailing at small quantity is done by women and children. The *Eucalyptus* fuel wood supply chain is schematically presented in fig. 1.

Role of women in *Eucalyptus* supply chain

The simplified supply chain represents the flow of the fuel wood from the Sululta and Sendafa plantation to Addis Ababa markets. Women and children have been found to be the most important and dominant actor in the entire *Eucalyptus* fuel wood supply chain in both cases. The supply chain consist three types of chain actors. These includes, Oromiya State forest enterprise, households residing around the plantation; and individual collectors and traders coming from town areas mainly from Addis Ababa. The *Eucalyptus* supply chain mainly serves poor households in Addis Ababa, hotels, and restaurants that are operating at small scale. As the cost of electricity and kerosene has become unaffordable to the poor urban households, supply of *Eucalyptus* fuel wood play crucial role in meeting the rising fuel wood demand.

Eucalyptus supply chain is currently serving two major economic objectives for women. The first one is, by providing income generation and self-employment opportunities for those engaged in the supply chain. The second one is through supplying alternative fuel wood for poor households in nearby town and Addis Ababa. The collection and transporting mode is slightly different in the two areas. In case of Sendafa, the dried leaves are collected at a central place and transported by truck (Figure 2). While at Sululta, women collect the dried branches of *Eucalyptus* tree and usually transport by carrying at their back (Figure 3).

Women enter the net work to generate income that would help them to fulfil their primary responsibility related to domestic activities. There are two types of women groups involved in fuel wood collection and selling activities. The first type is those women migrating from rural communities usually from the Southern Region to Addis and usually collect *Eucalyptus* for fuel from Sululta area. These women are engaged in fire wood collection as a sole source of income and livelihood in general. Such enterprise is meant to the migrants as an alternative opportunity to generate income. On average, these women earn about 50 Birr (about 3.5 USD) for a bundle of wood that weigh about 30 kg. These women spend more than 10 hours every day staring 5:00 a.m in the morning to 6:00 pm late in the afternoon. They have to travel uphill carrying a rope for tying and cushion (piece of shred clothes) for their back. They get back around 3:00 pm carrying bundle of thick loads that weigh more than 50 pounds or 25 kg at their back. They travel on average of more than 24 km round trip almost every day. The second type is those women involved in collecting and marketing of *Eucalyptus* leaf from the Sendafa area. The difference between the two sites is that at Sendafa, there is an initiative to establish cooperative where women and men can by and stock *Eucalyptus* leaf and wood. There is also organized youth group who buy from the cooperative and sale it to the Addis Ababa market. In this case the transportation is done by trucks.

Figure 1. collecting and transporting of dried part of *Eucalyptus* tree at Sululta

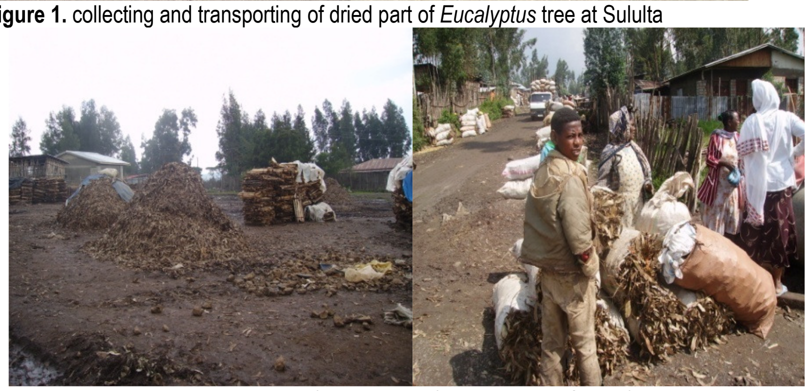

Figure 3 collecting and transporting of dried parts of *Eucalyptus* at Sendafa

Institutional support

The *Eucalyptus* fuel wood supply chain in the first place is categorized in an informal economic sector where actors involved in the sector are not registered, not subjected to any tax, hence have no institutional support. An observation in the study area and interview conducted with wereda agricultural officers revealed that the sector is currently providing to large and increasing number households as a source of income to sustain their living.

The Oromiya forest enterprises that own the plantation have recently banned any individual collector from entry into the plantation due to misuse and abuse of the forest through cutting branches and immature plants. This regulation will seriously affect large number of individuals who depend on the source for living. The Ethiopian Fuel wood Carrier Association is operating to help solve some of the problems faced by the members through providing alternative means that can help to generate income.

Major constraints in the *Eucalyptus* fuel wood supply chain

Respondents indicated the following major constraints that affect their day-to-day engagement in the *Eucalyptus* fuel wood supply chain.

Sululta

- Distance of the location from the main city that is travelled every day
- Difficulties to climb on the trees to collect dried leaves

Sendafa

- Unavailability of affordable means to transport collected fuel wood to market place
- Lack of access to financial credit services and if available fear of getting into debt

Fuel wood merchandizing activities (*buying and selling of fuel wood*) requires initial financial capital. The majority (more than 85%) of the cooperatives who are based at Sendafa are men. Many women are not encouraged to be part of this fuel wood merchandizing activities because of financial constraints and have no sufficient information on its sustainability and risk.

Conclusion and Recommendation

There is substantial number of poor women and men who are heavily dependent on *Eucalyptus* to earn their living. However, it is further observed that women and children are more involved in collecting, transporting, and selling to urban markets. Thus, *Eucalyptus* is contributing to generate income for copping and sustaining livelihood as well as provide household energy for the majority of the poor. Therefore, the sector requires further attention with in the national forestry research and rural development endeavour.

Despite the existence of different efforts, such as women fuel wood carrier association, the economic and financial status of women engaged in fuel wood supply are lower given the lower position of the occupation. Thus, it can be concluded that considering gender aspect as a development component and focusing on women with introducing income generating activities will contribute to improve the wellbeing of the family, the society and there by the well being of the nation. Several studies have suggested addressing problem and limitations through introduction of alternative transport facilities and other income generating activities as an important focus area. In addition to previous efforts and suggestion, this preliminary study can be used as baseline for developing future proposal and strategies on how to design empowerment mechanism for women, men, and children engaged in fuel wood supply for improving their access to productive resource and services that ensure the advancement in their livelihoods. Therefore, the following are suggested as potential option particularly to be considered in the forestry research:

- Understand underlying causes and impact of migration from different regions using participatory assessment should be conducted and addressed. There is still much groundwork needed to analyze the gender dynamics that influence the process.
- Conduct further research on the structure and functioning of the supply chain that include the planning and implementation of *Eucalyptus* management and gender roles
- Facilitate the establishment of strong women's cooperatives to enter the market in a better organized way
- Provide knowledge and information on the multiple uses of *Eucalyptus* (income generating non wood *Eucalyptus* and other forest products) so that women can get more benefit from the different uses, and also providing alternative viable income generating activities to improve economic status and gaining quality life.
- Providing means of alternative entrepreneurship in small scale business development
- Create awareness and sense of ownership for those engaged in fuel wood collection not only about parts to pick and gather for fuel wood but also how to protect the forest through rehabilitation of degraded areas to sustain their economic as well as environmental benefits
- Provide market support and improved transportation facilities through targeted extension and training services
- Forming alliance and strong linkages among different stakeholders (forestry research, Ministry of women's affair, Ethiopian women fuel wood carrier project, Oromiya State forest enterprise and other GO's and NGO's) with defined responsibilities, and shared accountability with formative monitoring and evaluation measure is highly indispensable.

Rferences

Addis Tiruneh, TekluTesfaye, Hugo Verkuijl, and Wilfred Mwangi. 2000. Gender Differentials in Agricultural Productivity among small holders in Ada, Lume and Gimbichu weredas of the central highlands of Ethiopia. Ethiopian Journal of Development Research, 22(1) 1- 23.

Amare Getahun.2002. *Eucalyptus* farming in Ethiopia: the case for *Eucalyptus* woodlots in the Amhara region. Bahir Dar Confrence Proceedings, 2002, pages 137-153. Ethiopian Society of Soil Science.

Chen IJ, A Paulraj. 2004. Towards a theory of supply chain management: the constructs and measurements. Journal of Operations Management, 22/2:119 - 150

Demel Teketay. 2000. Facts and experience on *Eucalyptus* in Ethiopia and elsewhere: ground for making wise and informed decision. Workshop on *Eucalyptus* Dilemma held on 15 November 2000 at Ghion Hotel, Addis Ababa.

Fikrete Haile. 1991. Women fuel wood carriers and the supply of Household energy in Addis Ababa and the pre-urban forest. Report Submitted to International Development Research Center and National Urban Planning Institute, Geneva.

Mersha Gebrehiwot. 2007. Gender mainstreaming in Africa Ethiopia. Food and Agriculture Organization, Rome

Motuma Tafa. 2008. Socio economic study of fuel wood collectors in Finfinnee forest enterprise: with particular reference to Entoto site. Research paper in the partial fulfillment of the requirements of the degree of bachelors of Arts in Sociology and Social anthropology. Addis Abeba University, College of social science.

Yeshi Chiche, Kaleb Kelemu (eds). 2008. Gender Differentials for planning Agricultural Research. *In:* proceeding of the workshop on Gender Analysis in Agricultural Research held 27 – 29 November 2006, Addis Ababa, Ethiopia

Chapter V

Eucalyptus Related Forest Policies

Eucalyptus Policies in Eastern Africa: A Result of Shifting Scientific Stand

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Abstract

Eucalyptus remains one of the darling tree species for both popular and scientific writings with unfortunately diverse and conflicting facts sufficient to confuse and misguide policy makers and the public. This can be excused perhaps in the popular media but not in science assuming principles and facts are adhered to than sectarian interest and activism. In eastern Africa, there has been a shift of position by leading international organizations that presented the *Eucalyptus* as a “magic tree” and guided scarce government resources into its planting and it remains disappointing that two or three years later, they brand it problematic. This paper focuses on policies on *Eucalyptus* in eastern Africa with focus on Kenya and Ethiopia and analyses policy orientation(s) and resultant impact on *Eucalyptus* management, status, and trend. It demonstrates how the policy environment and decision making on *Eucalyptus* is guided and or stifled by existing information and data from both popular and scientific writings. It opines sufficient room exist for the policy decision-making processes on *Eucalyptus* to benefit from a common and grounded scientific stand. If attained despite the perceived damage there is hope for informed policy decisions and pronouncements, as *Eucalyptus* remains too big to ignore.

Keywords: *Eucalyptus,* Information and data, policy orientation

Introduction

Eucalyptus remains one of the darling tree species and attempt on its descriptions, genus composition, profitable rotations and hybrids among other attributes easily become repetitious to both scientific and general audiences. It is probably the tree species with the most number of workshops, meetings and discourse in any year as it is the most cultivated tree in the world. Additionally divergent views, conflicting facts and account keep emotions and participation alive.

Eucalyptus, is no stranger to steep deep controversy with some calling for its extinction allegedly for negative environmental impacts, others claim it is the "magic tree" epitomizing variety development by combining coppice, fast growth and divergent economic product. These deep controversies are however not a new phenomena in eastern Africa or in the world at large as by 1913, not long after its introduction to Ethiopia, a directive was issued ordering the people in Addis Ababa to uproot half of the *Eucalyptus* planted in town (John Edy, 2001). Similar concerns and proposed actions are still considered in Rwanda, Kenya and Uganda (Jagger and Pender, 2000; Nduwamung et al.2007; Oballa et al. 2005).

Eucalyptus has indeed several diverse and desirable socio-economic impacts that range from financial (employment, increasing demand, good prices, diverse use) to environmental (coppice, ease of management, better yield). However, despite these specifically in eastern Africa where the majority of the population depends on wood for construction and for fuel, there remains criticism. The majority are related to its effect on the environment including soil, water, and biodiversity. Whether these condemnations are legitimate or deliberate, or simply a result of lack of accurate information is often questions and explains why many rightfully tend to turn to the scientific community to cast light to what can be broadly termed as "adverse public reactions" against *Eucalyptus* plantation (FAO, 2009).

Broadly speaking, the alleged impacts of *Eucalyptus* are a global narrative that seems to have three proponents- *Eucalyptus* growers, environmentalists and researchers. *Eucalyptus* growers obviously support planting it, while environmentalists backed by some agriculturalists emphasize the negative impact. The third category, researchers, or the scientific community stand is what this paper delves into.

This perhaps explains why to the policy community, questions linger over why scientific empirical evidence and consensus remains scant while works on *Eucalyptus* have consistently pervaded silviculture and social forestry for the past 30 years. Even if scantly, is it really to the extent only to provide a framework for discussion and not a common and grounded scientific stand for policy recommendation?

Materials Studied and Area Descriptions

Analysis focused on government policies, international shapers, media publications and utterances and the decisions or lack of affecting public mood, investment, and management of *Eucalyptus.* It illustrates key policy positions with case study on Ethiopia and Kenya and reviews key events that have tilted decisions both for and against *Eucalyptus.*

Results and Discussions

Began as, "Specie to save forests from further depletion"
Europeans introduced *Eucalyptus* to eastern Africa during the second half of the 19th century and it seems to have followed the serious forest decline and the emergence of wood deficit in these countries. *Eucalyptus* was introduced to Ethiopia as early as the 1870s through the establishment of block plantations surrounding the major cities to supply fuel wood for urban populations (Von Breitenbach, 1961; Bristow 1995) and Emperor Menelik II allowed the establishment of a trial plot of *Eucalyptus,* and 15 species of *Eucalyptus* were imported for trial in and around the capital city (Pohjonenand Pakulla 1990). It consistently received support during the revolution and after (1974) with Agriculture and rural development moving to a more central point in the political agenda of Ethiopia to date. According to Nduwamungu et al. (2007), Belgian missionaries introduced *Eucalyptus* in Rwanda in the early 1900s to supply the increasing demand for fuel wood and construction wood.

In addition to government initiatives, international support for rural afforestation with *Eucalyptus* was provided by the Sudo-Sahelian Office of the UN (UNSO), which initiated a fuel wood program that established over 9000 ha of fuel wood plantations between 1984 and 1988 (Stiles, Pohjonen and Weber 1991). In addition, since the mid-1980s, the African Development Fund and the World Bank undertook major plantation development projects in Ethiopia, with *Eucalyptus globulus* being the main species promoted (Pohjonon and Pakulla 1990). It rapidly spread thanks also to academic, research and development institutions including Alemaya Collage of Agriculture, Institute of Agricultural Research, and Chilalo Agricultural Development Unit (Amare, 2002).

In Kenya, the government was actively promoting *Eucalyptus* plantations throughout the country. By 2003 the "a new variety of genetically superior *Eucalyptus* trees" had been introduced touted it "could save Kenya's forests from further depletion and that "researchers say the new genetically superior *Eucalyptus* may be the future answer to afforestation in some of the arid zones and if well managed it could save the country's forests from further decimation."

In the first place, production was spearheaded by the National Agriculture and Livestock Extension Program - an extension initiative funded by the Swedish International Development Agency. Additionally, the planting was part of a National Agroforestry Research Project, a collaborative project jointly implemented by the Kenya Agricultural Research Institute (KARI), the Kenya Forestry Research Institute (KEFRI) and the International Centre for Research in Agroforestry (ICRAF). People were made to believe planting *Eucalyptus* would contribute to the national goal of alleviating poverty among the resource-poor farming communities. Politicians, policy makers and local farmers given the evidence produced by expert bodies believed and rural women became supportive (as over the years they had experienced fuel wood scarcity for their domestic use). The solution of planting *Eucalyptus* appeared quite reasonable for small farmers and particularly women.

As a result, Ethiopia and Kenya guided scare government resources into its planting assured of returns in energy, soil stabilization and reforestation sectors. The most important growers in eastern Africa are donor funded forestry projects, communities, private farms and non-Governmental Organizations.

To "Thirsty nature of eucalyptus"

Remarkably in the late 90's, a different picture began to be unveiled, much without warning and was snow balling fast towards discouraging planting *Eucalyptus* as the much aggrieved called for its uprooting. The August 2006, World Water Week meeting in Stockholm epitomizes the momentum. At that meeting, researchers warned that although planting the right tree species in the right areas could improve water efficiency, other species –such as pines and *eucalyptus*- could make the problem much worse. The announcement was based from its findings on water use by trees on 20 years of research in Kenya by Kenyan-based International Centre for Research in Agroforestry (ICRAF).

As a result, the scientists advised against planting fast-growing evergreen trees such as *Eucalyptus* and pines because of their high water consumption. A video - "Thirsty Trees: And the Search for Better Alternatives"- was presented at a side event organized that showed both government officials and local people agree that *Eucalyptus* impacts on water resources. The talk of especially a local person explaining that the level of what used to be "a very big river" has "gone down" as a result of the *Eucalyptus* trees planted along its margins marked a turning point especially when it went ahead to explains that, "women and children are the most affected by the reduction of water".

The concern over ecological implications of *Eucalyptus* on soil health, sustainability, crop output catalysed by the media catch the attention of activists and eventually policy makers and began precipitating legislation. In 1997, in Ethiopia, Tigray's administration enacted a new land policy that prohibits farmers from planting *Eucalyptus* on cultivable land (Council of the National State of Tigray 1997) to secure scarce farmland for food production.

In Kenya, debate culminated in September 2009 as the country's Environment minister ordered the uprooting of *Eucalyptus* trees from wetlands and banned their planting along rivers and watersheds. At the same time, Nobel Prize winner called for a ban on planting alien species and particularly *Eucalyptus,* while the experts continued to raise the alarm on the "thirsty" nature of *Eucalyptus.*

The fact that the minister has banned *Eucalyptus* trees in certain areas did not mean that commercial *Eucalyptus* tree plantations had been banned all together. This was definitely not the message going by the massive chopping of *Eucalyptus* almost everywhere. The above would have been unthinkable a few years before.

Then "Activism and popular media"
It seems the inability of the scientific community to clearly articulate the ecological implications of limiting or promoting the planting of *Eucalyptus* in different settings, economic incentives and disincentive, and *Eucalyptus* contribution to sustainable land use has natured a breeding ground for activism and political comments.

It is no doubt that activism and political comments when used in a robust media have provided extremely positive outcome in support of the environment leading to notable policy decisions and outcomes. However, this has worked positively when informed by science largely. However, due to some level of scientific lacuna the *Eucalyptus* debate gravitates somewhat into folkloric accounts even among scientists.

Conclusions

Is there or not sufficient evidence to conclude if *Eucalyptus* or *Eucalyptus* plantations, affect heavily on water resources? This is one of the questions among scientists consistently generate. Policymakers require scientific information as it were that would enable them ignore or acknowledge facts. It is surprising in comparison to popular media that science after investment of millions of dollars is more or less shrouded in less conclusive conclusions

> "Research undertaken provides us with some valuable evidence but no definitive conclusions with respect to whether or not *Eucalyptus* is ecologically appropriate species. We emphasize the complexities associated with the factors that determine the ecological impact of *Eucalyptus* trees both on adjacent crops as well as on soil and water conditions in general. Many of the studies undertaken address ecological impacts in isolation. However, realistically both the positive and negative effects of *Eucalyptus* on any given site are

> likely to be many and inter-related, making the question of the net effect of the tree crop on the site very complex." (Eastern Africa Workshop on *Eucalyptus* Bujumbura, 29^{th} – 31^{st} March 2010)

Definitely, researcher would recognize with this conclusion and it would not be surprising if this meeting also leads the same way. Nevertheless, what action would be expected to be drawn by a policy maker in office for five years or a poor resource farmer who needs to make decisions now especially when confronted with such scientific conclusion in comparison with popular media and high personalities

> "Figures provide evidence that one single 3-year old *Eucalyptus* "drinks" 20 liters of water per day. During the following years, consumption exponentially increases and at age 20 the tree will "drink" 200 liters per day!" (WRM, 2010)

It is definitely not a matter of competition but the continent stands to benefit from a common and grounded scientific stand. On a weekly basis, policy makers constantly make decisions under uncertainty; that is, they typically do not have the luxury of having in-hand perfect information on which to base their decisions.

On the other hand, scientists have a further responsibility- to make clear the results of their research findings, correct misinterpretation of environmental cues and foster proper use of scientific indicators in ways that reinforce or calibrate "ordinary" knowledge (Lindblom and Cohen, 1979)

The discussions in this meeting should thus provide not only valuable evidence but also definitive conclusions with respect to whether or not *Eucalyptus* is an ecologically appropriate species.
As an example,

> Based upon the review of ecological and economic impacts of *Eucalyptus,* several policy options are considered. The policy option with the largest potential economic benefit appears to be increasing allocation of marginal lands, populated areas, homesteads, and private *Eucalyptus* plantation. This option could increase average household income and wealth substantially. The ecological risks are considered but are controllable within countries existing work force of trained foresters. The potential ecological benefits are large since this option would be implemented in degraded areas. This and other options could help make *Eucalyptus* growing an important pathway of development.

If attained despite the perceived damage there is hope for informed policy decisions and pronouncements, as *Eucalyptus* remains too big to ignore.

References

Bristow S. 1995. *Agroforestry and community-based forestry in Eritrea*. Working Paper No.2. Washington, D.C.: World Bank.

Council of the National State of Tigray. 1997. *The National State of Tigray—Rural Land Proclamation No. 23/1997*. Mekelle: Council of the National State of Tigray.

FAO. 2009. *Eucalyptus* in East Africa; The socio-economic and Environmental Issues. Eastern Africa sub-Regional Office, Addis Ababa, Ethiopia.

Jagger, P J Pender. 2000 The role of trees for sustainable management of less-favored lands: the case of *Eucalyptus* in Ethiopia. Forest Policy and Economics Volume 5, Issue 1, January 2003, Pages 83-95

John Edy. 2001. An Amharic Reader. African Sun Publishing, Oakland

Linderblom CE, DK Cohen. 1979. Usable Knowledge: Social Science and Problem Solving, New Haven: Yale University Press, passim.

Nduwamungu J, E Munyanziza, JD Nduwamungu, B Ntirugulirwa, RJ Gapusi, JC Bambe, D Ntabana, G Ndizeye. 2007. *Eucalyptus* in Rwanda: are the blames true or false? Institute Des Sciences Agronomiques Du Rwanda (ISAR)

Oballa P, E Chagala-Odera, L Wamalwa, V Oeba, E Mutitu, L Mwangi. 2005. The performance of *Eucalyptus* hybrid clones and local landraces in various agro ecological zones in Kenya

Pohjonen V. T Pukkala. 1990. *Eucalyptus* globulus in Ethiopian forestry. *Forest Ecology and Management* 36: 19–31.

The Kenya *Nation Newspaper* achieve 2010; 28TH November 2009;

Von Breitenback F. 1961. Exotic trees in Ethiopia. Ethiopian Forestry Review 2: 19-38

WRM Bulleting .2010. Communities and Tree Monocultures. Issue 154 May 2010.

Group and General Discussion Resolutions

Conference participants were divided into groups. In each group, one of the three main topics listed bellow was discussed. The main issues were debated in general discussions that end up with concrete recommendations as future guidelines. The groups listed some positive and supposedly adverse effects in terms of social, economical, and ecological contributions of the *Eucalyptus* plantations. Emphasis was given to appropriate production, management, value additions, utilization, environmental, research, and policy issues. Thus, discussions and resolutions of each group in terms of major theme and sub-themes are presented as follows.

Theme1: Trends of *Eucalyptus* expansion and the drivers for expansion

On a worldwide basis, there are high trends of *Eucalyptus* expansion especially in South East Asia (China and India) and Latin America (Brazil, Chile, Argentina, etc). In Africa, expansion is not significant. Currently plantation forests supply more wood than natural forests with sustainable high yields, raw material source for different industries and high-income earnings.

Trends of expansion and utilization in Ethiopia

Tree growing by individual farmers and wood lot growers has been increasing along roadsides, in degraded/marginal lands, homesteads, etc. but the rate of expansion is not quantified. Large-scale plantations are limited due to the lack of participation of the private sector and on the other hand, the discouragement of *Eucalyptus* plantation by the Government Offices in most regions, although eucalypts wood is widely used in the construction and fuel wood sectors and it is an essential source of income for farmers and wood lot growers.

What are the drivers for expansion and international experience (America, Africa, Europe, and Asia)?

Why was *Eucalyptus* the preferred species for farmers and wood lot growers? Why were they selected in Ethiopia over better timber trees and against policy/regulation of the Government and continued planting even on farmland all over the country to such an extent? The drivers for expansion on a worldwide basis, including Ethiopia and Spain, are

- Wood deficit due to depletion of natural forests and improper utilization,
- Ease of management,
- Fast growing and high yielding ability per unit are and time.
- Coppicing abilities that reduces costs of production
- Wider use of eucalypts products: construction, fuel wood, poles and posts, agricultural implements, particle and hard boards production, scaffold etc),

- The expansion of pulp mills,
- The move towards the use of renewable energy source in relation to current global climate change,
- Secure persistent annual income (due to frequent crop failure because of drought),
- Market availability (local and neighbouring country),
- Hesitation for planting new species for fear of loss of benefits and slow growth rate and low yield,
- Lack of information dissemination of alternative tree species (wood characteristics, use, economic benefits etc),

Can *Eucalyptus* helped to solve timber shortage and save endangered forest of Ethiopia?

Eucalyptus provides raw material for construction, household energy (substitute cow dung and agricultural residue utilization), farm implements, furniture, and industrial and other house hold items. Thus, it helps to stabilize agriculture and to reduce pressure over the existing remnant natural forests and endangered tree species.

Theme 2: *Eucalyptus* research in Ethiopia

Problems/constraints: Potential research, policy, institutional and awareness creation gaps and mechanisms to fill the gaps

Why tree improvement and clonal forestry research are missing in Ethiopia? Why improved seeds are not available to Ethiopian farmers? When and how farmers can have access to genetically improved seeds and clones?

The major constraints in relation to tree improvement, research and policy issues detected were:

- In Ethiopia, there is a confusion on the identification of several *Eucalyptus* species;
- Wrong species- site- matching;
- Narrow genetic bases for tree improvement;
- Lack of appropriate management options that minimize ecological impacts, rotation, spacing, soil depletion, water consumption and increase wood quality and quantity;
- Shortage of adequate permanent research sites, seed stands and absence of seed orchards;
- Poor information about dissemination (poor media utilization);
- Deficient data base systems;
- Poor institutional linkage (collaboration and integration);

- Weak forestry research institution (manpower, facilities and infrastructures), poor linkage and collaboration with regional, federal and international institutes;
- Lack of land use policy that clearly indicates sites/land allocated to forestry Research and Development (R&D) activities; and
- Poor attention of the policy formulators/decision makers to forestry sector.

Possible collabourations

What are the possible collaboration lines in research and development (R&D) of eucalypts with ENCE and UPM of Spain and other countries? The possible internal and external collaborations would be:

- Seeking for assistance from Spain on vegetative propagation skill and infrastructure development;
- Experiencing sharing through mutual benefit arrangements; and
- Collaboration among institutions to conduct = cooperation/partnership and joint research.

How to add value on *Eucalyptus* forestry

How to introduce the carbon offsets as a new forestry export product? How to enter the global carbon credit trade using the Ethiopian smallholder forestry as input.

Carbon trading:

- Feasibility study of Carbon trading;
- Country wise assessment of the existing stock and determining the annual planting rate;
- Development of management tools to biomass and yield estimations; and
- Establishing cooperatives.

What is the potential/contribution of *Eucalyptus* products in relation to other current opportunities such as alternative raw materials to forest industries as timber/lumber, pulp, paper, and essential oil extraction? Industrial applications: through value addition

- Identifying suitable and marketable essential oil species.
- Identifying long fiber and promoting particle board and fiber board production = in addition to log and pole export.
- Promoting fuel wood plantations to reduce CH_4 emission from cow dung.

How to improve market chains and export of eucalypts logs and products. Market chains and export of logs and products entails: (dot may not be needed in each bullet below, rather comma would be appropriate):

- Identifying the cause of the poor participation of the privates sector;

- Devising incentive mechanisms to encourage private sector in *Eucalyptus* development;
- Establishing cooperatives; and
- Improving forestry road network and harvesting technologies that facilitate products transport.

Theme 3: Eucalypts environmental/ecological controversy: is it a misunderstanding or reality?

Controversies on adverse ecological effects of *eucalyptus*

- What evidence do we have?
- If the environmental/ecological problems exist, can they be solved? How?
- What strategies (e.g. niche, management, policy etc) can be followed to accommodate the ecological, economical and cultural/social roles of *Eucalyptus* species besides saving the endangered indigenous tree species?
- Which are the facts that shown the pros and cons of eucalypts that can help policy makers to understand realities and support smallholders?

There is not adequate research on side effects of *Eucalyptus* species. Moreover, foresters and smallholders do not have schemes/guides how to manage eucalypts plantations properly an add value to the products. As a general conclusion, *Eucalyptus* plantations mitigate the human pressure over the native species. Furthermore, they contribute to alleviate poverty by providing both: the necessary scarce resources and monetary incomes to Ethiopian farmers. Nevertheless, there may be undesirable side effects due to inappropriate management of *Eucalyptus* plantations. For example, substituting native species' stands or, in certain cases, competing with farm crops. In addition, the effects on the landscape and ecosystems of the extensive plantation of *Eucalyptus* crops in huge areas or sensitive sites have to be under consideration. In order to reduce and mitigate the potential undesirable side effects, two parallel lines of scenarios/activities = are proposed:

1) Their objectives research projects should be the optimization of degraded land rehabilitation and fostering native species regeneration. In addition, these projects should evaluate the alleged negative effects on biodiversity and environments. This research should define practical measures to avoid the misuse of plantations and to improve the knowledge-based species -site matching. It would also avoid banning unfairly certain land uses basing on opinions or feelings. The international research cooperation with countries of wide experience (Spain, Portugal, China, India, Australia…) would be very useful, thus joint programmes should be promoted; and
2) In the short term, *Eucalyptus* plantations have come to stay and it is even foreseeable a future increase in this land use. Therefore, it is necessary to establish and extend correct management practices to make them more productive and avoid their potential negative side effects. Measures to increase productivity: plant provenance selection for genetic improvement, optimum plantation density and rotation ages, better soil preparation can help the

positive effects and reduce the necessary to obtain the same resources. On the other hand, some practices could be regulated whit the contribution of the regional or local foresters and experts, such as foliage removing, excessive densities, and species site matching, etc.

Some political constraints were identified, regarding the lack of weight of forestry in the Ethiopian agricultural policy. Considerable efforts must be addressed to reach the decision makers in order to write down the *Eucalyptus* plantations contributions in the political agenda. At last, some ideas were pointed out and partially discussed as examples of technical options in best plantations management or alternatives to the *Eucalyptus* plantations where they were not appropriate.

Socio-economic and environmental/ecological benefits of Eucalyptus plantations and technical measures to alleged negative impacts

Benefits from *Eucalyptus* plantations

- *Eucalyptus* is contributing to supply efficiently the growing population demands. Besides its main use as fuel wood, it is a common construction material alternative to metals as well as a raw material for making/producing farm implements. In addition, it is utilized for essential oils distillation and honey production as well as for medicinal purposes. In other countries, it is a major raw materials source for the pulp and board industries;
- As efficient resources provider it releases human pressure on native vegetation and local biodiversity;
- *Eucalyptus* plantations have a high economic value for the rural population and industries. They have become a source of emergency cash for the poor households, source of raw material for industries when planted as a backyard crop;
- *Eucalyptus* can also be useful as agroforestry crop although there are still few experiences in Ethiopia. *Eucalyptus* has proven to serve as nurse tree for *Juniperus*, *Podocarpus,* and *Olea species*, as indicated from scientific trials und*er certain* conditions;
- *Eucalyptus* stands can be the habitat for diverse wildlife;
- *Eucalyptus* plantations, accordingly with Basona Werana Woreda experiences, reduce soil erosion when compared to bare sites;
- *Eucalyptus* sequesters carbon efficiently, what is very important in this era of climate change;
- Since construction timber exports are growing, *Eucalyptus* has become a source of foreign currency; and
- *Eucalyptus* plantations may have a relevant role in protecting degraded watersheds when planted in bare soils. In addition, they are useful in rehabilitating degraded sites, unfortunately quite common in Ethiopia due to the human pressure by agricultural, grazing and firewood collections.

Finding potential alternatives/substitutes to *eucalyptus*

- Generally, there is no better alternative species now, but research should go further to improve the productivity and other species and to identify other suitable ones, particularly native species;
- *Grevillea robusta* and *Acacia polyacantha* were mentioned as potential alternative species and could be integrated in the future plantation programmes. Applying adequate protection measures against bio-deteriorating agents (termites, beetles and fungi) will be compulsory to properly utilize the different wood-based products, since the products are less durable;
- Public forests, under adequate forest policy frames, could also help to recover native species' stands;
- In any case, it would be strictly necessary to include the *Eucalyptus* plantation issue in the Ethiopian agricultural policy; and
- To this goal, it is essential that the realistic and wise *Eucalyptus* plantations' management options could reach the decision-makers. In this way, trying to bring the attention of decision-makers to participate in the debates as well as procuring the specialized experts' access to the communication media are key factors.

Alleged negative impacts of inadequate *Eucalyptus* plantations management

- More research must be addressed to evaluate the competition among *Eucalyptus* plantations and near native species' stands or regeneration, agricultural crops and/or pasturelands;
- Some participants considered that *Eucalyptus* plantations undermine biodiversity and lack undergrowth vegetation. Other members of the discussion group did not understand why biodiversity is required to *Eucalyptus* plantations only, but not to other crops, like agricultural ones;
- There were critic opinions about the landscape effect of *Eucalyptus* plantations as a monoculture;
- The risk of losing native biodiversity – local genotypes – was alleged as related to the inadequate management of *Eucalyptus* plantations;
- Some of the participants expressed research results about Entoto's *Eucalyptus* stands poor ability to support animal diversity (particularly bird nests). Other participants showed photographic testimonies of the birds' presence in Entoto and elsewhere *Eucalyptus* stands; and
- Concerns about water consumption of *Eucalyptus* crops were expressed, referring to Munesa research results that showed less dry season flow in rivers close to *Eucalyptus* stands when compared to native forests.

Technical options/measures to mitigate negative impacts

- Some group members expressed the opinion that *Eucalyptus* should not be planted on farmlands;
- In general, there was a consensus in the fact that *Eucalyptus* should not be planted too dense, and under certain conditions foliage collections should be limited. These aspects must be further investigated;

- There was consensus about the convenience of species-site matching. In proper sites, the participants agreed in the positive use of improved species or varieties to increase productivity and quality;
- To achieve the same goal, silviculture techniques should be improved. Other objective of appropriate management systems is to get a greater added value;
- To extent new management systems, it would be most convenient to develop "*Eucalyptus* Best Management Practices handbooks" to be used by key actors/extension agents;
- The participants agreed in studying suitability of and developing the use of *Eucalyptus* for degraded sites rehabilitation; and
- The appropriate land use planning, including impact assessment schemes, was proposed as a main forest policy tool to avoid *Eucalyptus* inadequate management practice.

Conference Conclusions and Resolutions

The Ethiopian Institute of Agricultural Research, in collaboration with the Spanish Universidad Politécnica de Madrid and ENCE conveyed a Conference on *Eucalyptus* during 15th - 17th September 2010 at the Ethiopian Institute of Agricultural Research Head Quarter in Addis Ababa. The main issues of this conference were *Eucalyptus* species management, history, status, and trends in Ethiopia.

This conference also assisted to undertake opportunities, challenges, and device strategies of research, development, and utilization as way forward to balance maximize the economic benefits including value additions and minimize ecological impacts due to homegrown *Eucalyptus* species. This may lead to policy intervention/formulation and implantation issues on how, when and where to develop, manage and rationally use eucalypts. The different papers of the Conference were addressing to a various extent *Eucalyptus* socio-economic and ecological significance and adverse effects due to lack of proper management. Finally, the conference identified main problems and drew up some recommendations to every stakeholder including policy makers.

The *Eucalyptus* plantations have extended in the last few decades in Ethiopia, especially in lands belonging to peasants and communities. Their technological qualities, their quick growth and their coppicing ability have allowed the eucalypts to be the first source of firewood and construction wood. Therefore, *Eucalyptus* is contributing to poverty reduction and insuring food security for millions of rural households throughout the highlands of Ethiopia.

The plantation of *Eucalyptus* should be managed appropriately in such a way that its benefits can be maximized and its alleged negative impacts be kept minimal.

From the environmental point of view, it is necessary to add that *Eucalyptus* plantations play an outstanding role in the recovery of lands degraded by the erosion and the loss of fertility.

It is also imperative to extend good management practices so they arrive to the final users (agents of agrarian extension, peasants, wood lot growers and communities) thus they can obtain the best potential benefits of eucalypts. Therefore, it is an urgent need to create awareness on the appropriate spacing of *Eucalyptus* plantations and serious negative consequences of whole tree harvest and litter fall raking on soil fertility. Farmers have to be advised to harvest only woody components from their plantation. This activity shall be included explicitly in the agricultural extension package without any delay.

It is important to strengthen the national and international collaboration of different research and development sectors to exchange experience and information. Strong linkage and coordination between research, extension, and education is crucial.

In order to maximize the potential socio-economic and environmental benefits including value additions, reduce, and mitigate the potential undesirable side effects of *Eucalyptus,* the following highlights have been considered as major Resolutions of the Conference:

- Research projects shall be to be initiated based on permanent plots to deepen the knowledge about the potential role of *Eucalyptus* plantations on ecosystems and socio-economic aspects. It would also avoid banning unfairly certain land uses basing on opinions or feelings. The international research cooperation with Countries with wide experience (Spain, Portugal, China, India, Australia…) would be most useful. Thus, joint programmes shall be initiated and promoted in the future;
- In short-term, *Eucalyptus* plantations have come to stay and it is even foreseeable a future increase in this land use. Therefore, it is necessary to establish and extend correct management practices to make them more productive and avoid their potential negative side effects;
- Finding alternative/substitute species to the *Eucalyptus* plantations where they are not appropriate;
- Technical measures in best plantations management to increase productivity and quality that reduce negative effects, best provenance selection for genetic improvement, optimum plantation density and rotation ages, better soil preparation – can help the positive effects and reduce the necessary surface to obtain the same resources; and
- Regarding lack of weight of forestry in the Ethiopian agricultural policy, considerable efforts shall be addressed to reach the decision/policy makers in order to write down the significant role/contributions of *Eucalyptus* in the political agenda.

Finally, it is essential that these resolutions reach not only to policy makers, but also to research, development, extension sectors and wood processing industries; nongovernmental organizations, farmers and different stakeholders.

Closing Remarks

Prof. Luis Gil
Universidad Politecnica de Madrid

The presence and the cultivation of *Eucalyptus* in Ethiopia has been the subject of several dialogs and debates, which have been, included in the papers presented in this conference. Thanks to this species, the Ethiopian and Spanish foresters can continue their co-operation that has been initiated 13 years ago with Wubalem Tadesse.

Despite the fact that over five thousand kilometres Spain is far from Ethiopia, the *Eucalyptus* shadow brings us together. Its benefits and use spark interesting debates, as demonstrated by this conference.

Contrary to folk belief, *Eucalyptus* is not the green devil or the Attila of the autochthonous forest. On the contrary, as scientists working in the field of rural development have pointed out, *Eucalyptus* is tree of the poor, namely, those people who have nothing and collect their leaves and fiber wood from the public lands. Hence, *Eucalyptus* is also known for being a source of income since it promotes economic self-sufficiency for small landowners.

Due to economic interest as well as to the fact that *Eucalyptus* represents a means of rural development, this species deserve deeper scientific knowledge based on the development of current scientific methodology. This research, in turn, will bring up room for improvement in the form of suggestions and ideas as to how and where the species should be planted and used.

Ethiopia is a country that has witnessed the origin of humankind as an additional element of Natural History. Since then, *Homo sapiens* have been the dominant species that has eventually displaced the rest of the organisms in accelerated race with an unpredictable end. In those countries with a long-standing agro-pastoral tradition, the use of natural vegetation was removed. This process is accepted and justified by society but unfortunately, it has caused also high erosion and degradation in biodiversity and the lands with steeper slopes.

Eucalypts was introduced in Ethiopia in 1870. During the last decades, its use in plantations has reached an exponential increase due to the exceptional economic benefits that it offers to the small landowners. This is special relevant for *E. globulus* which is a very productive species apart from not being grazed by the livestock grown in the ***Ethiopian Highlands***.

Eucalyptus is a diverse genus that generates common landscape features in those regions that have been planted around the globe and thus, it can unite people from several continents. It constitutes a gift given by nature to rural communities in those places where it is significantly more productive as compared to the local forest species. When it is used in plantations for its superior rent –as opposed to alternative land-use practices- it is not correct to be compared to a forest; instead, it should be compared to an agricultural cultivation that does not require any fertilizers, pesticides, or fungicides. The rotation time for *Eucalyptus* plantation is almost as small as the ones typically used in agriculture much smaller than the typical rotation time used in autochthonous forest species.

However, eucalypts has never been regarded as a "kid of agricultural," probably because it is used in soils with typically low agricultural production. Furthermore, eucalypts is treated with methods typical of the forest science to provide timber products.

Being a vigorous hybrid between agronomy and forestry, eucalypts cannot be classified into one field or the other. In addition, it has never been accepted by urban communities that, however, demand its products. The reason is not easy to understand, therefore, should lie in the fact that *Eucalyptus* is an introduced species. Besides, its growth and yield –higher than native species– render it a tree selected by smallholders in their plantations. Nevertheless, eucalypts has never been used as a substitute for natural forest but as a species planted into abandoned and degraded land that has indeed being used previously to cultivate other introduced species.

Although present knowledge about what eucalypts use implies for Ethiopia is available – a fact demonstrated by the numerous contributions presented in this conference– we are aware that this knowledge is not sufficient and that we need new contributions that may promote the use of this valuable species for Ethiopian silviculture. It seems necessary to improve the productivity of the *Eucalyptus* plantations and to prepare manuals for managing these plantations in order to diminish the negative effects that the species may provoke when used in plantation forestry.

Thank you!

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