

EUCALYPTUS IN EAST AFRICA

The Socio-economic and Environmental Issues

FAO Sub-regional Office Eastern Africa

March 2009, Addis Ababa

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Foreword

The FAO Sub Regional Office for Eastern Africa is mandated to provide expertise and resources to eight countries: Burundi, Djibouti, Ethiopia, Kenya, Rwanda, Somalia, Sudan and Uganda.

The present document on Eucalyptus in East Africa is the result of a query shared by many about the perceived negative impacts of an important species. FAO did commission a study realized by two experts from Ethiopia: Dr. Gessesse, forester from Wondo Genet and Dr. Taklu, soil scientist.

The overall work has benefited from the support of many institutions and individual based in Ethiopia and Rwanda. I would like to thank them for their support and contribution.

May all the participants and organizers of that study find here our appreciation for providing a balanced set of scientific information based on a literature research on that important genus for forest plantation; and of field work and consultations with Eucalyptus growers and users.

We trust that this report will not be the end but the beginning of more intensive work on Eucalyptus, and that it will encourage and stimulate experts and users at national level to develop and work with prescriptions for the better management and exploitation of Eucalyptus.

Mafa Chipeta
Sub Regional Coordinator for Eastern Africa
and FAOR in Ethiopia, to AU & ECA

List of Abbreviations

CADU	Chilallo Agricultural Development Unit
CDF	Cartographie et des Forets de Rwanda
DANIDA	Danish International Development Agency
FAO	Food and Agriculture Organization of the United Nations
FINNIDA	Finnish International Development Agency
IAR	Institute of Agriculture Research of Ethiopia
MAI	Mean Annual Increment
UNSO	United Nations Sudano-Sahelian Office
USD	United States Dollar
WPP	World Population Policies
WRI	World Resource Institute

Executive Summary

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. 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.

Studies conducted in East Africa and elsewhere show that eucalyptus is among the most preferred trees, as it grows fast and survives in marginal environments. However, since its introduction, eucalyptus has been marred by controversies, surrounding its alleged negative environmental impacts and inability to provide the necessary productive and ecological services. As a result, skepticism prevented its promotion and in some drastic measures, planting was banned altogether. Among the concerns are that eucalypts may not adequately benefit mankind as forests, as they may not always provide quality wood, watershed and soil conservation, wildlife habitat and even recreational or aesthetic values. Other controversies related to its impacts on the environment are the removal of too much water from streams and underground water, adverse effects of their leaf litter on soil humus, heavy consumption of soil nutrients, the inability to prevent soil erosion, inhibition of growth of other plants and failure to provide food supplies or adequate habitat for wildlife. Often, the response is that the criticisms against eucalypts are unfair or emotional. Reports in forestry and environmental research show that the concerns are not only real, but also equally applicable to other exotic trees, not just eucalypts. Therefore, solutions and judgments must be specific to each case and based on accurate appraisals of biological, physical, economic and human factors. In East African countries, where there are huge gaps between demand and supply of wood as a result of escalating deforestation, the use of fast growing plantation species such as eucalypts is inevitable as they are preferred to other species, both exotic and indigenous, because of their peculiar features; these include easy reproduction through seeds and coppicing, fast growth, and good quality of timber and fibres. Therefore, instead of arguing whether to avoid plantation of eucalyptus or not, emphasis should be given to support the land users and policy makers in selecting the right species for the adequate sites and purposes; managing plantations so that the drawbacks are minimized and the benefits are optimised until alternatives are readily available should be the goal.

Introduction

Eucalyptus is a name issued from New Latin, genus name, from *eu-* + Greek *kalyptos* covered, from *kalyptein* to conceal; from the conical covering of the buds(Merriam Webster Dictionary). Eucalyptus is a genus of more than 500 species, and it has become the most planted genus of trees in the world (Demel 2000). The major planting of this tree species, outside its home environment, was started in 1904 in Brazil. Eucalyptus is native to Australia, the Malaysian region and the Philippines. Today eucalyptus plantations cover at least 12 million hectares throughout the tropical zone, 90 percent of which has been established since 1955 (Turnbull 1999). This species was introduced to East Africa between late 19th and early 20th century. Already in the early 1970s, the area covered by eucalyptus in Ethiopia, Rwanda, Uganda, Kenya and Sudan reached 95684 ha (FAO 1979). The largest plantations during the same time existed in Ethiopia and Rwanda, with 42,300 and 23,000 ha, respectively.

Concerns about negative impacts of eucalypts on the environment have raised worries about planting the species. These worries resulted in banning eucalyptus planting on farmlands, stream banks and catchments areas. In 1913, not long after its introduction to Ethiopia, a directive was issued ordering the people of Addis Ababa to uproot half of the eucalyptus planted in the 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; SPGS; Oballa et al. 2005).

The alleged negative environmental impact of eucalyptus is a global narrative. In this connection, FAO tries to provide unbiased views by commissioning several global, regional and country level studies (Davidson 1985; FAO 1988). The narrative seems to have three proponents- eucalyptus growers, environmentalists and researchers. Eucalyptus growers obviously support planting it, while environmentalists backed by agriculturists emphasize the negative impact. The third category, researchers, argues for a cautious and fair evaluation of pros and cons.

Major arguments against eucalypts include: they drain water resources; they enhance soil erosion; they suppress undergrowth, they deplete soil nutrients; they induce allelophatic effects (Davidson 1985; FAO 1988; Demel 2000; Amare 2002; Nduwamung et al. 2007). Major arguments supporting eucalyptus planting include: they are a fast growing tree; they require minimum care; they grow in wide ecological zones and poor environments; they coppice after harvest; they are resistant to environmental stress and diseases; their seeds are easy to collect, store and no pre sowing treatment is required (FAO 1979; Zerfu 2002; Mekonnen et al. 2007; Nduwamung et al. 2007).

Several researchers question the concerns and the blames levelled against this tree citing that:

- the arguments raised against it are grossly generalized;

- the concerns have emphasized the negative environmental impacts without careful consideration of the temporal and the spatial scales at which the impacts are intolerable;

- the accusations have undermined the contribution of this tree to the livelihood of smallholder farmers and it's general socio-economic significance.

This study is aimed at addressing some questions. What is the basis for the counter arguments? Are environment-centred arguments more important than socio-economic contexts? Can we identify ways by which each type of eucalypt impact or benefit is analysed case by case? What are the contexts under which eucalypts should be evaluated?

The general narratives surrounding eucalypts were examined in both environmental and socio-economic realms, to be able to provide a balanced view for decision makers, foresters, environmentalists and the general growers. The method employed is desktop study largely based on existing reports, commissioned studies and academic papers. Two short field visits were conducted in Rwanda and Ethiopia.

This report a) presents the history and status of eucalyptus in East Africa including Ethiopia, Sudan, Somalia, Djibouti, Kenya, Uganda, Rwanda and Burundi; b) describes the products and services obtained from this tree species; c) outlines the types of eucalyptus management; d) presents the environmental impacts of eucalyptus on climate, hydrology, soil and biodiversity. Finally, concluding remarks and recommendations are provided.

Eucalyptus in East Africa

This part of the report addresses the history of eucalypts, the reason why it was introduced and the trend of expansion and the existing area coverage in East Africa. East Africa covers a total area of about 524 million ha with a human population of 218 million (Table 1). This region supports a wide variety of forests and woodlands that range from dense tropical forests in the humid mountain regions of Uganda, Burundi and Rwanda to the dry savannahs of Sudan, Ethiopia, Somalia and Djibouti. Eucalyptus is one of the most important planted tree species in this region with per capita area of about 34 m2.

Table 1 Population, land and forests of east Africa

Countries	General Description Human Population (1)	Total Land (ha) (1)	Forest (ha) (2)	Natural forest (ha) (2)	Plantation forest (ha) (2)	Eucalyptus forest (ha) (3)
Ethiopia	83,099,000	122,148,000	4,593,000	4,377,000	216,000	506,000
Somalia	8,699,000	63,754,000	7,131,000	Na	Na	Na
Djibouti	833,000	231,800	6,000	Na	Na	Na
Sudan	38,560,000	250,000,000	61,627,000	60,986,000	641,000	23,000
Kenya	37,538,000	58,265,000	17,096,000	16,864,000	232,000	60,000
Uganda	30,884,000	24,103,800	4,190,000	4,147,000	43,000	11,000
Rwanda	9,725,000	2,633,800	307,000	46,000	261,000	102,765
Burundi	8,508,000	2,783,000	152,000	67,000	86,000	40,000
Total	217,846,000	523,919,400	95,102,000	86,487,000	1,479,000	742,765

Source: (1) WPP (2007), (2) WRI (2000), (3) Amare (2002); FAO (1979); Oballa et al. (2005); CDF (2007).

It is difficult to determine the exact area coverage of eucalyptus in East Africa. Different figures are reported for the same country, such as in Ethiopia, where at least two area estimates are reported by Demel (2000) and Amare (2002), 477,000 ha and 506,000 ha respectively. For some countries like Sudan and Uganda, recent figures could not be found. For others like Somalia and Djibouti, no information was available. Additionally the reported figures seem to represent large-scale plantation and village/community stands. Huge amount of trees exist mixed in other land use types; growing on homesteads; planted on farm boundaries and along roadways. The area of coverage of these trees may not be easy to estimate and is often overlooked from the estimation. During the visits in Ethiopia and Rwanda, it was observed that smallholder growers in rural and urban areas own few to several scattered eucalyptus trees.

History of eucalyptus in East Africa

Europeans introduced eucalyptus to eastern Africa during the second half of the 19th century and later at the beginning of the 20th century. The introduction of eucalyptus to East Africa seems to have followed the serious forest decline and emergence of wood deficit in these countries. According to Nduwamungu et al. (2007) Belgian missionaries introduced eucalyptus to Rwanda in the early 1900's to supply the increasing demand for fuel wood and construction wood. Eleven years later, harvesting of poles from the first plantations was reported in the southern province. In Ethiopia this tree was introduced during the reign of Emperor Menilek II (1868-1907) in 1894/95 (Von Breitenbach, 1961). The introduction and growing of eucalyptus was meant to supply fuel wood and construction wood to the new and growing capital city, Addis Ababa. Eucalyptus was introduced to Uganda around 1912 to supply fuel wood for railways and administrative centres as well as to drain swamps (attempting to reduce malaria) (SPGS undated). Eucalyptus was introduced in Kenya as early as 1902, the aim of the initial introductions was to supply fuel wood for the Kenya – Uganda railway (Oballa et al. 2005). In Burundi the earliest planting of Eucalyptus commenced in 1931 (FAO 1979). Eucalyptus was introduced to these countries from Australia, southern Europe and South Africa. Today, eucalyptus is the characteristic feature of the rural landscape and a very important aspect of smallholder livelihood in most parts of Ethiopia, Rwanda and Burundi.

At the moment Ethiopia holds the largest eucalyptus plantation in East Africa and is one of the pioneer countries that introduced the species. Today the most important commercial eucalyptus species in this country are Eucalyptus globulus known locally as 'Nech-Baharzaf' or 'White Eucalypt' and Eucalyptus camaldulensis known locally as 'Key-Baharzaf' or 'Red Eucalypt'. However, the most widespread species include E. camaldulensis, E. citriodora, E. regnans, E. saligna and E. tereticornis.

The cultivation of eucalyptus gradually spread throughout Ethiopia thanks also to academic, research and development institutions including Alemaya College of Agriculture, Institute of Agricultural Research (IAR) and Chilalo Agricultural Development Unit (CADU) (Amare 2002). Currently more than 100 eucalyptus species are grown in Africa, 70 of them grown in Kenya (Oballa 2005) and about 55 of them are cultivated in Ethiopia (Friis 1995). Some important eucalyptus trees grown in East Africa are listed in Table 2

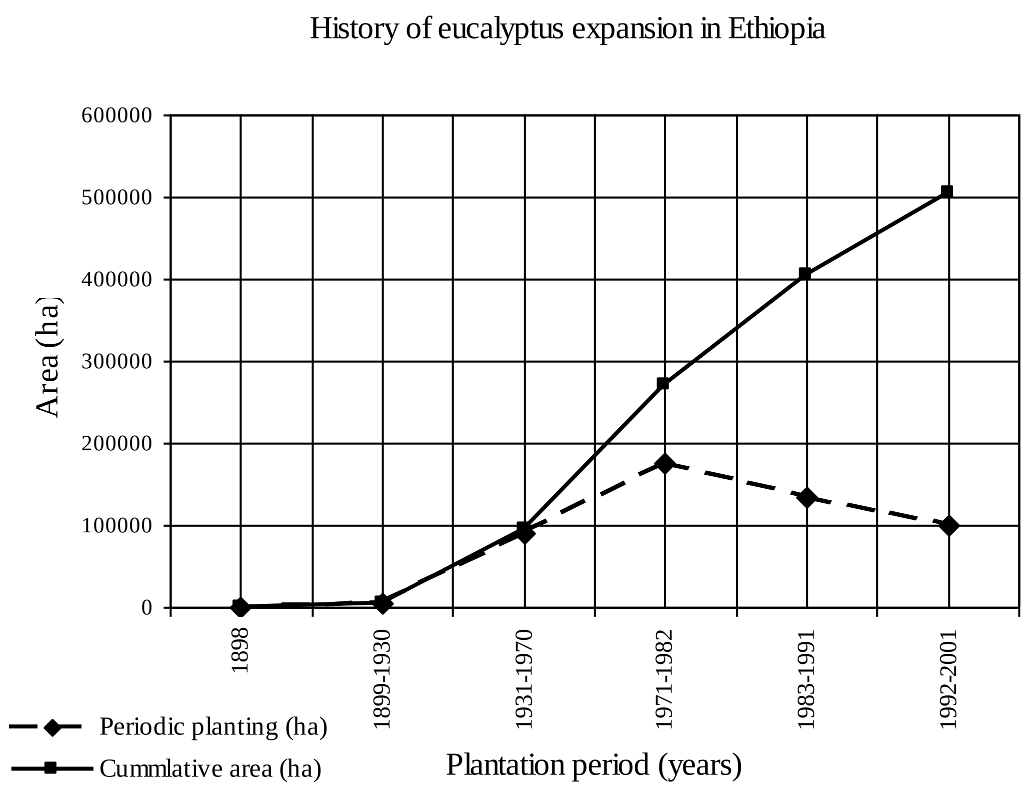

Figure 1 Increase in the magnitude of eucalyptus plantation in Ethiopia since its introduction to the country

Source: Amare (2002).

The most important growers of eucalyptus in East Africa are donor funded forestry projects, communities, private farmers and NGOs. 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 Debreberhan, Dessie, Gondor, Baherdar, Nazret and Addis Ababa. In Debreberhan alone UNSO invested over 3 million USD to plant 2600 ha of eucalyptus (Pohjonen and Pukkala 1990). Beyond these, the other most important eucalyptus growers in Ethiopia are smallholder farmers of the Southern Nations Nationalities and Peoples Regional State, Oromia Regional State and Amhara Regional State.

Table 2 Some of the well-known eucalyptus species grown in east Africa

Name	Ethiopia	Somalia	Djibouti	Sudan	Kenya	Uganda	Rwanda	Burundi
E. grandis	X				X	X		
E. saligna	X				X		X	X
E. camaldulensis	X			X	X	X	X	X
E. globulus	X				X		X	
E. paniculata						X	X	
E. teriticornis						X	X	X
E. maculata							X	
E. regnans								
E. fastigata					X			
E. microcorys							X	
E. maidenii							X	X
E. robusta						X	X	X
E. veminalis	X				X			
E.rudis								X
E. citiodora	X						X	X
E.botryoides							X	X
E. resinifera								X
E. bicostata	X				X			
E. longifolia							X	
E. punctata							X	
E. urophylla						X		
E. microtheca				X				
E. gomphocephala				X				
E. intertexta				X				
E. melanophloia				X				
E. largiflorens				X				
E. ochrophloia				X				

Source FAO 1979

Summary: Eucalyptus has been grown in East Africa for over a century. People developed important local knowledge of eucalyptus management. This certainly contributes to the steady expansion of eucalyptus in the region. However, this knowledge was not able to improve yield and enhance productivity of the tree.

Products and services

Several products and services of eucalyptus are known in East Africa (table 3). Eucalyptus can be used for fuel wood timber, plywood, power and telephone transmission poles, pulp, building and fencing posts, rails, medicine, honey production, tannin, perfumery and environmental conservation (FAO 1979; Davidson 1989; Demel 2000; Amare 2002; Zerfu 2002; Oballa 2005; Nduwamungu et al. 2007).

The product and services are found to vary with plantation scale. Fuel wood production is the major objective of large-scale eucalyptus plantations in east Africa (Nduwamungu et al. 2007; Oballa et al. (2005).

Table 3 Some of the known products of eucalyptus in East Africa

Products and services of eucalyptus	Descriptions
Products	
Fuel wood	The most important benefit of eucalyptus in all East African countries is household energy
Lumber	It is only in Rwanda where lumber is produced commercially. However, household level pitsaw is practiced in Ethiopia
Transmission poles	Almost all power and telephone lines especially in Ethiopia use eucalyptus transmission poles
Plywood	There are few plywood plants using eucalyptus in Ethiopia
Pulp	There is no commercial pulp production from eucalyptus in East Africa
Scaffolding	The construction boom in East Africa including skyscrapers, bridges, dams and roads use eucalyptus scaffolding
Building and fencing posts	Almost all wooden houses and wooden fences are built from eucalyptus in Ethiopia
Rails	Eucalyptus was important in the Kenyan and Ugandan rail way construction
Medicine	Eucalyptus is used as a medicine at household and community scale I*n* Ethiopia *E. globulus* leaves are used to treat common cold and flus
Honey production	Eucalyptus flowers pollen are important bee forage in east Africa (Ethiopia and Rwanda)
Tannin	This is not a well known product in east African countries
Perfumery	Few commercial distillers exist in Ethiopia where essential oil is produced from the leaves of *E. globulus* and *E. citriodora*
Ecosystem services	
Nurse tree	Experiences in Ethiopia showed that some indigenous trees such as *Juniperus procera*, *Podocarpus falcatus* can regenerate well under eucalyptus stands
Environmental conservation	Eucalyptus trees are planted for gully stabilizations, soil conservation and road embankments strengthening
Socioeconomic services	
Economic	Eucalyptus is a high value cash crop. In Ethiopia about 25% of farmers income is from eucalyptus
Access to credit	In Rwanda eucalypts stands are recognized as collateral to borrow money from banks
Social significance	Owning eucalyptus stand is considered a sign of affluence/wealth
Land tenure	Farmers plant eucalypts to ensure land tenure security in case of dispute or if the landowner cannot cultivate the land for some reason
Livelihood	Contribute positively to income/food security. Growing of eucalyptus is considered a growers green bank account

Sources: FAO 1979; Davidson 1989; Demel 2000; Amare 2002; Zerfu 2002; Oballa et al. 2005; Mekonen et al. 2007; Nduwamungu et al. 2007, (Jagger and Pender 2000; Pohjonen and Pukkala 1990)

Smallholder farmers both in Ethiopia and Rwanda grow eucalyptus mainly for poles, fuel wood, construction wood, furniture making and farm implements (see table 4). In Ethiopia according to Amare (2002), eucalyptus trees are suitable for two key functions, namely the construction of economic housing/fencing and for household fuel wood needs of both urban and rural households. In Rwanda, smallholder growers produce charcoal and lumber (Nduwamungu et al. 2007) which are not widely known in Ethiopia. In Ethiopia essential oil is extracted from the leaves of *E. citriodora* and *E. globulus*.

Table 4 Price comparison of some eucalyptus products from Ethiopia and Rwanda

Products	Unit	Price Ethiopia (USD)	Price Rwanda (USD)
Construction wood	m^3	25-30	Na
Fuel wood	m^3	12-14	7-12
Charcoal	Kg	Na	0.2-0.4
Lumber	m^3	Na	180-230
Transmission pole	Piece	5-8	10-15

Source: the Rwandan data was collected from wood market in Kigali while the Ethiopian data was derived from price list of Arsi Forest Agency in south central Ethiopia. Leaves, seeds and seedlings are sold in Ethiopia. In Addis Ababa, Ethiopia, selling leaves supports the livelihood of several poor women.

Socio-economic services

Eucalyptus has several desirable socio-economic benefits including financial, employment and security.

According to the interview in Ethiopia, farmers prefer to plant eucalyptus 1) for use at the household level (construction, fire wood, farm implements); 2) to sell for use as shown in table 4; 3) for soil conservation and gully stabilization; 4) to drain marshy land, which could harbour malaria; 5) to ensure land tenure security.

The study of Mekonnen et al. (2007) in central Ethiopia, reported that the major factors driving farmers to plant eucalyptus are: increasing demand for wood products in the market, the unavailability of wood on farm, its high rate of biomass production, its ease of cultivation and wider adaptability, its non palatability to livestock, the decline in land productivity for agricultural use, the decline in off-farm employment opportunities

Eucalyptus generates substantial income to rural households. In central Ethiopia eucalyptus generated a quarter of annual cash incomes (Mekonnen et al 2007). The same study showed that 74 percent of firewood sold was eucalyptus. Importantly, eucalyptus yields better income than other exotic trees, even better than some agricultural crops (Amare 2002).

Eucalyptus plantation projects have provided employment for thousands of unskilled labourers. In addition to employment, such projects in Ethiopia provided community development support such as building residences, roads, schools, health posts and flour mills.

Another important contribution of this tree is security. Eucalyptus stands proved to be an important guarantor for farmers who want to maintain the ownership of their rural land while living in urban areas (Amare 2002). Growers, by planting eucalyptus, secure ownership of the land and at the same time keep the land productive while they are away. On top of this, the amount of eucalyptus trees indicates the level of affluence of the growers. In Rwanda, banks accept eucalypts stands as collateral to lend money.

This tree species is important in the construction industry of East Africa. The poles of eucalyptus are used for scaffolding in the constructions of high-rise buildings, bridges, dams, and roads.

Summary:

Several products and services deriving from eucalyptus are known in East Africa. The scale of eucalyptus plantation determines the type and nature of products and services. The diversity of products and services is one of the reasons why eucalyptus is the preferred tree among growers. Eucalyptus has several desirable socio-economic benefits including financial, employment and security. The spread of eucalyptus throughout extensive areas and cultivation by many growers may have made it difficult to systematically manage the possible negative impacts.

Eucalyptus Management

The yield of eucalyptus and its environmental impact is greatly influenced by the types of management. Management outcome is determined by the objectives set by the processes of propagation, silvicultural activities and yield.

Objectives

Eucalyptus management is determined by the nature of the objectives set; for example, silvicultural treatment employed to produce fuel wood is different from that of timber production. While the earlier favours optimum volume development, the latter favours cylindrical and knot free stem development. The plant spacing for fuel wood production is often narrower than timber production.
The scales of plantation (commercial scale or smallholder scale) also influence management of eucalyptus. Commercial scale plantations are often established for fuel

wood, pulp, particleboard, chipboard and extracts such as essential oil and medicines. In such plantations highly skilled experts are employed, clear functional prescriptions are put in place and activities are financially intensive. Commercial scale plantations produce their own seedlings and employ organized site preparation and harvesting techniques. On the other hand smallholder management is based on local knowledge (of site selection, seedling production, tending operation, harvesting and marketing) and is labour intensive. Farmers in Ethiopia have very good knowledge and experiences that enable them to grow eucalyptus effectively. In southern Ethiopia farmers collect seeds, grow seedlings (bare-rooted or potted), plant and tend the trees, all without significant extension services.

In both commercial and smallholder scales, eucalyptus is mainly cultivated as a mono-crop. However, some smallholder growers mix eucalyptus with fruit trees and forest trees. Occasionally, as observed in Rwanda, eucalyptus is planted in agro forestry settings.

The information obtained in Ethiopia indicated four types of smallholder eucalyptus growers: those who plant few to several individual eucalyptus within their homestead, those who plant eucalypts in any spare land they have access to near their farms, and road sides, those who sacrifice some of their land use to farm eucalypts, and individual investors who plant eucalyptus by leasing land.

Table 5 Characteristics of smallholder growers of Eucalyptus in Ethiopia

Investment	Sources and cost
Plant material (seed, seedlings)	Plant materials are produced by the growers or obtained from forestry departments NGOs or bought for small price
Labor (site preparation, tending, harvesting)	The major sources of labor are family members and acquaintance these demand farmers minimal cost
Time	Time devoted to cultivating eucalyptus is mainly during off farm period often with minimal cost by using family time
Land	Often cost of land is negligible as home stead, farm boundary, road embankment, and degraded land are used
Tools	Farming tools are also used for land preparation, tending operation and harvesting
Finance	Smallholder growers financial investment include money spent to purchase seedlings and for employing tree cutters and transport fees

In comparison with agricultural crops and other tree crops smallholder growers' in Ethiopia produce eucalypts cheaply (Table 5). Eucalyptus seeds can be obtained locally, and fertilizers and chemicals are not often required. In the case of most agricultural crops farmers need to spend substantial amount of money to purchase seeds, imported fertilizers and imported chemicals.

Seed and Nursery

Eucalyptus seeds are collected from dominant and co-dominant trees. The fruits are hand picked (either after felling the tree or by climbing it), then air-dried, to be able to harvest the seeds. To insure viability, the seeds are stored in a sealed container at a cool temperature. There is tremendous variation between eucalyptus species in the number of seeds per unit weight. For example the number of seeds of *Eucalyptus camaldulensis* and *Eucalyptus globulus* are 698,000/ kg and 78,000/ kg, respectively.

Eucalyptus seeds require no pre-sowing treatment. In a nursery seeds can be sown in a seedbed or directly into container/plastic pots. Nursery soils need to combine organic matter with adequate water holding capacity and sand to allow good drainage. After the sowing it is important to water the containers regularly, preferably once in the morning and once in the evening. The purpose of watering is to keep the containers moist but not sodden. It is necessary to protect the seedlings from excessive sunlight and storm rains. Over shading could make the seedlings susceptible to dumping off that weaken or kill seedlings. Before planting it is important to prepare the seedlings for the field conditions by reducing water and pruning the roots.

Planting and Spacing

Planting establishment starts with site clearance by removing all plant and ground impediments. The optimal time to plant is early in the wet season. Smallholders prepare planting sites to agricultural standards removing all competitive weeds while commercial scale growers dig hole for individual seedlings. The spot at which the seedling is planted is determined after the spacing between two plants is decided. The spacing for fuel wood is often different from the spacing for lumber production. The fuel wood trees are often set at 2m by 2m (2,500 trees/ha) to 1m by 1m (10,000 trees/ha) while lumber trees are set from 2m by 2m (2,500 trees/ha) to 2.5m by 2.5 m (1,600 trees/ha). Spacing adopted by smallholder growers often range between 0.25m (160,000 trees/ha) and 0.5 m (40,000 trees/ha). This is markedly different from the generally recommended spacing and number of trees per hectare for both lumber and energy production.

Coppice

Eucalyptus management is divided between seed stand and coppice stand. Most eucalyptus tree species have the ability to coppice. Coppicing would be the preferred management technique for biomass production. The crop is coppiced at intervals of less than four years depending on the size of material (e.g. pole, biomass) required. A preferred stump size that gives adequate number of coppice shoots is about 12 cm. Time of coppice harvest should be when an adequate supply of soil moisture exists. One to three shoots per stump are left to grow. After 3-4 rotations of coppice, it is advisable to replace the stand with a seedling stand. The frequency of coppicing is related to both the size of product required and the original spacing. For some species of eucalyptus there is evidence that the coppice crop should give substantially higher yields, resulting in an increase of 20% -50%. Successful regeneration of eucalyptus from coppice costs a small fraction of the cost of establishing the initial seedling crop.

Yield

Depending on the objectives set, eucalyptus can produce for between 5-25 years. For example in Ethiopia *E.globulus* usually harvested at an age of 5-7 years for pole and construction wood while the maximum wood production is commonly attained at 18 years (Pohjonen and Pukkala, 1990). Mean annual increment (MAI) of eucalyptus in Ethiopia ranges from 10m^3/ha/yr to 57 m^3/ha/yr while MAI of conifer tree species ranges from 4.2 m^3/ha/yr to 9.6m3/ha/yr. In natural woodland species MAI is approximately 1.2 m^3/ha/yr (Pohjonen and Pukkala 1990; EFAP 1994). In Rwanda it was learned that eucalyptus grows for 5-25 years to produce fuel wood, poles, and lumber respectively.

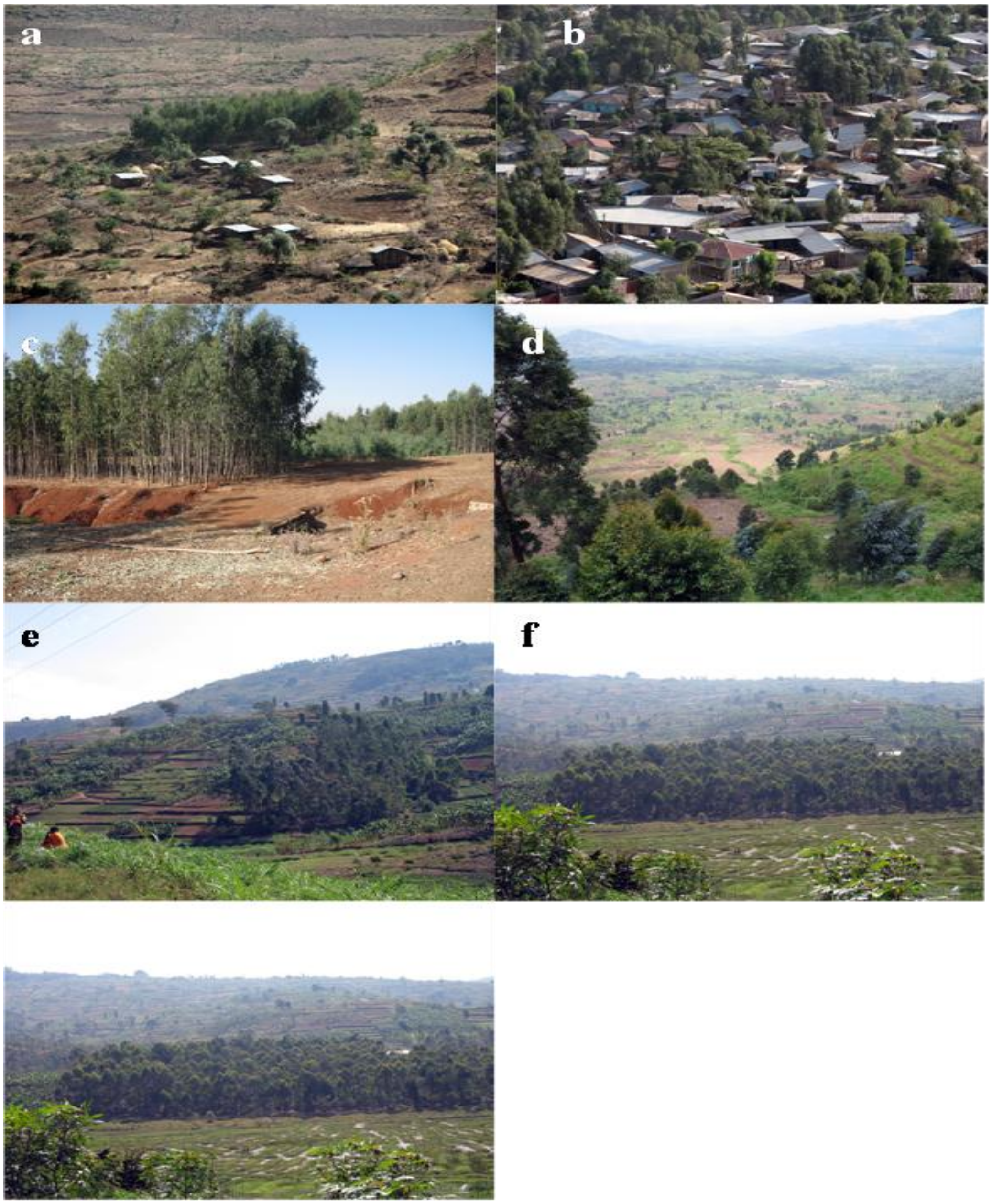

Figure 2 Some examples of eucalyptus management in Ethiopia and Rwanda

(a) eucalyptus stand in degraded and dry part of north Ethiopia ;(b) integration of eucalyptus trees in urban setting in south Ethiopia ; (c) eucalyptus cultivation on deep productive soils of farmlands in north Ethiopia ; (d) Eucalyptus trees incorporated in agricultural fields in north Rwanda ; (e) smallholder eucalyptus stand within agricultural landscape in north Rwanda (f) shows eucalyptus grown in a valley north Rwanda

Environmental Concerns Related to Eucalyptus

Despite the diverse services provided by eucalyptus plantations, especially in east Africa where the majority of the population depends on wood for construction and for fuel, there remains criticism . The majority of problems often cited are related to its effects on the environment including soil, water and biodiversity. Whether these condemnations are legitimate or deliberate, or simply a result of a lack of accurate information is often questioned. In a summary report in which he reviewed a bulk of literatures regarding eucalyptus plantation in Ethiopia, Demel (2003) discussed the various aspects of what he calls "adverse public reactions" against eucalyptus plantations. The report states that the trees are often accused of depleting soil nutrients, reducing soil water reserves, replacing traditionally used natural forests and changing cultural forest practices, threatening ecological stability and diversity as they are often grown in monoculture plantations. Also, adverse effects of their leaf litter on soil humus, failure to control or some times to aggravate soil erosion and inhibition of the growth of other vegetation under their canopy and not providing food supplies or adequate habitat for wildlife are mentioned (FAO, 1988; Anonymous, 1992). He argues that some of these criticisms are related to expectations of the uses that exceed the potential of the trees.

In this regard, Demel (2003) explains that eucalypts have often been heralded as wonder species that would bring immediate solutions to local wood and erosion problems. When this is followed by planting of eucalyptus, often without considering the agro-ecology and species compatibility and the exact needs of the community, it fails to perform as promised. This may leave the local people with vegetation which is little, if at all, better than what was there before the plantation. In such circumstances, the blame often falls on the eucalypts rather than the real culprit, which is bad forestry practice (Poore and Fries, 1985). Similarly, Davidson (1989) argues that the criticisms would equally apply to other exotic trees planted in many countries, not just eucalypts.

One of the principal reasons for planting eucalypts is because they grow faster than other species on the same site. This rapid growth is directly associated with greater consumption of water and nutrients (Demel, 2003). Therefore, any balanced argument should compare the nutrient and water depletion to the outputs produced.

It is common knowledge that forests and trees supply a variety of benefits that are often crucial to the well-being of people. For example, when environmental quality or material production potential has deteriorated, 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 (Demel, 2003). In the tropics and sub-tropics, eucalypts are often judged to be faster growing than other species and the most likely to survive on difficult sites (FAO, 1988). Eucalyptus is among the species considered in such situations, but may not necessarily be without some undesirable effects. This has been witnessed during the field visits in different parts of the Ethiopian highlands, where farmers plant eucalyptus on degraded lands, by and large with success . However, the successes as reported by farmers are not without problems such as the issue of too much water uptake which results in springs drying up, inhibiting growth of crops. In line with this, as summarized by Jagger and Pender (2000), there are both negative and positive arguments in literature about eucalyptus (Table 6).

Table 6 Ecological effects of Eucalyptus

Effect	Positive	Negative
Biomass production	• Planting fast growing eucalyptus may be one of the best short-term options for the provision of critically required biomass.	• Land scarcity may be a constraint to wide-scale tree planting, however wasteland and degraded land is in good supply.
Effects on soils, nutrient depletion and topsoil retention	• On degraded hillsides and wastelands the net soil nutrient contribution of eucalyptus through leaf litter is likely to be positive. • Good potential for topsoil retention on degraded hillsides.	• Eucalyptus trees deplete soil nutrients needed by agricultural crops, however the spatial magnitude of depletion is not known. • The ability of eucalyptus to provide organic matter is questionable.
Allelopathic effects	• Rainfall may decrease or negate the allelopathic effects of trees on crops.	• Allelochemicals negatively influence agricultural production and are a more significant factor in dry regions.
Hydrological impacts	• In regions with erratic and severe rainfall the ability to take up large quantities of water may reduce runoff, flooding and water logging • On previously barren slopes, tree cover may reduce erosion and gully formation caused by rainfall.	• Eucalyptus may compete water away from agricultural crops decreasing agricultural output as far as 10 meters away from where trees are planted. • Wide scale hydrological impacts are uncertain.
Resistance to pests, pathogens and random disturbances	• Some species of eucalyptus have avoided attack from some commonly observed insect pests and are unpalatable to livestock. • Some species are drought, flood and fire resistant.	• Pests and pathogens may migrate to unaffected regions causing medium-term losses. • Non-palatability of leaves to livestock is problematic for farmers who require livestock fodder.

Source: Jagger and Pender (2000)

There are a large number of eucalyptus species with widely varying properties, although only a few comprise the most popular plantation species. Their performance and ecological effects also vary accordingly. Furthermore, the effects of the same species may vary greatly in moist or arid sites or on different soils or topographies (Demel 2003). Just as widely as types of species and the ecological nature of sites vary, so do the array of needs of various communities can also vary. Therefore, while some of the criticisms could be valid, judgments and solutions must be specific to each case and based on accurate appraisal of biological, physical and human factors (FAO, 1988).

Effects on Climate

Micro- climate at regional level

Among the criticisms against eucalypts plantations is that they promote a change in the local climate. This is because of their very high evapotranspiration rate, which drains water from the soil leading to a lower water table. This high evapotranspiration rate is claimed to adversely affect local rainfall levels, resulting in possible desertification of the area. Others argue that the contribution of the continental water evaporation to the hydrologic cycle is known to be very small compared with that of the oceans (Lee 1980). Besides, the mere presence of a forest in a certain area does not necessarily affect the occurrence of rainfall in that area (Penman 1963). Based on a literature survey in "Eucalyptus Planting in 'Social Forestry' in India: Boon or Curse?", Jo Lawbuary concluded that the claim that plantations may lead to desertification is not substantiated, and ultimately such a process is more concerned with human agency, rather than an intrinsic feature of the genus (http://www.ganesha.co.uk/Articles/Eucalyptus.htm#Criticisms%20of%20Eucalyptus).

However, in some regions, such as the Amazon basin, the forest can influence local precipitation. Shuttleworth (1988) suggests that the canopy can affect the air-circulation pattern that flows from the Atlantic Ocean into the basin. There are also situations in which forests are located in hilly regions along the coast and are subjected to a constant fog, which condenses on the canopy and falls to the forest soil adding to the rainfall level (Lima 1993). Costin and Winbush (1961) observed a similar effect in some native eucalyptus forest in Australia. However, this can hold true for any forest, be it plantation or natural, though the magnitude of the effect may vary depending on the morphologic and physiological characteristics of the species. In terms of their effects on regional rainfall or on other regional climatic parameters, there is nothing to distinguish eucalypts from plantations of any other tree or from different types of native forests of similar structure and albedo.

Micro- climate at local level

Some studies have shown that the microclimate within eucalyptus plantations may be different from those of other species and native forests, but the data are not conclusive (Poore and Fries 1985). The effects of eucalypts on micro-climate at the local level are generally well recognized. The effects in this regard include lowering of the temperature, CO_2 fixation, shading etc. In Senegal, for example, microclimate changes occurred when Eucalyptus plantations were established on Acacia forest sites (Bernhard-reversat, 1988). However, the extent of these effects depends on the amount of leaf surface carried by the trees in relation to the surface area of the ground covered. In the shaded area, average air temperatures are lower, extremes of air and surface soil temperatures are reduced and there is a higher surface air humidity compared to areas with no trees. Generally, the greater the leaf area and the more horizontal the leaves are, the greater the shading effect and the higher the evapotranspiration rate. Eucalypts cast less shade, on average, than other broadleaved trees, but there are big differences in the amount of shade cast by different eucalyptus species because they have different leaf sizes and orientations. However, the influences which are the result of shading can be manipulated based on the need through increasing or reducing the density of planting. Therefore, there is no sufficient reason to distinguish eucalypts from other genera with similar crown architecture regarding micro-climate at the local level.

Shelterbelt and Windbreaks

Windbreaks are used to reduce the wind's force or velocity to make life more liveable for humans, plants, and animals in areas where wind speed is too high without protection. In dry areas prone to wind erosion, they reduce soil erosion and limits dust storms. In cold areas, it can help reduce the impact of the cold and can help to protect against freezes by cutting back on wind-chill (Knudson, Yahner and Correa, 1970). Some estimates show that homes can save about 30% of their heating and cooling costs by having a windbreak, which reduces the effect of hot and cold winds (http://library.csustan.edu/bsantos/section2.htm).

Furthermore, windbreaks reduce wind damage to crops so that potential yields are maintained. Although any barrier can serve as wind break, effective and sustainable windbreaks can be selected based on suitability criteria. Among the criteria for selecting tree species for windbreak is wind-firmness. Eucalyptus has an extensive lateral root system which makes it wind-firm, so that it can be fit as windbreak. For example, in California, USA, eucalyptus windbreaks are used to protect vineyards, nut and fruit trees, vegetables and grain. As one has observed, "Eucalyptus windbreaks in some sections have changed the aspect of the country, and by moderating the winds have improved the local micro-climate (http://library.csustan.edu/bsantos/section2.htm).

Hydrological Impacts

Depletion of the water table and effects on the hydrological cycle are commonly cited arguments against the planting of eucalyptus. However, according to Jagger and Pender (2006), there are few empirical studies that address the issue of water use by eucalyptus and its direct effect on adjacent crop output, despite the abundance of subjective and unreliable evidence. The general hypothesis is that high water requirements and characteristics such as deep root systems give eucalyptus a comparative advantage over other plants with respect to water usage (Jagger and Pender, 2006). Allison and Hughes (1983) have shown increased recharge after clearing previously forested areas. They reported that in a semi-arid region in Southern Australia (average rainfall 250-300 mm/yr), the recharge rate beneath native eucalyptus spp. was <0.1 mm/yr, where as the recharge was found to increase significantly to between 5 and 30 mm/yr following clearing and subsequent cropping. This is particularly serious when eucalyptus trees are planted in regions prone to drought conditions as the trees may cause drying of soil and water sources. The hydrological impacts of eucalyptus are often manifested in terms of its canopy interception, runoff regulation, water uptake, and soil moisture depletion.

Canopy Interception

Interception is a phenomena whereby a portion of rainfall remains in the canopy to slowly drop to the ground through a process known as stem flow or to be lost by direct evaporation (Lima 1993). Among the most significant hydrologic effect of eucalyptus plantation, as well as any other tree plantations or forest cover is interception of rainfall. When comparisons are made between forests and open areas, such as pastures and native grasslands, a higher evaporation rate can occur in the forest cover, thus diminishing the water supply of the watershed (Calder 1985).

The capacity of a forest canopy to store or hold water can be measured by using a leaf area index. The typical leaf area indexes of some eucalypt species are smaller than those of other forest species, which suggests that the total interception by eucalypts may be comparatively low (Gash 1979). Lima and Nicolielo (1983) reported that a study conducted in Brazil indicated that a 6 year old *E. saligna* plantation lost 12.2% of rainfall water by canopy interception. This is comparable to the findings of Lima (1976) who reported that two, 13 year old pine plantations (*P. caribaea* and *P. oocarpa*) have shown losses of 12% where as a savanna-like vegetation showed a loss of 27%. The loss from secondary Atlantic forests varied from 12.4% (Castro et al. 1983) to 18.2% (Cicco et al. 1986), and the range in Amazonian rain forest was 8.9% (Lloyd et al. 1988) to 19.8% (Franken et al. 1982). This shows low interception loss due to eucalyptus plantation as compared to many other forest species.

Given the diversity of existing eucalypt species in general and those existing in East Africa in particular, it is premature to draw any final conclusions about the loss of rainfall resulting from canopy interception by forests in the tropics and in the region. However, a review of the work and data available in Brazil as well as other parts of the world suggests that, on average, the water interception loss by eucalypt plantations is less than that of other tree plantations or native forests (Lima 1993).

Effect on Runoff

The effects of eucalypt on run off, and therefore on erosion, vary greatly according to local conditions of climate, the growth stage of the forest, slope, and use of the ground vegetation and litter by local people. Vertessey et al. (1996) studied the hydrology of mountain ash (*Eucalyptus regnans*) forest in a high-rainfall environment in Southern Australia and analysed relationships between forest age and runoff volumes. Old-growth forest yielded up to twice as much annual runoff as younger re-growth forest. The same process was observed in a mixed-species forest in drier catchments (www.catchment.crc.org.au). The driving mechanism behind this process is leaf area index, which was highest between the ages of 30 and 40 years (FAO 2002). The findings have important consequences for the management of the catchments, which are used for water harvesting. FAO (2002) recommends long harvesting rotations for these areas to obtain maximum runoff yields. The runoff volume depends also on the protection afforded to the soil by ground vegetation and litter, and the differences between eucalypt and other trees depend upon the effect of the various tree species. Wider spacing at planting and thinning etc. on steep and erodible slopes favors growth of other vegetation under the tree component, which together with the accumulation of litter can provide cover to the forest floor leading to less erosion. This has been witnessed during the field visit to West Shoa in Ethiopia where the forest floor is covered with grass which is used as grazing ground due to sufficient space between the trees to allow penetration of sunlight (Fig. 3). In this particular case, there is no evidence of soil erosion observed. Unfortunately, there is little or no concrete information in literature regarding optimum spacing of eucalyptus to allow undergrowth without compromising the productivity of the trees. It is believed an optimum spacing depends on the agro-ecological conditions and the species of the eucalyptus, among others. Consequently, it is recommended that such information for the various species growing in the different agro-ecologies of East African countries be generated through research. In addition, terracing and other physical soil and water conservation structures can compensate for poor ground cover.

Figure 3 Eucalyptus plantations around Ginchi, West Shoa in Ethiopia with sufficient spacing to allow undergrowth

Effects on Ground Water

There is little documented evidence regarding the effects of eucalyptus on ground water. The capacities of the more than 600 eucalypt species for water uptake vary depending on the type of root system; some have superficial root systems and others have deeper systems (Jacobs 1955). As in most natural forests and forest plantations, the roots of most eucalypt plantations are concentrated in the superficial layers of the soil (Reis et al. 1985). However, some eucalypt roots can grow to 30 m in depth (Jacobs 1955) and extract water from 6 to 15 m deep (Peck and Williamson 1987). In a watershed where ground water depletion is a concern, the deep rooted species should be avoided to prevent ground water depletion.

Farmers in the highlands of Ethiopia believe that eucalyptus plantations around water sources significantly affect the flow rate of springs. Some have witnessed that springs have disappeared due to eucalyptus plantation, and as a consequence, the community banned any further plantation around water sources such as ponds and springs. However, in some instances, they are used as drainage of marshy areas, which could otherwise harbor mosquitoes. This was observed during the field visit to West Shoa in Ethiopia, where farmers plant eucalyptus on heavily waterlogged areas (Figure 4) or flood plains. The farmers in this region explain that eucalyptus planted in such environments, once established, grow very fast as they get access to water throughout the years. They claim that the income that can be obtained from the sale of the annually harvested eucalyptus can outweigh what could have been obtained from the same plot, if they were to plant other crops.

Figure 4 Eucalyptus plantations on marshy areas in West Shoa, Ethiopia

Effects on Water Yield and Soil Moisture

Water scarcity is an increasingly severe problem across the developing world, with many countries in East Africa already experiencing severe water scarcity (Jagger and Pender, 2000). Certain trees that are integrated into agricultural systems can increase the efficiency of water use, while plantations of fast-growing trees can exacerbate the problem of water shortages. Perhaps the most controversial water-related issue relating to eucalypt plantations is the effect on the water content of the soil. It is claimed that eucalypt trees absorb more water from the soil than any other tree species. The results of two decades of research on the water use and water balance effects of trees in Kenya shows that eucalyptus consumes more water, especially during its early growing stages compared to *pinus* species (Dye and Bosch, 2000). The finding of this study has implications for water management, forestry and agro-forestry in water scarce, semi-arid and arid regions.

The uptake of soil water depends mainly on the architecture of root systems and the depth of root penetration (Lima 1993) as well as stand density and soil and environmental conditions. As in most natural forests and forest plantations, the roots of most eucalypt plantations are concentrated in the superficial layers of the soil (Reis et al. 1985). As eucalyptus species are quite variable in terms of their root systems, their water uptake capacities also vary depending on the type of their root systems (Jacobs 1955). The growth of the eucalypt root system depends on environmental factors such as soil compaction (Nambiar 1981). This has been verified by examination and studies for *E. urophylla*, *E. pellita, E. camaldulensis, E. grandis, E. cloeziana* and *E. citriodora*, in which only *E. citriodora* and *E. pellita* were able to develop fine enough roots to penetrate a compacted layer (Krejci et al. 1986).

The leaf area of the eucalyptus plants is also another important factor affecting the rate of water consumption. Hatton et al. (1998) concluded that there was a strong linear relationship between tree leaf area and mean daily water use for a wide range of eucalypt species grown under similar climatic conditions. Meyers et al. (1996) arrived at the same conclusion for non-water limited situations, stating that species (including *Pinus radiata*) with unrestricted access to water have similar rates of water use at similar stages of canopy development.

On the other hand, there is evidence indicating that eucalypts species adjust their consumption to availability of water. According to Dabral and Raturi (1985) the maximum consumption of water by *E. tereticornis* in the Dehra Dun (India) climate was during the rains (60%), followed by winter (26%) with the least during summer (14%). This implies that eucalyptus consumes more water when it is amply available and can cut its consumption when faced with scarcity. However, there is evidence showing that eucalyptus species may consume more water than is replaced by rainfall. The study of Dabral and Raturi (1985) at Dehra Dun concludes that over a period of 36 months, water used was more than the rainfall received during the period which could be at the expense of previously stored water.

Calder and Prasanna (1993) found an interesting result from the research conducted at different sites in dry tropical climate. At one site, the water use of a young *E. tereticornis* plantation was found to be no different from that of an indigenous dry deciduous forest. At two other sites, the annual water use of the eucalypt plantation and the indigenous forest was found to be equal to the rainfall. At yet another site, with deeper soil, water use of the eucalypt plantation was greater than the rainfall; 3,400 mm of water was used versus 2,100 mm of rainfall received over a three year study period. During these three years, rainfall was less than normal and yet at none of the sites was there any evidence of abstraction from the ground water. Provided that the water consumption estimate was accurate, the source of the extra water is unknown. One hypothesis was that, if roots penetrate successively deeper layers, water 'mined' would account for it. The other hypothesis suggested by Dabral and Raturi (1985) is the use of water stored in the soil, from years with higher than average rainfall.

Boden (1991) studied seven year old *E. grandis* plantations in three plots with mean annual increment (MAI) of 26, 16 and 6 tonnes per ha per annum. Tree vigor was found to be inversely proportional to soil water status. The soil water status under the largest trees was consistently and substantially drier than under the smaller trees. The least vigorous trees were growing marginally quicker than the largest trees. It is assumed that the latter have utilized available water resulting in a slowing down of their current growth (Boden, 1991). This interpretation corroborates with the previous reports that the overall use of water by eucalypts is limited to the total rainfall regime of the area, in the absence of access to the water table (Gurumurti and Rawat, 1992). The plantation of extensive forests of eucalypt in any deforested catchment will substantially decrease water yield from that catchment while the felling of such forests will increase it (Lima 1993).

The rate of water uptake by the eucalyptus plantation depends also on its growth stage. According to Dye and Bosch (2000), the effects of eucalypt plantations on soil moisture reserves apparently start to appear at the age of approximately 4-6 years (Fig.5), when the soil water deficit created by the plantations during the year is similar to the one observed in mature forests. According to Dye and Bosch (2000) *eucalyptus grandis* takes up, almost twice as much water as *pinus patula* does during the first decade after planting.

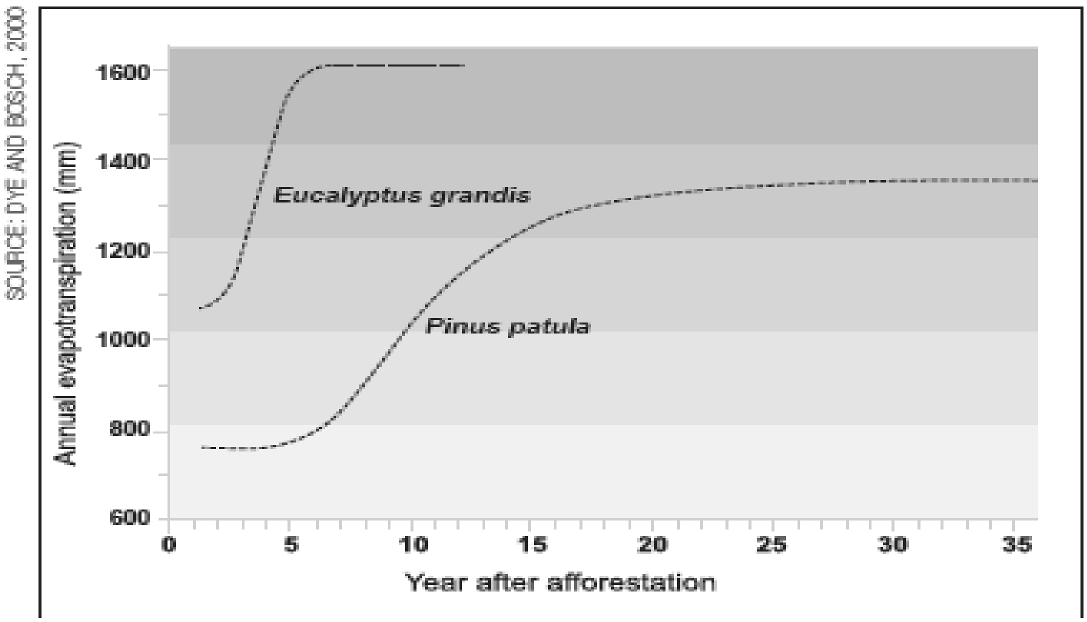

Figure 5 Water requirements of two popular ever green species

Like soil water uptake, evapotranspiration from eucalyptus is also correlated with water availability. The average catchment's evapotranspiration of a well stocked eucalypt forest is probably around 1000 mm/yr for rainfall regimes above 1200 mm/yr. For drier regions, evapotranspiration declines, perhaps reaching a value of 450 mm/yr when the rainfall regime is of the order of 500 mm/yr. For wetter regions, evapotranspiration increases, eventually reaching a value of 1500 mm/yr for tropical eucalypt forests of lower latitudes. Comparative studies have shown average annual evapotranspiration in pine plantations to be in the same order of magnitude as that observed in eucalypt forests. Thinning and selective cutting in mature eucalypt forests increased stream flow by an average value of approximately 400 mm/yr. The effect of clear felling on catchment's yield was at its highest during the second year after the cut.

Observations in Central India and in the foothill zone of the Himalayas indicate that, in regions in which large areas of *E. tereticornis* plantations have been raised, the level of water in wells falls until the plantations were about 6-8 years in age, the culmination of the mean annual increment and thereafter reverts to the earlier levels (ANON 1989, Chaturvedi, 1993). In the case of older plantations of *E. globulus* in the Nilgiris (India) no adverse effects have been noticed on the hydrological cycle (Chaturvedi, 1993). The monthly evapotranspiration of an *E. globulus* plantation in Portugal, with an average yield of 8-12 m^3/ha/yr worked on 10-12 year rotations, was the same as that of a natural open stand of cork oak (*Quercus suber*) with under story of shrubs. The regenerating coppice of eucalypt exceeded this only by 4 mm/month at the end of the drought cycle (Almeida and Riekerk, 1990; Madeira, 1989). Therefore, the effect of eucalyptus on soil moisture and water yield of a watershed depends not only on the species (root architecture, rood depth and leaf area), but also on the age, climatic conditions where it grows and the management regime of the plantation, which includes frequency of cuttings.

Water Use Efficiency

As discussed earlier, among the major criticisms against eucalyptus is related to its high water consumption. In comparing species regarding water and nutrients consumption, not only the absolute volume of water consumed, but also the amount of biomass and other desirable goods and services produced per unit of water consumed is important (Jagger and Pender 2000). In other words, how efficient the water is used to produce beneficial products, how abundant is the water in the target area, and which suitable alternative species is available to provide the necessary socio-economic and environmental services for the area deserve important consideration before making decisions.

A study conducted to compare soil moisture under a five year old *E. grandis* plantation, a five year old *P. caribaea* plantation, and a savanna-like native forest showed a similar pattern of annual variation in soil water for the three forest covers (Lima et al. 1990). However, in terms of timber production, the eucalypts used water more efficiently than did the natural vegetation. The water use efficiency of *E. tereticornis* as compared to that of species of other genera including fast growing species such as *Albizia falcataria, Melia azadarach* and *Acacia auriculiformis* has been proven (Pudjharta, 1986; Tiwari, 1992). While the earlier findings were that *E. tereticornis* used 0.48 mm - 0.55 mm of water to produce one gram of dry matter under unrestricted supply of water, in rainfed conditions of Dehra Dun (India), only 0.122 mm of water was used under moisture stressed environments, reconfirming its capacity to cut down water consumption.

Data related to water use efficiency of eucalypts grown in East African environment is quite limited. But from their study conducted under conditions of the Ethiopian highlands, Pohjonen and Pukkala (1990) reported that *E. globulus* converts energy and available water into biomass more efficiently compared with exotic coniferous tree species. Therefore, although some species of eucalyptus may consume more water than the indigenous forests or other plantation forest, which may lead to reduced water yield and leaves less available water for other crops growing in association with the tree, it’s more efficient in terms of converting the water into biomass.

Effects on Soil Quality

Soil quality is often referred to in soil science literature as the capacity of soil to function within natural or managed ecosystem boundaries to sustain plant and animal productivity, maintain or enhance water and air quality, and support human health and habitation (Larson and Pierce, 1994). Improper land use and soil management, which often leave the soil with less or no vegetation, are often cited as the major causes of soil quality deterioration. However, fast growing tree plantations may also lead to soil quality decline when they are poorly planned and not properly managed. According to Jagger and Pender (2000), the impact of tree plantations upon soil resources has been very much debated and there is no complete consolidated view, partly due to the fact that the impact is much dependent on variable site and forest conditions. The effects of eucalypts on soils have been studied in several countries over many years (Florenzano 1956; Kindu et al., Malik and Fries, 1985; Poore & Fries, 1985; Lugo et al., 1990; Lemenih et al., 2004; Lemma, 2006; 2006a, Kindu et al., 2006a). Most of the concerns related to effects on soil quality deal with depletion of nutrients and allelopathy caused by the litter, which is said to exert an antibiotic effect on soil microorganisms. This concern was verified by research that showed a very low concentration of nitrifying bacteria in eucalypt plantations litter (Florenzano 1956).

Moreover, a number of studies indicated that changes in some soil properties are influenced by tree species (Malik and Fries, 1985; Poore & Fries, 1985; Lugo et al., 1990; Lemenih et al., 2004; Lemma, 2006). The effect often depends on the management regime of the plantation. For example, Pennington *et al.* (2001) found a significant soil quality change after clear felling and high intensity burning in Australian eucalyptus plantations. Under such management condition, soil bulk density increased from 0.58 mg/m^3 to 0.70 mg/m^3, while 3850 kg/ha of carbon and 107 kg/ha of nitrogen was lost from the soil.

A comparison made between 1 to 8 year old *E. tereticornis* plantations and natural mixed broad leaved forest in the central Himalaya showed a soil quality decline under eucalyptus (Bargali et al., 1993). Other studies indicated that various soil physical quality indicators decreased with increasing age of the plantations. In addition, soil chemical properties, notably organic carbon, total nitrogen, phosphorus and potassium decreased as a result of reforestation with eucalyptus and further decreased with increasing age. However, this is not unique to eucalypts only. For example, plantations of first and second rotation Hoop pine (*Araucaria cunninghamii Aito ex A. Cunn*.) in subtropical Australia showed a declining trend for some soil basic properties with an increased number of cutting cycles (Chen et al., 2004). From a study conducted on Chinese *Cunninghamia lanceolata* plantations, (Sheng *et al.* 2004) reported decreases in soil microbial activity, deterioration of soil structure, depletion of soil nutrient storage and nutrient availability decline as the number of cutting cycles increased.

Nutrients cycle

Nutrient cycling in forest plantations can be defined as the exchange of nutrient elements between the living and non-living components of the forest ecosystem (Mulugeta, 2008). The uptake of nutrients by plant roots, their incorporation into living tissue, and the release of nutrients during organic matter decomposition cause nutrients to flow or cycle within terrestrial ecosystems. Therefore, the nutrient cycling process involves nutrient uptake and storage in vegetation in perennial tissues, litter production, litter decomposition, nutrient transformations by soil fauna and flora, nutrient input from the atmosphere and the weathering of primary minerals, and nutrient export from the site by harvest, leaching, erosion and gaseous transfers (Johnson, 1994; Heilman and Norby, 1997) and litter raking (Fig. 6).

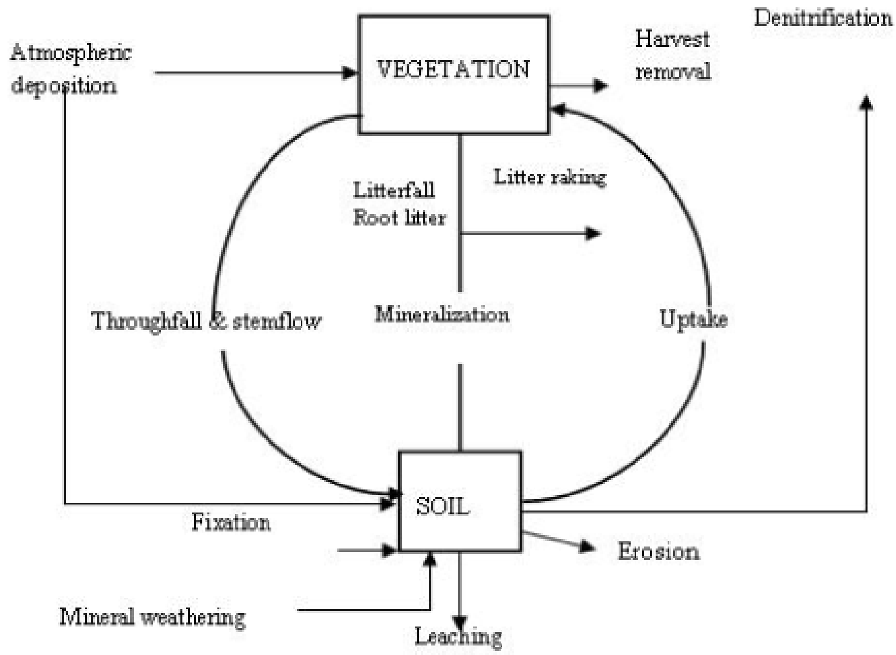

Figure 6 Schematic presentation of nutrient cycling processes in forest plantation ecosystem

Source: Mulugeta (2008)

When considering tree species to be used for afforestation or for integration into farming systems as agro-forestry, depletion of soil nutrients is one of the most commonly cited criticisms associated with eucalyptus trees (Jagger and Pender, 2006). In contrast to other commonly used afforestation and agro-forestry species such as leucaena and acacia, eucalyptus are non-leguminous, so that they do not fix nitrogen from the atmosphere, an essential element for soil health and sustainability. Therefore, advocates of agro-forestry often cite the fact that leguminous trees contribute nitrogen to soils, enhancing crop productivity and sustainability. In contrast, non-leguminous trees such as eucalyptus may out-compete agricultural crops for scarce but essential soil nutrients. Because of this and other drawback, fast growing non-legume trees like eucalyptus are not recommended for intercropping with annual crops.

Among the important factors that determine the nutrient status of soil under forest is the species composition. According to Mulugeta (2008), monoculture plantation forestry may affect soil chemical properties in two ways: nutrient depletion from the soil into the tree components, and changes in the chemical status of the soil surface as the litter layer and organic matter becomes dominated by one species. Evidently, forest management practices can aggravate or reduce the magnitude of the effects.

Nutrient cycle at a specific site can be improved through mixing eucalyptus with nitrogen fixing species such as acacia. Forrester et al (2005) have compared monocultures of *E. globulus* (E) and *A. mearnsii* (A) and mixtures of these species planted in a species replacement series: 100% E, 75% E + 25% A, 50% E + 50% A, 25% E + 75% A, and 100% A. The result indicated that highest and the lowest aboveground biomass was obtained from 50/50 mixtures and monoculture, respectively. Owing to the higher nitrogen concentrations of *A. mearnsii* litter, nitrogen contents of annual litter-fall were at least twice as high in stands containing *A. mearnsii* as in *E. globulus* monoculture. Stands with *A. mearnsii* also cycled higher quantities of phosphorus (P) in annual litter-fall than *E. globules* monocultures. Thus mixing *A. mearnsii* with *E. globulus* increased the quantity and rates of nitrogen and phosphorus cycled through aboveground litter-fall when compared with *E. globulus* monocultures. Thus, mixed-species plantations appear to be a useful silvicultural system to improve nutrition of eucalypts without fertilization.

Soil Nutrient Depletion

Species vary widely in their inherent nutrient requirements and use (Cole and Rapp, 1981). Most of the environmental concerns about short rotation forestry management such as that of eucalyptus revolves around nutrient removal with harvest (Heilman and Norby, 1997). There is a significant support in the literature for the assertion that all fast growing tree crops such as *Eucalyptus* are associated with a more intense uptake of nutrients from the soil into vegetation, compared to slow growing forests (Mulugeta, 2008; Ranasinghe 1991) and hence deplete the nutrients on a site, regardless of whether or not they are leguminous (FAO, 1985).

Several studies have indicated significant differences in soil nutrient status between plantation forests and adjacent natural forests in different parts of the world including tropical Africa (Mulugeta, 2008). The studies showed the possibility of changes in the chemical status of the soil induced by a plantation, but there have been conflicting reports in this regard (Cornforth, 1970; Lundgren, 1978; Hase and Fölster, 1983; Kadeba and Aduayi, 1985; Yirdaw, 2002; Lemenih, 2004; Lemma, 2006). According to Michelsen et al (1993) who compared the nutrient status of soils under exotic tree species with those under indigenous juniper and natural forest soils, soils under cupressus and *E. globulus* were generally found to have the lowest nutrient (especially phosphorus and nitrogen) content. Indigenous woodland soils provided much higher nitrogen and phosphorus content in above ground herbaceous plants, indicating that nutrient cycling in sites dominated by exotic tree species is more constrained.

A summary of data collected from across the tropics for pines, eucalyptus and leucaena indicated that the rates of nutrient removal were high except for leucaena, which enhanced soil fertility (Hase and Fölster, 1983, Jorgensen and Wells, 1986 and Pennington et al., 2001). Similarly, Aborisade and Aweto (1990) found that in moist sites where teak and gmelina were planted, total exchangeable basic nutrients in the topsoil showed a definite decrease over those in the primary rain forest.

According to Mulugeta (2008) whole tree harvesting coupled with short harvest cycles result in soil nutrient depletion far greater than conventional forest harvest. For example, if the felling cycle is long and if branches, leaves and bark are left in situ, the natural inputs build up the nutrient chain sufficiently to maintain the production of wood over a number of rotations (ANON (1989, Basu, and Aparajita Mandi 1987, Kushalappa,1987, Kushalappa, 1993). Consequently, when eucalyptus is grown as a short rotation crop for high biomass production and removal, soil nutrients are depleted rapidly. The reduction in nutrient content of the soil under such conditions may be explained by the nutrient drain through harvest removals (Lundgren, 1978).

Evidently, there should be an optimum harvesting cycle that ensures the nutrient balance of the ecosystem is maintained, while the benefits from the trees are also optimized. This is believed to depend on various factors including the prevailing agro-ecology. For example, Kushalappa (1987) analyzed the nutrient status of a 12 year old *E. tereticornis* plantation near Bangalore (India). According to this study, the inputs to the soil through weathering of the parent rock, litter, rain wash and root mortality outweighed the loss of the nutrients due to harvesting, when the felling cycle was 12 years or more. But in the case of shorter rotations, the loss had to be compensated through addition of fertilizers (ANON 1989, George, 1986, George and Varghese, 1991; Jorgensen and Wells, 1986, Pande, Tandon and Rawat, 1987, Tiwari, 1992, Wise and Pitman, 1981). However, this would apply the same way to any other fast growing and highly productive crops under a similar rotation.

Addition of fertilizers to eucalyptus has become a regular feature of management in different parts of the world including Argentina, Brazil, Portugal, Spain and South Africa. It is also practiced in high density plantations in India (Knudson, Yahner, and Correa, 1970, Patel, 1988, Schutz, 1976). But in places like East Africa, where fertilizer application for food crops is still very low, this option remains too remote to be practical. Therefore, regulating the harvesting cycle at optimum rate could be an affordable and feasible alternative.

The impact of eucalyptus trees on nutrient content of soils is manifested in retarded performance of other crops grown in mixture with or adjacent to the tree. Studies from various regions in sub-Saharan Africa provide evidence of the negative impacts of eucalyptus on agricultural production (Jagger and Pender, 2006). A case study from Nigeria examined yields of maize, sorghum and groundnuts planted in pots with composite soil samples from three to twelve year old exotic tree plantations of neem, prosopis, *E. camaldulensis*, and a control (where the control consisted of mixed surface soil from outside and adjacent plantations) (Verinumbe, 1987). After 60 days of growth, the results indicated that yields of maize and sorghum were highest under neem, whereas groundnuts produced high yields under the control and prosopis. For the three agricultural crops studied, the mean crop yield under neem, prosopis, eucalyptus and control were 13.99, 8.32, 6.80 and 4.76 grams per plant, respectively. The data suggest that although eucalyptus soils are superior to the control, they do not lead to strong crop growth even when a leguminous crop is planted (Jagger and Pender, 2006). Therefore, eucalyptus is not a preferred species as long as agro-forestry is concerned, but in case planted with crops for some reasons, the spacing should be wide enough to reduce competition and the harvesting cycle should be long enough to allow regeneration of nutrients. Application of inorganic and organic fertilizers can help mitigate the effects.

Nutrient use efficiency

Nutrient use efficiency can be estimated as the amount of aboveground net primary production per kilogram of nutrients taken up (Binkley et al. 1992). Like its water use efficiency, compared with a range of crops, eucalypts can achieve a high biomass production on a low nutrient uptake. According to Grove, *et al*. (1991), as little as one-half to one-tenth that of most agricultural and estate tree crops are required to produce one unit of biomass. As a consequence, they can be successful on poor soils, even without fertilizer. Forrester, *et al*. (2005) observed that nitrogen use efficiency was higher for *E. globulus* than for *A. mearnsii* and the nitrogen and phosphorus use efficiency of the stand declined with increasing proportions of *A. mearnsii*. This was in part related to the improved availability of these nutrients in the soil as the proportion of *A. mearansii*. In other words, the nutrient use efficiency of eucalyptus increases with the decrease of the availability of the soil nutrients. This is well understood by farmers, as witnessed during the field visit in the central highlands of Ethiopia. Farmers suggested that eucalyptus can be planted on agriculturally marginal lands where other crops are not economically feasible. Although this may not lead to optimum growth rate of eucalyptus, in the long run it allows the productive use of degraded lands like quarry areas, gullies, etc., which may gradually be healed.

Effects on Soil Erosion and Land Degradation

Land degradation has become an increasingly serious problem, especially in the tropics and subtropics, where many soils are inherently poor in nutrients and at high risk of degradation due to erosion (Jagger and Pender, 2000). The main causes for land degradation include improper land use, poor agricultural practices, deforestation and overgrazing, among others. Soil erosion is among the most important surface processes that result in severe land degradation in the tropics. Trees influence soil erosion mainly through intercepting of rainfall which dissipates its kinetic energy to detach the soil particles. However, the rain drops that are intercepted eventually drop to the soil surface with different erosive energy, which depends on the size and orientation of the leaves. Large leaves produce larger size droplets which have greater impact energy on the ground. Accordingly, erosive energy of rain under the crowns would be least for Casuarina spp, with the acacias (e.g., *A. auriculiformis*) and narrow-leaved eucalypts (e.g., *E. camaldulensis*) occupying the mid-range and the broad-leaved eucalypts (e.g., *E. globulus*) at the top of the range for eucalypts, but even these have much smaller leaves than Anthocephalus spp and very much smaller leaves than *Tectona grandis*, the latter of which has been widely planted in tropical plantations, particularly in Asia. Consequently Jagger and Pender (2000) concluded that there is no evidence to single out eucalypts for special criticism with regard to soil erosion by water under trees. It has been hypothesized that long term exposure to allelo-chemicals may result in exposure of the soil to erosion, which may have implications for sustainable land use over time (Jagger and Pender, 2006). With regard to soil erosion by water, it is important to focus more on ground cover and ground level activities such as cultivation, compaction by foot traffic, livestock grazing and trampling and harvesting/logging damage. In other words, the crop management component of the Universal Soil Loss Equation rather than the type of species of trees planted is important. According to FAO (1996), eucalypt plantations have made great contributions to soil and water conservation in China. Data from Jingdong county shows that after the establishment of eucalypt plantations, the density of soil decreased by 6% and 99% of the mud and sand movement were intercepted. Hedge rows of eucalyptus can be used as wind break with a significant impact on wind erosion in dry land areas.

Allelopathy

Allelopathy is the release of chemicals from leaves or litter that inhibits the germination or growth of other plant species (FAO 1985), and consequently reduces the output of crops. An allelopathic effect of eucalyptus is among the issues dominating agroforestry literature (May and Ash 1990). Allelophatic exudates from eucalyptus tree components showed an inhibiting effect on undergrowth vegetation regeneration and growth (Poore & Fries, 1985). Allelopathic or phytotoxic compounds are known to be mainly phenolic acid (Glass, 1976; Rice, 1984). These phenolic compounds are degraded with decomposition of plant residues, resulting in alleviation of phytotoxicity of the decomposing plant residues (Tian et al., 1992).

Eucalyptus leaves have been reported to have phenolic acids, tannins and flavonoids (Babu and Kandasamy, 1997; Chapuis-Lardy et al., 2002). Bioassay experiment with eucalyptus litter extracts and leaf leachate showed a high level of phytoxocity (Michelsen, *et al*., 1993; Bernhard-Reversat, 1998). According to Souto, *et al*. (2001) a soil bioassay showed clear inhibitory effects on germination and growth of under-storey plants, particularly soils from *Eucalyptus globulus Labill*., and *Acacia melanoxylon R.Br*. stands compared to *Pinus radiata D.Don*. in Spain. However, much of the work mentioned in the literature lack experimental precision, in particular, they lack proper controls and insufficient replications (Jagger and Pender, 2006). Most of the studies put forward as "evidence" for eucalypts being strongly allelopathic involve laboratory studies of artificial extracts on germination of seeds or early growth of potted plants which may not accurately represent the field conditions.

Selamyihun Kidanu (2004) reported soil bioassay studies with three agricultural crops: chickpea (*Cicer arietinum*), tef (*Eragrostis tef*) and durum wheat (*Triticum turgidum*) under laboratory and field conditions in Ethiopian highlands. According to his findings, bioactive compounds from *E .globulus* decomposing litter fall did not affect test crop seed germination and root growth. However, litter extract with 5% dry matter concentration significantly impeded germination and root growth of the tested agricultural crops. On a farm field experiment, a declining barley yield was observed in proximity to *E. globulus* plantation (Selamyihun Kidanu *et al*., 2005). Sanginga and Swift (1992) used greenhouse and field experiments to examine the effects of *E. camaldulensis* and *E. grandis* on maize germination, nutrition and growth of maize in Zimbabwe. Results suggest that germination of maize under eucalyptus leaf litter was dependent upon the quantity of leaf litter applied to the experimental plot, and that there is evidence of a positive 'fertilizer effect', from decomposing leaf litter.

Field trials comparing sites planted with eucalyptus and indigenous miombo woodland concluded that although significant variation in soil mineral content was observed (depleted magnesium and potassium in eucalyptus soils), there was little evidence to indicate that allelopathic effects were significantly inhibiting maize growth (Lisanework and Michelsen 1993).

A study by Jayakumar *et al.* (1990) investigated the effect of aqueous extracts of freshly fallen leaves of *E. globulus*, raised along river banks in Tamil Nadu in Southern India. It was observed that the growth of weeds and grasses beneath these trees seemed inhibited, and thus the author sought to study the effect of eucalypt leaf extracts on the growth of peanut (Arachis hypogaea) and maize (Zea mays) seedlings. The leaf area, plant height, and leaf chlorophyll content of both test species were significantly inhibited by the *Eucalyptus aqueous* leaf extracts. In consistency with this effect, Molina *et al*. (1991) suggested that eucalyptus releases toxic allelo-chemicals into the soil system mainly through litter decomposition products.

Evidently, the results vary across a wide spectrum of conditions from humid, fertile sites to dry, infertile ones. The magnitude of the negative effects may be influenced by rainfall. It is likely that allelochemicals do accumulate in soil, however, these chemicals are highly soluble and rainfall is likely to leach them out of the soil surface (May and Ash 1990). Thus, the effects of allelopathy are likely negatively related to rainfall. Malik and Sharma (1990) noted that allelopathic effects are more severe in low rainfall regions prone to soil erosion than in drier regions. This has significant implications when taken in the context of the East African region where erratic rainfall and highly erosive soils prevail. However, the hampering effect on growth of under-storey or adjacent intercropped crops is more often the result of extreme competitiveness for water and nutrients than allelopathy. Farmers in the highlands of Ethiopia relate this hampering effect to competition for water and nutrient as witnessed during the field visit for this study.

Effects on Biodiversity

Some authors (e.g., Peterken, 1996; Kidanu, 2004) indicated a negative impact of forest plantations on biodiversity. In contrast, several studies compared the undergrowth vegetation composition in plantations and natural forests (Parrotta, 1995; Senbeta et al., 2002; Lemenih et al., 2004; Montes et al., 2005; Rouvinen and Kuuluvainen, 2005) and concluded that forest plantations may promote the regeneration of native species and foster the subsequent succession processes. The effects of plantations on undergrowth vegetation composition and diversity differ strongly based on the characteristics of the surrounding landscape (agriculture, savannah, or native forest), uniformity of horizontal

(spatial heterogeneity) and vertical (stratification) structural diversity of over- storey tree species and management regimes (Malcolm et al., 2001; Kint, 2005).
Studies indicate that monoculture eucalyptus plantations have the potential to alter the diversity of plant and animal species across landscapes (Lugo, 1997; Souto et al., 2001). Harrington and Ewel (1997) found that 26-32 year old plantations of *E. saligna* in Hawaii contained 42 species in the under-storey. In contrast, Hüttl and Loumeto (2001) found that afforestation of savannas with eucalyptus facilitated the establishment of native forests. Bird and mammal use of the plantations was also substantial, and varied with the tree species planted (Brosset, 2001). In southern China, with the establishment of eucalyptus plantations on barren land, the ecological conditions distinctly improved and the number of life forms increased (FAO 1996). It was reported that 71 bird species lived in eucalypt plantations of Guiqi County, Jiangxi Province, more than that in *Pinus massoniana* plantations.

However, inter-cropping eucalyptus with other species, especially leguminous plants has many advantages in establishing eucalypt plantations. For example, improvement of soil fertility, cure and control of insect and pests damages, water and soil conservation was observed due to intercropping of eucalyptus with other species in China (Zhao Tingxiang et al., 1990). The conclusion is that the establishment of eucalypt plantation under reasonable and responsible management does not stand a ghost of a chance of worsening the environment, but combining it with other species especially leguminous plants may improve biodiversity over a monoculture plantation.

Conclusion and Recommendations

The introduction and expansion of eucalyptus to date in East Africa is largely related to the fast decline of native forest and sustained rise of wood deficit, increasing demand for fast growing tree species, decreasing landholding per household and increasing urbanization and the mounting need for construction material.

More than a century of cultivating in East Africa created wide spread local knowledge of eucalyptus species. The role it played to curb the elastic wood demand in the region makes it a popular tree crop. Eucalyptus provides several products and services for the people of east Africa. It is the tree of choice for smallholder growers, because plantations can be established cheaply (minimum investment), it can be cultivated easily (simple management), it has a consistent market and its products fetch good prices. These benefits in general continue to enhance the expansion of eucalyptus in East Africa and make it one of the most widely planted exotic trees in the region.

The success of this species in the East African landscapes is not without limitations. The increasing interest of smallholder growers to cultivate this species complicates systematic eucalyptus management to minimize environmental impact. Due to multiple use of the species, growers favor mono-crop cultivation. Mono-crops are not only risky in case of species-specific disease outbreaks and insect infestations, but also exacerbate the negative effects on the environment. Despite the existence of longstanding and widespread local knowledge of eucalyptus species in the region, little has happened with regards to genetic improvement and productivity enhancement. Although eucalyptus is very popular among the growers, there is a valid concern over the tree's undesirable effects on the environment, which among others includes aggressive water consumption, nutrient uptake, exacerbating soil erosion, allelophatic effect and suppressing biodiversity.

However, the wide range of literature reviewed provides no rationale for banning eucalyptus planting altogether. An unbiased comparison of their benefits against the adverse effects they might induce favors their continued planting, but in such a way that their detrimental effects are minimized and the benefits are optimized. Decisions should be made on a case by case basis as each situation could be different and needs separate analysis because the environmental impacts vary with site characteristics. Generally, as long as wise management is put in place such as cautious site selection (proper species and site matching) and careful silvicultural practices (optimal stand density maintenance and mixed plantation options) eucalypts can be grown safely.

Wise decisions should be made about whether to plant eucalyptus, where to plant, how to plant and how to manage it, depending on the purpose of the planting. There are four important points to consider when evaluating the use of eucalyptus. 1) The demand for wood products is increasing with growing urbanization. Potential trees that can replace eucalyptus are not yet found. 2) The amount of eucalyptus plantations are doubling every decade and more and more smallholder farmers are growing eucalyptus globally and in East Africa. This seems to be an unstoppable trend. 3) Most of the counter arguments leveled against eucalyptus are from its adopted environment rather than its native environment. 4) Eucalyptus is not the only aggressive exotic species grown in East Africa with potential of harming the environment. Therefore, unbiased criteria should be used to compare eucalyptus with other tree crops or agricultural crops.

In doing comparative analysis it is important to: evaluate physiological characteristics of the crops and the environmental setup of the sites where they grow; identify the threshold area beyond which comparable crops have a damaging environmental impact; examine management conditions under which the crops are kept (mono crop or poly crop); take into account the conversion efficiency of the nutrients and water consumed to its useful products; examine the extent to which the resources (nutrients and water) are limiting; the preference and attitude of the producers in reference to the simplicity of growing eucalyptus; overall socioeconomic significance and impact.

In future endeavors, the choice of eucalypt species for plantations should be based on many criteria such as maximum wood production, ecological sustainability, marketability of the planted species, usefulness of the species to the local population, etc. 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 process should always involve the land users as they often have unique criteria beyond the obvious ones.

While the detrimental effects of eucalyptus such as nutrient and water depletion could be controlled through forest management techniques, including fertilization and regulated harvesting, the decision where to plant or on which land should take into consideration not only the technical feasibility, but also the need of the land users. As their consumption of nutrient and water increases with cutting cycles, for long-term site quality and sustainability of biomass production, prolonging the length of cutting cycles coupled with avoiding the recurrent litter raking may reduce the negative impacts. Also, planting density has significant implications not only on nutrient and water consumption, but also on the performance of understory vegetation which does not only affect the biodiversity of the system, but also runoff and soil erosion. Therefore, planting density should be determined depending on the purpose of plantation, and the agro-ecological circumstances of the target area. In general, it can be suggested that eucalyptus should be kept away from crop lands and sources of springs in water limited areas. Degraded lands such as gullies, quarries, pavements, etc can be planted with eucalyptus which has the potential of increasing the productivity of such areas. For larger scale plantations in the landscape, sufficient spacing should be provided to allow understory vegetation. Finally, encouraging mixed cropping (possibly with leguminous trees), avoiding short cutting cycles, avoiding litter racking and removal of understory vegetations and encouraging application of manure and other organic residues will give eucalyptus the advantage it needs to achieve its greatest potential economic benefits, all the while reducing the negative impact it can have on the environment.

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