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Eucalyptus in East Africa

Socio-economic and environmental issues

Gessesse Dessie, Teklu Erkossa

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For further information please contact:

Comment is welcome; please send any views to:
Walter Kollert, Planted Forests Officer,
Forest Management Team (FOMR), FAO,
Viale delle Terme di Caracalla, 00153 Rome, Italy
e-mail Walter.Kollert@fao.org

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Eucalyptus in East Africa

Socio-economic and environmental issues

Gessesse Dessie[1], Teklu Erkossa[2]

[1] Wondo Genet College of Forestry and Natural Resources, Ethiopia

[2] International Water Management Institute, Ethiopia

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List of Abbreviations

CADU	*Chilallo Agricultural Development Unit*
CDF	*Cartographie des Forêts 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*
R&D	*Research and development*
SIDA	*Swedish International Development Cooperation Agency*
UNSO	*United Nations Sudano-Sahelian Office*
USD	*United States Dollar*
WB	*World Bank*
WFP	*World Food Programme*
WPP	*World Population Policies*
WRI	*World Resources Institute*

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Executive summary

In September 2010 a Conference on *Eucalyptus Species Management, History, Status and Trends in Ethiopia* was held in Addis Ababa, Ethiopia, organised by the Ethiopian Institute of Agricultural Research. This document was one of the main position papers submitted to the meeting; it has been published within the series of Forest Management Working Papers of the Forestry Department of FAO in order to reach a wider audience and to promote discussion and comment.

Eucalyptus, one of the most planted genera of trees in the world, has been grown in East Africa for over a century and people in the region have thus accumulated important local knowledge of its management. The area of eucalypt plantations has now expanded greatly, so that today this genus dominates many rural and urban landscapes often because it suits the limited resources of smallholder growers and generally yields more money than other tree crops. Increasing demand for fuelwood and construction material has also created dependable markets for *Eucalyptus* products which have contributed to the steady expansion of its area in the region.

Studies conducted in east Africa and elsewhere show that the eucalypts are among the most preferred trees, as they grow fast and can survive in marginal environments. Its alleged negative environmental impact and inability to meet both production and service functions simultaneously has, however, often been controversial. At government level scepticism has thus grown to promoting it and in some drastic measures planting was even banned. Among the concerns are its inability to provide quality wood or services such as watershed or soil conservation, wildlife habitats and even recreational or aesthetic functions. Other controversies have related to its impact on the environment such as heavy use of soil water, thus affecting streams and underground water, its adverse effect of the leaf litter and soil humus, high consumption of soil nutrients, inability to prevent soil erosion, inhibition of growth of other plants in the understory and failure to provide food supplies or adequate habitat for wildlife.

The counter-arguments have included claims that the criticisms are not based on fact or emotional. Research reports show that the concerns are real, but are also equally applicable to other exotic trees. Solutions must be specific to each case and based on accurate appraisal of biological, physical and human factors. In East African countries, where there are huge gaps between the demand and supply of wood as a result of escalating deforestation, the use of fast-growing plantation species such as the eucalypts is inevitable as they are preferred to other species, either introduced or native, because of their fast growth and useful products. Thus, emphasis should be given by extension services and other advisers to supporting land users in selecting the right species for the right site and the desired purpose and in plantation management to minimizing drawbacks and optimizing benefits while continuing the search for alternatives.

Introduction

Eucalyptus, a genus of more than 500 species, has become the most planted genus of tree in the world (Demel 2000). The major planting of the eucalypts, outside its native environment of Australia, the Malaysian region and the Philippines, started in 1904 in Brazil. Today *Eucalyptus* plantations cover at least 12 million ha throughout the tropical zone, 90% of which have been established since 1955 (Turnbull 1999). The genus was introduced to East Africa in the late 19th and early 20th century and by the early 1970s the area of eucalypts in Ethiopia, Rwanda, Uganda, Kenya and Sudan had reached 95,684 ha (FAO 1979). The largest plantations at that time were in Ethiopia and Rwanda, at 42,300 ha and 23000 ha, respectively.

Concerns began to be raised around this time about possible negative impacts of these plantations on the environment, which resulted in banning their planting on farmlands, stream banks and catchments areas. Indeed, in 1913, not long after its introduction to Ethiopia, a directive was issued ordering the people of Addis Ababa to uproot half of the eucalypts planted in the town (Edy 2001). Similar worries have persisted even up to now in Ethiopia, Rwanda, Kenya, and Uganda (Jagger and Pender 2000; Nduwamungu *et al.*2007; Oballa *et al*. 2005).

Most criticisms are based on a range of technical, ecological and socio-economic arguments (FAO, 1988). According to Davidson (1989), many of the criticisms are unfair, biased, nationalistic or emotional. He noted that the criticisms would apply equally to other exotic trees planted in many countries; they are not peculiar to the eucalypts. On the one hand, the genus is highly popular with farmers as a cash crop but on the other hand the eucalypts are blamed for a great many evils, notably the drying up of water courses, suppression of other vegetation, a cause of erosion and adverse effects on nutrient cycling and soil properties (Munishi, 2009; Demel, 2000; FAO, 1988).

The alleged negative environmental impact of *Eucalyptus* is a global concern; FAO thus tried to provide unbiased views by commissioning several global, regional and country level studies e.g. Davidson 1985; FAO 1988. There seem to be three groups involved: growers, environmentalists and researchers. *Eucalyptus* growers obviously support its planting, while environmentalists, backed by agriculturists, emphasize the negative impact. Researchers, the third category, argue for a cautious and fair evaluation of the pros and cons.

The main arguments against the eucalypts include: 1) it drains water resources 2) it enhances soil erosion 3) it suppresses undergrowth 4) it depletes soil nutrients 5) it introduces allelopathic effects (Davidson 1985; FAO 1988; Demel 2000; Amare 2002; Nduwamungu et al. 2007). The arguments supporting the genus include: 1) it is a fast growing tree 2) it requires minimum care 3) it grows in wide ecological zones and poor environments 4) it coppices after harvest 5) it resists environmental stress and diseases 6) the seeds are easy to collect, store and no pre-sowing treatment is required (FAO 1979; Zerfu 2002; Mekonnen *et al*. 2007; Nduwamungu *et al*. 2007).

Several researchers question the concerns above, stating that:

- the arguments against the planting of the eucalypts 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 opposition has undermined the potential contribution of this tree to the livelihoods of smallholder farmers.

This study aims to address the following questions:

- What are the bases for the counter arguments?
- Are environment-centred arguments more important than socio-economic?
- Can we identify ways through which the impact (cost or benefit) of each of the species of *Eucalyptus* are analysed?
- By what parameters, or within what contexts, should the eucalypts be evaluated?

The various studies on the eucalypts were examined from the point of view of both their environmental and socio-economic impacts, to provide a balanced view for decision-makers, forest managers, environmentalists and growers. The method employed was 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) a description of the products and services obtained from this tree species c) an outline of the types of management d) a presentation of the environmental impacts on: climate, hydrology, soil, and biodiversity. Finally, concluding remarks and recommendations are provided.

Eucalyptus in East Africa

This section addresses the history of the eucalypts in East Africa, the reasons they were introduced and the trend of expansion and the existing area coverage. The East African region at present covers about 524 million ha with a human population of 218 million (Table 1) and supports a wide variety of forest and woodland types, ranging from moist forest types, including montane forests, to dry savannah woodlands. A dramatic decline in forest cover in eastern Africa along with a growing population means that timber, poles for building and wood for fuel are in short supply. To overcome this shortage, the region is increasingly turning to *Eucalyptus* plantations (ECAPB, 2006).

Table 1 Current population, land and forests of East Africa

Countries	General Description					
	Population (1)	Land (ha) (1)	Forest (ha) (2)	Natural forest (ha) (2)	Plantation forest (ha) (2)	*Eucalyptus* forest (ha) (3)
Ethiopia	83099000	122148000	4593000	4377000	216000	506000
Somalia	8699000	63754000	na	na	na	na
Djibouti	833000	231800	6000	na	na	na
Sudan	38560000	250000000	61627000	60986000	641000	23000
Kenya	37538000	58265000	17096000	16864000	232000	60000
Uganda	30884000	24103800	4190000	4147000	43000	11000
Rwanda	9725000	2633800	307000	46000	261000	102765
Burundi	8508000	2783000	152000	67000	86000	40000
Total	217846000	523919400	95102000	86487000	1479000	742765

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 of *Eucalyptus* in East Africa since different figures have been reported for the same country e.g. for Ethiopia there are at least two area estimates reported by Demel (2000) and Amare (2002), of 477 000 ha and 506 000 ha respectively. Secondly for some countries like Sudan and Uganda recent figures could not be found, while for others like Somalia and Djibouti no information was available. Additionally the reported figures seem to represent large-scale plantation and significant village/community stands. Huge numbers of trees exist in other land use types, such as homesteads, farm boundaries and beside roads. The area of these trees may not be easy to estimate and is often overlooked from estimates. During the authors' visits to Ethiopia and Rwanda, it was observed that many smallholders in rural and urban areas own a 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 at the beginning of the 20th century. The introduction of the eucalypts 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 the genus to Rwanda in the early 1900s to meet the increasing demand for fuelwood and construction wood. Eleven years later, harvesting of poles from first plantations was reported in the Southern province.

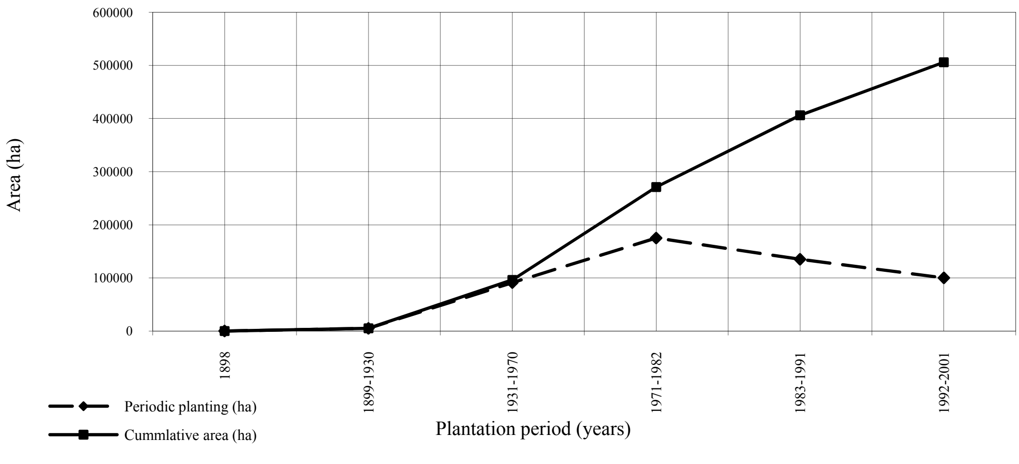
Ethiopia

In Ethiopia the genus was introduced during the reign of Emperor Menilek II (1868-1907) in 1894/95 (Von Breitenbach, 1961). The purpose was to supply fuelwood and construction timber to the new and growing capital city, Addis Ababa. In the 1970s, the plantation area around Addis Ababa was about 15,000 ha while in other parts of the country approximately 76,000 ha of plantations had been established. Between 1975 and 1994, further new plantations were established mainly in peri–urban areas with aid from international donors such as UNSO, SIDA, WFP, and WB (FAO, 2006). Currently, about 55 species of eucalypt have been grown in Ethiopia, of which between five and ten are widely planted. In Ethiopia, the most widespread species include *Eucalyptus camaldulensis, E. citriodora, E. globulus su bsp. globulus, E. regnans, E. saligna* and *E. tereticornis* (Friis, 1995); *E. globulus* and *E. camaldulensis* are the major species planted in the highlands of Ethiopia. *Eucalyptus* growing in Ethiopia is mostly confined to the highlands, where there are suitable moisture and temperature regimes. They are generally superior in their field performance to other exotics and native species, thus farmers plant large numbers of eucalypts, particularly *E. globulus*, on small areas of land and manage them to yield a variety of products, including leaves and small branches for fuel, poles and posts for house building and other farm uses. According to Demel (2000), many people in Ethiopia are absolutely dependent on the eucalypts as a source of fuel and house building material. The introduction of this species into Ethiopia was a success because of the huge gap between demand and supply as a result of escalating deforestation (Henry, 1973), and the introduction of a fast-growing, browse-resistant plantation species was inevitable (Tesfaye, 2009; Demel, 2000; Zerfu, 2002; Zerfu *et al.*) with *E. globulus* known locally as 'Nech-Baharzaf' or 'white Eucalypt, and *E. camaldulensis* known as 'Key-Baharzaf' or 'Red Eucalypt', being the species by Ethiopian most preferred by farmers (Minda, 2004; Amare, 2002; Zerihun, 2002; Gebre-Markos, 1998; Daba, 1998).

At the moment Ethiopia has the largest area of *Eucalyptus* plantations in the east Africa and is one of the 10 pioneer countries that introduced the eucalypts. Its cultivation has gradually spread throughout Ethiopia encouraged by 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 in Kenya (Oballa 2005) and about 55 cultivated in Ethiopia (Friis 1995). Some important *Eucalyptus* species grown in East Africa are listed in Table 3.

Figure 1: History of *Eucalyptus* expansion in Ethiopia since its introduction to the country



Source: Amare (2002)

Uganda

Eucalyptus was introduced to Uganda around 1912 to supply fuel wood for railways and administrative centres as well as to drain swamps in an attempt to reduce malaria. Now it is grown for a variety of uses including: fuel for tobacco curing; domestic and industrial energy (e.g. tea and sugar drying, baking, charcoal for steel and cement manufacturer); the provision of posts and poles for fencing and electricity transmission; building mud-and-pole houses; aesthetic use in towns; and for shelter belts in agriculture. By December 1975 there were 11,528 ha of eucalypt plantations in Uganda, not including small woodlots, and ornamental and road side shade trees. Soil has not yet been found to be a limiting factor to growing eucalypts in Uganda except that waterlogged soils must be drained before planting, and the drains must thereafter be kept in good condition (FAO, 1985).

Kenya

Kenya is a largely semi-arid country with forest cover of less than 2%. Kenya's forests have been shrinking primarily due to logging and conversion of natural forests to agricultural land. To counter the problem, Kenya established significant areas of tree plantations (Anonymous, 2003) and thus has extensive experience with planting the eucalypts, which were introduced to Kenya as early as 1902 with the aim of supplying fuelwood for the Kenya to Uganda railway (Oballa et al. 2005). Between 1903 and 1906 some 19 species were tried, with *E. saligna* and *E. globulus* being selected as the best yielding trees. With the decline in the use of fuelwood for the railway in 1948 conversion of the plantations to produce poles for power lines and telecommunication was proposed and there were attempts to use them for sawtimber. The eucalypts in Kenya have also been used in rural areas for fuel and pole production and for wind breaks. The total area planted in plantations up to 1973 was 11,296 ha, excluding wind breaks and avenues. The principal planting areas are in the highlands between 1800m and 2700m altitude and with a rainfall of 750 to 1800mm (FAO, 1985). *Eucalyptus* hybrids are now widely planted in the country. See table 2 for Kenyan experience with *Eucalyptus*.

Table 2: Kenyan experience with *Eucalyptus*

Species	Gro``wth characteristics	Ecozone	Application/use	Remarks
E. grandis	Alt 1400-2200m, Rain ≥1000mm	I, II, III	Transmission poles, timber, pulp, fuelwood	R&D developed fast growing, straight trees 45 m3/ha/yr
E. saligna	Alt 1600-2500m, Rain ≥1000mm	I, II, III	Transmission poles, timber, pulp, fuel wood	
E. globulus	Alt 2000-3000m, Rain ≥1000mm	I, II, III		
E. camaldulensis	Alt ≤ 1400m, Rain 600-1000mm, Poor saline soils & prolonged dry seasons	III, IV	Transmission poles, timber, pulp, fuel wood	R&D developed fast growing, annual height 4m
E. regnans	Alt 2500-3000m, Rain >1000mm, Tallest tree 90m, does not coppice	I, II, III	Eucalyptol, cosmetics, Timber, pulp	
E. paniculata	Alt 1600-2000m, Rain ≈1000mm straight stems, resistant to decay	III, IV	Transmission poles, sleepers, parquets, wood fuel	

E. maculata	Alt 1600-2000m, Rain ≈1000mm, wood heavy	II, III, IV	Ornamental trees, shade, heavy construction	
E. citriodora	Alt 1200-2000m, Rain ≈1000mm, Fast growth, good form & timber	II, III	Eucalyptol[1], timber	
E. Hybrids (GC)	Alt ≤1700m, Rain ≤1200mm Medium potential areas			R&D site matching for Ecozone

Source: Oballa and Chikamai, 2010.

Burundi

In Burundi the earliest planting of *Eucalyptus* commenced in 1931 (FAO 1979) in order to protect the remaining natural forests, reafforest hills and mountains, and to support agroforestry practices. This has resulted in significant contributions to the forest resource and the benefits from them. The eucalypts were among the principal tree species involved in the afforestation programme.

Rwanda

Eucalyptus species were introduced in Rwanda in the early 1900s and by 1911/12 harvesting of poles from the first plantations was reported at Save (Huye District, Southern province). Making up more than 60% of all plantations in the country, *Eucalyptus* has continued to dominate the landscape in plantations and woodlots (Nduwamungu *et al* 2007) and it is estimated that in 1989 there were more than 150,000 ha of eucalypt plantations and woodlots in Rwanda (Habiyambere, 1997; cited in Nduwamungu *et al* 2007). The major species encountered in woodlots and plantations include *E. grandis, E. saligna, E. globulus, E. camaldulensis, E. tereticornis, E. microcorys, E. maculata*, and *E. maidenii.* In Rwanda the *Eucalyptus* species were planted together with a number of conifers and some indigenous species. Despite its socio-economic benefits, *Eucalyptus* plantations in Rwanda have come under increasing criticism from politicians and environmentalists in relation to its alleged negative environmental impact, to the extent that it has been suggested that they should be uprooted and prohibited in the country (Gahigana, 2006; cited in Nduwamungu *et al* 2007).

Sudan

Eucalyptus plantations were introduced in northern Sudan to counter a shortage of fuelwood which arose because of increased loss of savannah woodland from its conversion to large-scale sorghum cultivation. By 1969 there were 7,560 ha of eucalypts, largely irrigated plantations of *E. camaldulensis* and *E. microtheca*, which are among the most important plantations of this species in the world. The soils on which these irrigated plantations were established were heavy, cracking clays with a high pH value (FAO, 1985). *Eucalyptus* plantations in Sudan have been encouraged in the past few decades as in other East African countries, though there has been some controversy.

[1] Eucalyptol has medicinal uses and is used in flavorings, fragrances, and cosmetics

Experience in other countries

The objectives of establishing eucalypt plantations in other East African countries such as Somalia, Eritrea and Tanzania have been similar to their neighbours: to supply the population with fuelwood, poles and other forest products and to supply industrial fuelwood for the mining industries.

By 1980 the total area of forest plantations in tropical countries was estimated to be about 10 million ha increasing at the rate of about 1.1 million ha yearly (FAO, 1988). Both the total area of plantations and the rate of increase grew considerably in the following years, as illustrated in Table 3 below which was based on a sample of 61 countries with significant areas of plantations.

Table 3 Plantation area 1990-2005, by function 1 000 ha

Region (countries sampled)	1990		2000		2005	
	Productive	Protective	Productive	Protective	Productive	Protective
Africa (58)	10 163	2 083	10 581	2 283	10 876	2 462
Asia (47)	28 925	17 666	36 206	19 459	44 414	20474
Europe (47)	17 942	4 588	20 997	5 591	21 651	6 027
North & Central America (37)	10 595	187	16 711	1 227	17 653	1 190
Oceania (24)	2 447	1	3 477	14	3 833	32
South America (15)	9 094	39	11 383	54	12 132	57
World	79 165	24 562	99 356	28 628	110 560	30 529
	103 727		127 984		140819	
Rate of change			90-00, 1.7%/year		00-05, 1.9%/year	

Source: FAO, 2006

Historically, *Eucalyptus* has been among the most planted genus of trees in the world and it was said that, with over 100 countries growing *Eucalyptus* in plantations, no other trees had been so widely propagated (FAO, 1988). By 2005 a global review of planted forests[2] (FAO, 2006) showed that worldwide the genus *Pinus* was the most generally planted, followed by *Cunninghamia*, then *Eucalyptus* and in fourth place, *Acacia*.

A large number of eucalypts have been planted throughout the tropics and sub-tropics but nine species appeared to be the most used: *E. camaldulensis, E. globulus, E. g randis, E. maculata, E. pa niculata, E. robusta, E. saligna, E. urophylla,* and *E. viminalis* (Friis, 1995). In East Africa it was said that over 100 species of this genus have been grown. The success and widespread cultivation of eucalypts is because of its ability to adapt to varied environments and ecosystems and the ease with which it can be cultivated and managed. Some of its advantages include availability and easy propagation of seed, relative ease of plantation establishment, tolerance of a wide range of environmental conditions, fast growth and efficient conversion of solar energy, wood of high specific gravity and calorific value, good coppicing ability, exceptional drought-hardiness, good economic returns, un-palatability of the foliage to livestock - or tolerance of browsing, and relative tolerance to diseases and pests (Davidson, 1989; FAO, 1988).

Planting rates of the eucalypts approximately doubled each decade until the end of 1980s and it was then expected that the area covered by eucalypts would increase to about 15-20 million ha by the end of the 20th century (Turnbull, 1999, cited in Demel, 2000). Despite the importance of the eucalypts in tropical and subtropical planted forests it is not known, however, what the global or regional area is of the genus.

[2] 'Planted forests' include both plantations and the planted component of semi-natural woodlands

Worldwide the main centres of *Eucalyptus* plantations were (and still are) in Brazil, India, China, South Africa, Spain and Portugal (FAO, 1992). It was introduced to these, and other, countries from Australia, where it is native, as well as from secondary sources in southern Europe and South Africa. Today, it is the characteristic feature of the rural landscape, and a very important aspect of smallholder livelihoods, in Burundi, Ethiopia, Kenya, Rwanda and Uganda. The most important growers of eucalypts 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 fuelwood for the towns of Debreberhan, Dessie, Gondor, Baherdar, Nazret and Addis Ababa. In Debreberhan alone UNSO invested over 3 million USD to plant 2 600 ha of eucalypts (Pohjonen and Pukkala 1990). 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 4 Some common *Eucalyptus* species grown in East Africa

Species	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. tereticornis						X	X	X
E. maculata							X	
E. regnans								
E. fastigata					X			
E. microcorys							X	
E. maidenii							X	X
E. robusta						X	X	X
E. viminalis	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

Socio-economic services

Although *Eucalyptus* plantations have faced controversies, country reviews of the situation in India, Australia, Brazil, Argentina, Spain, China, South Africa, Ethiopia, Kenya, Uganda, Tanzania and others revealed that, in general, planting of the eucalypts has increased and has helped to raise people's living standards by providing building materials, fuel wood, poles and farm timber (Munishi, 2009; Tesfaye, 2009; Chin Ong, 2003; Demel, 2000; Amare, 2002; Jagger and Pender, 2000; FAO, 1979). Eucalypt plantations have acted as a buffer against financial crisis for many poor farmers on land unsuited to sustainable agriculture and in many developing countries the area of private planting was much greater than that planted by government departments or industry. Furthermore, the plantations have increased job opportunities both in the plantations and in processing industries, (FAO, 1985).

In Ethiopia socio-economic evaluations of *Eucalyptus* have been carried out, mainly on *E. globulus* and *E. camaldulensis*. They showed that planting the genus made a substantial contribution to the income of a household, even more than agricultural crops did, especially where the indigenous woodland was degraded and the people were suffering from fuel shortages, water scarcity, erosion and land degradation (Tesfaye, 2009; Holden et al., 2003; Amare, 2002; Zerihun Kebebew, 2002; Jagger and Pender, 2000; Gebre-Markos, 1998; Daba, 1998). *Eucalyptus* plantations in the country expanded from state owned plantations to community woodlots and household compounds while in the degraded and drier parts of the country it has become the principal means of livelihood. Asaye (2002) reported that, on average, at least 26% of total family income came from such plantations.

Likewise, a socio-economic evaluation of growing *Eucalyptus* in Kenya indicated that at least 20% of total family income came from the sale of wood products from these plantations (Gustavsson and Kimeu, 1992). In terms of financial returns, *Eucalyptus* growing was next to tea, or even better if price declines occurred for tea. Similarly, in Tanzania and other East African countries, the eucalypts were among the major species grown under smallholder forestry, contributing significant quantities of building poles, firewood, charcoal, small timber, and cash (Munishi, 2009; FAO, 1985). A study on the role of *Eucalyptus* plantations in meeting wood requirements in its homeland (Australia) also showed that a number of fast growing eucalypts, established in plantations grown at rotations of less than 30 years, had considerable potential to provide valuable wood products such as sawn and veneer products (Waugh, 1995).

In general, the eucalypts have been planted for various socio-economic purposes in African countries such as Ethiopia, Ivory Coast, Kenya, South Africa, Sudan, Tanzania, Uganda, and Zimbabwe, as well as in India and Pakistan, Brazil, Ecuador, Paraguay and many other countries in South America, Israel and other Middle Eastern countries as well as in its native Australia. The economic returns from a wide range of *Eucalyptus* products are good: it is used for fuelwood, poles, construction materials, pulp wood, timber, raw material for many industrial uses, oil and medicine, tannin, for fibre and particle board, for honey production, for livelihood support and for employment among many other benefits (FAO, 2006, 2005, 1985, and 1979).

Social and economic problems have arisen from insensitive plantation establishment or unwise management, but many of those accounts that have been highlighted in the literature appear to be exaggerated and to ignore the benefits of the genus. In most developing countries in the tropics and sub-tropics, the clearance of trees for agriculture on marginal lands and for meeting firewood needs has caused environmental degradation made worse by lack of a national land use policy. Eucalypts offer the chance to ameliorate the situation if properly managed and implemented and in fact, the potential contribution of the genus has remained largely unexplored.

Ethiopian farmers who have been interviewed stated that they preferred to plant *Eucalyptus*:
1) for use at household level (construction, firewood, farm implements);
2) to sell;

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 eucalypts were: increasing demand for wood products; the unavailability of wood; their high rate of biomass production; ease of cultivation and adaptability; non-palatability to livestock; the decline in agricultural land productivity; and the decline in off-farm employment opportunities. The same study showed that *Eucalyptus* generated substantial income for rural households while in central Ethiopia *Eucalyptus* generated a quarter of annual cash incomes and seventy four per cent of firewood sold. Importantly, *Eucalyptus* yields better income than other exotic trees and even better than some agricultural crops (Amare 2002). *Eucalyptus* plantation projects have provided employment for thousands of unskilled labourers and in addition such projects have provided money for community development support such as roads, schools, health posts and flour mills.

Another important contribution of this tree has been security of tenure. *Eucalyptus* stands proved to be important guarantors for farmers who wanted to maintain the ownership of their rural land while living in urban areas (Amare 2002). Growers, by planting eucalypts, secured ownership of the land and at the same time kept the land productive while they were away. In addition, in Rwanda, banks have accepted eucalypt stands as collateral for loans. The genus has been very important in the construction industry of East Africa. The poles are used for scaffolding in the construction of high-rise buildings, bridges, dams, and roads.

Products and services

Table 4 lists some products and services of the eucalypts in east Africa. They can be used for fuelwood, 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). Fuelwood production has been the major objective of large-scale *Eucalyptus* plantations in East Africa (Nduwamungu et al. 2007; Oballa et al. (2005).

Table 5 Some of the known products of *Eucalyptus* in East Africa

Products and services of *Eucalyptus*	**Description**
Products	
Fuelwood	Domestic energy - probably the most important forest product in E. African countries – but also commercial energy.
Lumber	Only in Rwanda is lumber produced commercially, but at household level pitsawing is practiced e.g. in Ethiopia
Transmission poles	Almost all power and telephone lines, especially in Ethiopia, are *Eucalyptus*
Plywood	There are a few plywood plants e.g. in Ethiopia
Scaffolding	The construction boom in East Africa (skyscrapers, bridges, dams and roads) used *Eucalyptus* scaffolding
Building and fencing posts	Almost all wooden houses and fences were built from *Eucalyptus* in Ethiopia
Rail way sleepers (ties)	Important in the Kenyan and Ugandan railway construction

Medicine	Used as medicine in households and communities, e.g. in Ethiopia where *E. globulus* leaves used to treat common cold and flu'
Honey production	Flowers important for honey
Perfumery	Some commercial distillers e.g. in Ethiopia where essential oil produced from leaves of *E. globulus* and *E. citriodora*
Environmental services	
Nurse tree	Experience in Ethiopia showed some indigenous trees e.g. *Juniperus procera*, *Podocarpus falcatus* regenerated well under *Eucalyptus* stands
Environmental conservation	Planted for gully stabilization, soil conservation and strengthening road embankments
Socioeconomic services	
Economic	High value cash crop e.g. in Ethiopia about 25% of farmers' income from the eucalypts
Access to credit	In Rwanda eucalypt stands recognized as collateral for loans
Social significance	Owning eucalypt stand considered a sign of affluence/wealth
Land tenure	Farmers plant eucalypts to ensure land tenure/security
Livelihood	Contribute positively to income/food security as "green" bank account

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

Smallholder farmers both in Ethiopia and Rwanda have grown the eucalypts mainly for poles, fuelwood, construction wood, furniture-making and farm implements (Table 4). In Ethiopia according to Amare (2002) *Eucalyptus* trees are suitable for the two key functions, namely the construction of economical housing/fencing and for the fuelwood 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 6 Price comparison of some *Eucalyptus* products from Ethiopia and Rwanda, *c*. 2009

Products	Unit	Price Ethiopia (USD)	Price Rwanda (USD)
Construction wood	M3	25-30	Na
Fuelwood	M3	12-14	7-12
Charcoal	Kg	N.a.	0.2-0.4
Lumber	M3	N.a.	180-230
Transmission pole	Piece	5-8	10-15

Source: Rwandan data collected from wood markets in Kigali; Ethiopian data derived from price list of Arsi Forest Agency in south central Ethiopia.

Leaves, seeds and seedlings are sold in Ethiopia; in Addis Ababa selling leaves has supported the livelihood of several poor women.

Eucalyptus management

The yield of *Eucalyptus* and its environmental impact is greatly influenced by the type of management. Management outcome is determined by the objectives, the processes of propagation, silvicultural activities, and yield.

In Australia enrichment planting has been used to give mixed species plantations, and the broadcast sowing of seed (especially in older even-aged stands) has been practiced to maximize yield where seed may be in short supply (Jacobs, 2010). Experience from *Eucalyptus* plantation in Brazil showed that it was possible to double production by fertilizing and irrigating plantations in less fertile soils and it was possible to minimize the risk of some pests and diseases (e.g. ant and caterpillar infestations) through the introduction of broad genetic base in the breeding program (Lorentzen, 2001, cited in Christersson and Verma, 2006). In Kenya and South Africa, the introduction of hybrids or clonal eucalypts with even faster growth rates has raised concerns over susceptibility to insect attack or disease.

Objectives

Eucalyptus management is determined by the objectives set e.g. the silvicultural treatment to produce fuelwood is different from that for timber production. While the former aims for high volume, the latter aims for cylindrical and knot free stems. The spacing for fuelwood production is often closer than for timber production.

The scale of the plantation project (e.g. commercial or smallholder) also influences the management of the eucalypts. Commercial plantations are often established for fuelwood, pulp, particleboard, chipboard and extracts such as essential oil and medicines. In such plantations skilled staff are employed, clear functional prescriptions are in place and activities are financially intensive. Commercial plantations usually produce their own seedlings and employ technically advanced site preparation and harvesting techniques. On the other hand smallholder management is based on local knowledge (of site selection, seedling production, tending operations, harvesting and marketing) and is labour intensive. Farmers in Ethiopia have good knowledge and long experience - for example in southern Ethiopia farmers without access to extension services collect seeds, grow seedlings, and plant and tend the crop.

In both commercial and smallholder plantations, *Eucalyptus* is mainly cultivated as a single species. However, some smallholders growers mix *Eucalyptus* with fruit trees and forest trees. In Rwanda *Eucalyptus* may occasionally be planted in agro-forestry systems. In Ethiopia there are four types of smallholder *Eucalyptus* growers:

- those who plant few to several individual trees within their homestead;
- those who plant eucalypts in spare land near their farms, and road sides
- those who devote some of their land to farm eucalypts
- those who plant on leased land.

In comparison with agricultural crops and other tree crops smallholders in Ethiopia produce eucalypts cheaply (table 6). The seeds can be obtained locally, and fertilizers and chemicals are rarely required. With most agricultural crops farmers need to purchase seeds, and imported fertilizers and chemicals.

Table 7 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 or NGOs or bought cheaply.
Labour (site preparation, tending, harvesting)	The major sources of labour are family members and neighbours, with minimal cost
Time	Time devoted to cultivation is mainly during off-farm periods, often with little cost by using family labour.
Land	The cost of land is usually negligible; farm boundaries, road embankments, and degraded land often used
Tools	Existing agricultural tools are used for land preparation, tending and harvesting.
Finance	Smallholders financial investment may include cash for seedlings, employing tree cutters and transport fees.

Seed and nursery

Eucalyptus seeds are generally collected from dominant or co-dominant trees with the fruits being hand-picked either after felling or by climbing, and then air-dried. To ensure good viability the seeds are often stored in an air-tight containers at cool temperature. There is tremendous variation between species in the number of seeds per unit weight. For example the number of seeds of *E. camaldulensis* and *E. globulus* are 698 000/ kg and 78 000/ kg respectively.

The seed requires no pre-sowing treatment. In the nursery it can be sown in a seedbed or directly into containers/plastic pots. Nursery soils should include organic matter to improve water holding capacity, and sand to allow good drainage. After sowing the containers are watered regularly, preferably twice a day morning and evening to keep the containers moist but not sodden. The seedlings are protected from sunlight and rain although over-shading can make the seedlings susceptible to damping-off which may weaken or kill them. Before planting the seedlings are prepared for the field conditions by reducing water and pruning the roots.

Planting and spacing

Establishment starts with site clearance, and the removal of debris. Smallholders often prepare planting sites to agricultural standards with all competing weeds removed while commercial scale growers only dig holes for individual seedlings. The spacing for fuelwood is often different from the spacing for lumber production, with the former often at 2m by 2m (2,500 trees/ha) or even 1m by 1m (10,000 trees/ha) while the latter is generally between 2m by 2m (2,500 trees/ha) to 2.5m by 2.5 m (1,600 trees/ha). The spacing adopted by smallholders, however, in fact often ranges between 0.25m (160,000 trees/ha) and 0.5 m (40,000 trees/ha), which is markedly different from the recommended spacing for both lumber and energy production. The time of planting is preferably during the early wet season.

Coppice

Eucalyptus plantations may be standards or coppice. Most eucalypts have the ability to coppice which is the preferred management technique for biomass production. The crop is coppiced at intervals generally of less than 4 years depending on the size of material required, when an adequate supply of soil moisture exists. The preferred stump height to give the required number of coppice shoots is about 12 cm. Between one to three shoots per stump are usually left to develop. After 3-4 coppice rotations it has been found advisable to replace the coppice crop with seedlings. The frequency of coppicing is related both to the size of product required and the original spacing. For some species of *Eucalyptus* there is evidence that the coppice crop may give a substantially higher yield over single stems, of between 20% and 50%. Successful regeneration of *Eucalyptus* from coppice costs a small fraction of the cost of establishing the initial seedling crop.

Yield

Rotations of the eucalypts are usually between 5-25 years. For example in Ethiopia *E.globulus* has usually been harvested at 5-7 years for pole and construction wood while maximum wood production is commonly attained at 18 years (Pohjonen and Pukkala, 1990). Mean annual increment (MAI) of the eucalypts in Ethiopia range from $10m^3$/ha/yr to $57m^3$/ha/yr while MAI of conifers range from $4.2m^3$/ha/yr to $9.6m^3$/ha/yr. In contrast, the MAI of natural woodland is approximately $1.2m^3$/ha/yr (Pohjonen and Pukkala 1990; EFAP 1994). In Rwanda the rotation of the eucalypts has been 5-8, 10-18 and 20-25 years to produce fuelwood, poles, and lumber respectively.

Environmental concerns related to *Eucalyptus*

Okia (2009) has reported that the eucalypts have been blamed for many evils, including the drying-up of water courses, the suppression of other vegetation, erosion, and adverse effects on nutrient cycling and soil properties. These are serious accusations made by authors from many countries and they have even overshadowed the benefits of the eucalypts.

No single fact should be taken as sufficient evidence to promote or to discourage the planting of the eucalypts, though the results from a large number of studies taken together may yield valid generalizations (Jagger and Pender, 2000; FAO, 1988; Davidson, 1985). The environmental issues related to the growing of the eucalypts on farm land and near river banks has often been due not only to the genus as an aggressive user of water and soil nutrients but also due to high planting densities and short rotations (Amare, 2002). There is no question that trees in general and the eucalypts in particular utilize large amounts of water and nutrients, but the returns that can be realised in terms of biomass production per unit of input must also be considered.

Despite the diverse benefits provided by eucalypt plantations, especially in east Africa where most people depend on wood for construction and for fuel, there is lingering criticism. Most of the problems cited have related to its effects on the environment, including soils, water and biodiversity. Whether these criticisms are based on fact or arise from deliberate bias or even lack of accurate information may be questioned. In a summary report in which he reviewed much of the literature regarding *Eucalyptus* plantation in Ethiopia, Demel (2000) discussed the various aspects of what he called "adverse public reactions" against eucalypt plantations. His report stated that the trees are often accused of depleting soil nutrients, reducing soil water reserves, replacing natural forests and threatening ecological stability and diversity since they are often grown in monoculture. The adverse effects of their leaf litter on soil humus, their failure to control soil erosion – and sometimes even to cause it - the suppression of other vegetation under their canopy, and not providing food supplies or adequate habitat for wildlife have also been mentioned (FAO, 1988). Some of these criticisms may be related to expectations of the users that exceed the potential of the trees.

In this regard, Demel (2003) explains that the eucalypts have often been heralded as wonder species that would bring immediate solutions to local wood and erosion problems. Obviously, this rapid growth is necessarily associated with greater consumption of water and nutrients (Demel, 2003). When the eucalypts fail to perform as promised it may leave the local people with a resource which is little, if at all, better than what was there before the plantation and the blame often falls on the eucalypts rather than the real cause, 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 the eucalypts. Therefore, any balanced argument should compare the nutrient depletion to the outputs produced for each unit of water and nutrient consumed than the absolute amount consumed in isolation.

It is a 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 and since exotic trees have proved to be faster growing than native trees they have been planted 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 usually the genus considered in such situations, but the undesirable effects may not have been taken into account. This has been seen during field visits in different parts of the Ethiopian highlands, where farmers plant the eucalypts on degraded land by and large with success. However, these successes are not without problems as the issues of high water uptake leading to springs drying, and the suppression of neighbouring crops were acknowledged by all farmers interviewed. In line with this, as summarized by Jagger and Pender (2000) there are both negative and positive arguments in the literature about the genus (Table 8).

There are a large number of *Eucalyptus* species with widely varying properties, although only a few comprise the most popular plantation species. Their performance, including environmental effects, also varies widely. Besides, the effects of the same species may differ depending on site or soil or topography (Demel 2003). The needs of various users can also vary just as widely as the species and the nature of sites. Therefore, while some of the criticisms may be valid, judgments and solutions must be specific to each case and based on accurate appraisal of biological, physical and human factors (FAO, 1988).

Table 8 Some positive and negative effects of *Eucalyptus*

Aims/outcomes	**Positive**	**Negative**
Biomass production	Planting fast-growing eucalypts may be a good short-term option for the provision of biomass.	Land scarcity may be a constraint to wide-scale tree planting, although wasteland and degraded land generally available.
Soil improvement or prevention of erosion	On degraded hillsides and wastelands the net soil nutrient contribution of the eucalypts 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, but 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.	Allelo-chemicals negatively influence agricultural production and are a more significant factor in dry regions.

Hydrological impacts	In regions with erratic but sometimes heavy 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 decrease agricultural output as far as 10 metres away from the plantation edge. Wide scale hydrological impacts are uncertain.
Resistance to pests, pathogens and random disturbances	Some species of *Eucalyptus* have proved resistant to attack from some common 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 of no use to farmers who require livestock fodder.

Source: Jagger and Pender (2000)

Effects on Climate

Macro- climate at regional level

One of the criticisms against *Eucalyptus* plantations is that they may cause a change in the local climate. This is because of their very high evapo-transpiration rate, which may lead to a lower water table. This high rate of soil water loss is claimed adversely to affect local rainfall levels, resulting in possible desertification of the area. But others argue that the contribution of the land mass to the hydrologic cycle is 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).

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.

Some studies have shown that the microclimate within *Eucalyptus* plantations may be different from those of other species and from native forests, but the data are not conclusive (Poore and Fries 1985). In terms of their effects on regional rainfall or on other regional climatic parameters, however, 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

The effects of the eucalypts on micro-climate at local level are very well recognized. They 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).But 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 evapo-transpiration rate. Eucalypts cast less shade, on average, than other broadleaved trees, but there are big differences in the amount of shade cast by different species because they have different leaf sizes and orientations. The influences which are the result of shading can be manipulated based on need, by increasing or reducing the density of planting. Therefore, there is no reason to distinguish eucalypts from other genera with similar crown architecture regarding micro-climate at local level.

Shelterbelt and Windbreaks

Windbreaks are used to reduce the wind's force or velocity to benefit humans, plants, and animals in areas where wind speed is high. In dry areas prone to wind erosion, they may reduce soil erosion and limit dust storms. In cold areas, they can help reduce the wind chill. Some estimates show that homes can save about 30% of their heating and cooling costs with a windbreak, which reduces the effect of hot and cold winds (Santos, 1997).

Although any barrier can serve as wind break, effective and sustainable windbreaks can be selected based on some 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, and in California *Eucalyptus* windbreaks have been used to protect vineyards, nut and fruit trees, vegetables and grain. As Santos, 1997) 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.

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 have been few empirical studies that have addressed the issue of water use by the eucalypts and their direct effect on adjacent crop output, despite the abundance of subjective and unreliable examples. The general hypothesis is that high water requirements and characteristics such as deep root systems provide the eucalypts with a comparative advantage over other plants with respect to water usage (Jagger and Pender, 2006). Others have shown increased recharge after clearing previously forested areas where it was 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, whereas 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* species are planted in regions prone to drought as the trees may cause drying of the soil and water sources. These hydrological impacts of *Eucalyptus* are often described in terms of canopy interception, runoff regulation, water uptake, and soil moisture depletion, which are discussed below.

Canopy Interception

Among the most significant hydrologic effects of *Eucalyptus* plantations, as well as of other tree plantations or natural forest cover, is interception of rainfall. Some of the rainfall reaches the ground directly, through drip from the canopy, or through stem flow, while the remainder may be lost by direct evaporation (Lima 1993). When comparisons are made between forests and open areas, such as pastures and native grasslands, higher evaporation can occur in the forest, thus diminishing the water supply to the watershed.

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 on a six year old *E. saligna* plantation showed that 12.2% of rainfall was lost by canopy interception. This is comparable to the findings of Lima (1976) who reported that two 13 year old pine plantations (*Pinus caribaea* and *P. oocarpa*) had shown losses of 12% whereas 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), while the range in Amazonian rain forest was 8.9% (Lloyd *et al*. 1988) to 19.8%. *Eucalyptus* plantations appear to have lower interception losses compared with 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 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 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 climatic conditions, 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 (*E. regnans*) forest in a high-rainfall environment in southern Australia and analysed relationships between forest age and runoff. Old-growth forest yielded up to twice as much annual runoff as younger re-growth forest and the same was observed in a mixed-species forest in drier catchments. The driving mechanism behind this process is leaf area index, which was highest between the ages of 30 and 40 years (FAO 2002). These findings have important implications for the management of catchments used for water harvesting. For example, FAO has recommended long harvesting rotations to obtain maximum runoff yields.

Runoff volume depends also on the cover of the ground vegetation and litter. Wider spacing at planting and heavy thinning on steep and erodible slopes usually favour growth of vegetation under the tree canopy, which together with the accumulation of litter can help to reduce erosion. This was seen during the field visit to West Shoa in Ethiopia where the forest floor is covered with grass which arose because of the wide spacing of the stems, and it is thus used for grazing livestock. In this particular case, there was no evidence of soil erosion. Unfortunately, there is little or no concrete information regarding optimum spacing of *Eucalyptus* to encourage the development of the understorey or ground vegetation without compromising the productivity of the trees. It is believed that optimum spacing depends on the agro-ecological conditions and the species of the *Eucalyptus*, among other factors. Consequently, it is recommended that information for the various species growing in the different eco-zones of east African countries be acquired through research. In addition, terracing and other physical soil and water conservation structures can compensate for poor ground cover.

Effects on ground water

There is little documented evidence regarding the effects of *Eucalyptus* on ground water. The capacity of eucalypt species for water uptake must vary depending on the type of root system - some have superficial root systems while others are deeper rooted (Jacobs 1955). As in most natural forests and forest plantations, many roots are concentrated in the superficial layers of the soil (Reis *et al* 1985) but 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). Species chosen for plantations on watersheds where ground water depletion is a concern should thus avoid deep-rooted types.

Farmers in the highlands of Ethiopia believe that *Eucalyptus* plantations around water sources significantly affect the flow of springs. Some have witnessed the disappearance of springs, evidently due to *Eucalyptus* plantations, and as a result, the community has banned any further plantations around water sources such as ponds or springs. On the other hand, in some instances they have been used to drain marshy areas, which could otherwise harbour mosquitoes. This was witnessed during the field visit to West Shoa in Ethiopia, where farmers planted eucalypts on heavily waterlogged areas (Figure 5) or flood plains. The farmers in this region explain that *Eucalyptus* planted in such places grow very fast as they access soil water throughout the year. The claim that the estimated income that can be obtained from the sale of the crop which can be harvested every year can outweigh the benefits from other crops on the same plot.

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 shortages (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 may exacerbate the problem of competition for water. Perhaps the most controversial water-related issue relating to eucalypt plantations is the effect on soil water. It has been claimed that the eucalypts absorb more soil water than other tree species and indeed the results of two decades of research on the water use and water balance effects of trees in Kenya show that *Eucalyptus* does consume more water, especially during its early growing stages, compared to *Pinus* spp. The finding of this study has implications for water management, as well as forestry and agro-forestry practices in water-scarce semi-arid and arid regions.

As discussed earlier, the uptake of soil water depends mainly on the architecture of root systems and the depth of root penetration as well as stand density and soil and environmental conditions. The growth of eucalypt root systems depends also on factors such as soil compaction (Nambiar 1981). This has been verified for *E. urophylla*, *E. pellita*, *E. camaldulensis*, *E. grandis*, *E. cloeziana* and *E. citriodora* where only *E. citriodora* and *E. pellita* were able to develop fine roots to penetrate a compacted layer (Krejci *et al* 1986).

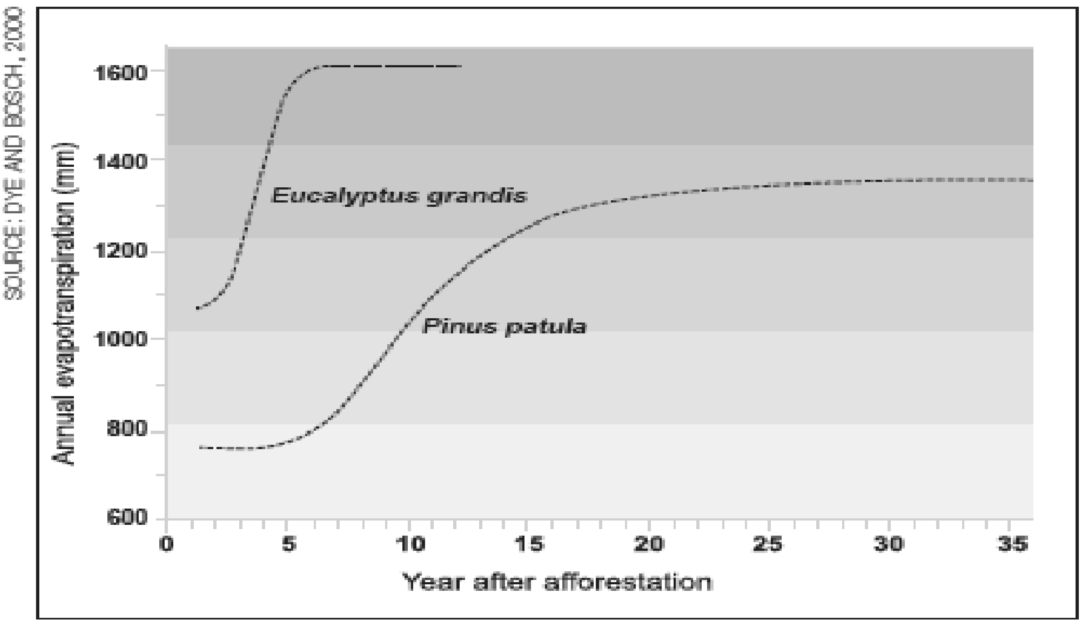
The leaf area of *Eucalyptus* plants is also another important factor affecting the rate of water consumption. Hatton et al. (1998) concluded that there was a strong linear relationship between tree leaf area and mean daily water use for a wide range of eucalypt species grown under similar climatic conditions. Myers *et al* (1996) arrived at the same conclusion for non water-limited situations, stating that species (including *Pinus radiata*) with unrestricted access to water had similar rates of water use at similar stages of canopy development. On the other hand, there is evidence that eucalypt species adjust their consumption to availability of water. According to Dabral and Raturi (1985) the maximum consumption of water by *E. tereticornis* grown in Dehra Dun (India) was during the rains (60%), followed by winter (26%), with the least during summer (14%). This implies that this species consumes more water when it is amply available and can cut its consumption when faced with scarcity. However, there is other evidence showing that *Eucalyptus* species may consume more soil water than it has been recharged by rainfall. The study of Dabral and Raturi (1985) concluded that over a period of 36 months water used was more than the rainfall received during the period, possibly at the expense of previously stored water.

Calder *et al* (1993) reported on research conducted at different sites in dry tropical climates. At one site, the water use of a young *E. tereticornis* plantation was no different from that of an indigenous dry deciduous forest but 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; that is 3,400 mm of water was used against 2,100 mm rainfall received in the 3 year period of study. During this time, rainfall was less than normal and yet at none of the sites was there any evidence of abstraction from the ground water. Assuming that the water consumption estimate was accurate, the source of the extra water was unknown. One hypothesis was that roots penetrated successively deeper layers while another hypothesis suggested by Dabral and Raturi (1985) was 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 MAI of 26, 16 and 6 tonnes per ha per annum respectively. Tree vigour 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 faster than the largest trees. It was assumed that the latter have utilized available water resulting in a reduction in their current growth (Boden, 1991) which corroborates previous reports that the overall use of water by the eucalypts is limited to the total rainfall regime of the area, in the absence of access to the water table (Gurumurti and Rawat, 1992). Extensive plantations of eucalypts in any deforested catchment will thus substantially decrease water yield from that catchment while the felling of such forests will increase it (Lima 1993).

The rate of water uptake by a *Eucalyptus* plantation depends also on its growth stage. 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 that observed in mature forest. *E. grandis* may take up almost twice as much water as *Pinus patula* during its first decade.

Figure 2: Water requirements of two evergreen species



Evapo-transpiration from *Eucalyptus* is also correlated with water availability. The average water loss of a well stocked eucalypt forest is probably around 1000 mm/yr for rainfall regimes above 1200 mm/yr but for drier regions, evapo-transpiration declines, perhaps reaching a value of 450 mm/yr when the rainfall regime is of the order of 500 mm/yr. For wetter regions, evapo-transpiration increases, eventually reaching a value of 1500 mm/yr for tropical eucalypt forests at lower latitudes. Comparative studies have shown average annual water use in pine plantations to be of the same order of magnitude as that observed in eucalypts. Thinning and selective cutting in mature eucalypts increased stream flow by an average value of approximately 400 mm/yr. The effect of clear felling on water yield was greatest in the second year after the cut.

Observations in Central India and in the foothills of the Himalayas indicate that, in regions in which large areas of *E. tereticornis* plantations have been raised, the level of water in wells fell until the plantations were about 6-8 years in age, at the culmination of MAI, and thereafter reverted to the earlier levels (Anon 1989). In the case of older plantations of *E. globulus* in the Nilgiris (India) no adverse effects were noticed on the hydrological cycle. The monthly evapo-transpiration of an *E. globulus* plantation in Portugal, with an average yield of 8-12 m^3/ha/yr on a rotation of 10-12 years was the same as that of a natural open stand of cork oak (*Quercus suber*) with an understory 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* species on soil moisture and water yield of a watershed depends not only on the root architecture, root depth and leaf area of the species but also on the age, climatic conditions and the management regime (including frequency of cutting of the plantation.

Water use efficiency

As discussed earlier, one of the criticisms of the eucalypts is their high water consumption but in comparing water use and nutrient consumption, one must take account not only the absolute volume of water consumed, but also the amount of biomass and other goods and services produced per unit of water consumed (Jagger and Pender 2000). In other words, the efficiency of water use must be taken into account as well as its abundance, and possible alternative species to provide the same benefits.
A study which compared soil moisture in 5 year old plantations of *E. grandis*, *P. caribaea*, and a savanna-like native forest showed a similar pattern of annual variation in soil water for all three (Lima *et al* 1990). In terms of timber production, however, the eucalypts used water more efficiently than the natural vegetation. In another study, the water use efficiency of *E. tereticornis* was compared to that of species of other genera, including fast growing *Albizia falcataria*, *Melia azadarach* and *Acacia auriculiformis* (Pudjharta, 1986; Tiwari, 1992). While the earlier findings were that *E. tereticornis* used 0.48-0.55 mm of water to produce one gram of dry matter under unrestricted supply of water, in rainfed conditions at Dehra Dun (India), only 0.122 mm of water was used under moisture-stressed environments, reconfirming its capacity to reduce water consumption at times of shortage.

Data related to water use efficiency of eucalypts grown in East Africa is limited. But from a study conducted in the Ethiopian highlands, Pohjonen and Pukkala (1990) reported that *E. globulus* converted energy and available water into biomass more efficiently when compared with exotic coniferous tree species. Therefore, although some species of eucalypts may consume more water than the indigenous forest or other plantations, which may lead to reduced water yield and leaves less available water for other crops growing in association with the tree, it is more efficient in terms of converting 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 ecosystems 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 reduced or no vegetation, are often cited as the major causes of soil quality deterioration. But fast-growing tree plantations may also lead to soil quality decline when they are poorly planned or badly managed. According to Jagger and Pender (2000), the impact of tree plantations upon soil resources has been very much debated and there is no accepted overall view, partly due to the fact that the impact depends on site and forest conditions.

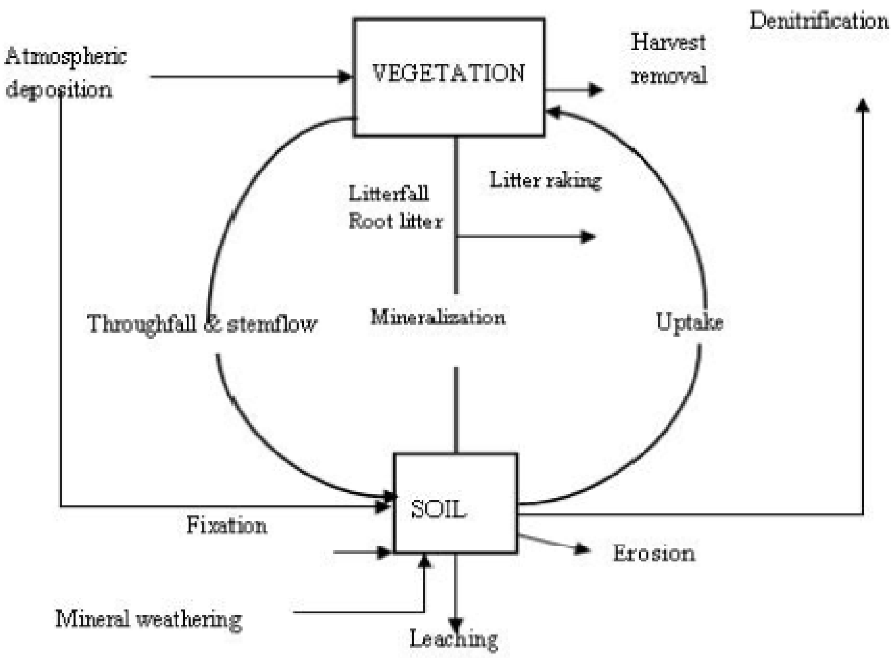
The effects of the eucalypts on soils have been studied in several countries over many years (Kindu *et al* 2006a and 2006b, Poore & Fries, 1985; Lugo *et al* 1990). Most of the concerns related to effects on soil quality deal with the depletion of nutrients and allelopathy caused by the litter, which is said to exert an antibiotic effect on soil micro-organisms, verified by research that showed a very low concentration of nitrifying bacteria in eucalypt plantations litter. 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). The effect often depends on the management regime of the plantation. For example, a significant soil quality change after clear felling and high intensity burning has been found in Australian *Eucalyptus* plantations. Under such management conditions, soil bulk density increased from 0.58 mg m^{-3} to 0.70 mg m^{-3}, while 3850 kg C ha^{-1} and 107 kg ha^{-1} N were lost.

A comparison made of 1 to 8 years old *E. tereticornis* plantations and natural mixed broad leaved forest in the central Himalayas showed a soil quality decline under *Eucalyptus*. Other studies indicated that various soil physical quality indicators decreased with increasing age of the plantations. In addition, soil chemical properties, notably organic carbon, and total N, P and K decreased as a result of reforestation with *Eucalyptus* and further decreased with increasing age. This is not specific to the eucalypts; plantations of first and second rotation Hoop pine (*Araucaria cunninghamii*) in subtropical Australia showed a declining trend for some soil basic properties with an increased number of cutting cycles. A study conducted on *Cunninghamia lanceolata* plantations in China reported decreases in soil microbial activity, deterioration of soil structure, depletion of soil nutrient storage and nutrient availability as the number of cutting cycles increased.

Nutrient cycling

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. The uptake of nutrients by plant roots, their incorporation into living tissue, and the release of nutrients from organic matter through decomposition causes nutrients to cycle within terrestrial ecosystems. Therefore, the nutrient cycling process involves: nutrient uptake and storage in vegetation in perennial tissues, litter production, litter decomposition, nutrient transformation by soil fauna and flora, nutrient input from the atmosphere and the weathering of primary minerals, and nutrient export from the site by harvest and other removals, leaching, erosion and gaseous transfers – see Fig. 6.

Figure 3 Schematic presentation of nutrient cycling processes in forest plantation ecosystems



When considering which tree species should be chosen for afforestation or agro-forestry, the depletion of soil nutrients is one of the most commonly cited criticisms associated with the eucalypts (Jagger and Pender, 2006). In contrast to other trees commonly used, such as *Leucaena* and *Acacia*, *Eucalyptus* species do not fix nitrogen from the atmosphere as the leguminous species do. Fast growing non-legume trees like *Eucalyptus* are therefore not recommended for intercropping with annual crops.

Among the other important factors that determine the nutrient status of soils under forest is species composition. According to some authorities, monoculture plantation forestry may affect soil chemical properties in two ways: nutrient depletion from the soil into the tree components, and change in the chemical status of the soil surface as the litter layer is dominated by leaf fall derived from one species. Forest management practices can aggravate or reduce the magnitude of these effects. For example, the nutrient cycle at a site can be improved by mixing *Eucalyptus* species with nitrogen-fixing species such as *Acacia*. Forrester *et al* (2005) have compared monocultures of *E. globulus* (E) and *Acacia 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 N concentrations of *A. mearnsii* litter, N content of annual litter-fall was at least twice as high in stands containing *A. mearnsii* as in *E. globulus* monoculture. Stands with *A. mearnsii* also recycled higher quantities of phosphorus (P) in annual litter-fall than *E. globulus* monocultures. Mixing *A. mearnsii* with *E. globulus* increased the quantity and rates of N and P cycled through aboveground litter-fall when compared with *E. globulus* monocultures and mixed-species plantations appeared to be a valid system to improve nutrition of eucalypts without fertilization.

Soil Nutrient Depletion

Species vary widely in their inherent nutrient requirements and use. Most of the environmental concerns about short rotation forestry management, such as that of *Eucalyptus* revolve around nutrient removal following harvest. There is 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, compared to slow growing forests and hence they deplete the nutrients on a site.

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. They showed the possibility of change in the chemical status of the soil induced by a plantation, but there have been conflicting reports in this regard. Some scientists have compared the nutrient status of soils under exotic tree species with those under indigenous juniper and natural forest soils, and have found that soils under *Cupressus* sp. and *E. globulus* generally had the lowest nutrient status (especially phosphorus and nitrogen). Indigenous woodland soils provided much higher nitrogen and phosphorus content in the above ground herbaceous plants, suggesting that nutrient cycling on sites dominated by exotic tree species is reduced.

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. Similarly, others have found that on moist sites where teak and *Gmelina* were planted, total exchangeable basic nutrients in the topsoil showed a decrease over those in the primary rain forest.

Whole-tree harvesting coupled with short harvest cycles may result in greater soil nutrient depletion than conventional forest harvesting. For example, if the felling cycle is long and if branches, leaves and bark are left *in situ*, the breakdown and build up in the nutrient chain was sufficient to maintain wood production 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, 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 ecosystem. For example, Kushalappa (1987) analyzed the nutrient status of a 12 year old *E. tereticornis* plantation near Bangalore (India). The inputs to the soil through weathering of the parent rock, litter, rain wash and root mortality out-balanced 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 and Varghese, 1991; 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.

The addition of fertilizers to *Eucalyptus* species 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 East Africa, where fertilizer application for food crops is still very low, this option remains impractical. Therefore, regulating the harvesting cycle at optimum rate could be an affordable alternative.

The impact of eucalyptus trees on the nutrient content of soils is shown in the poor performance of other crops grown in mixture with, or adjacent to, the trees. Studies from various regions in sub-Saharan Africa provide evidence of the negative impacts of *Eucalyptus* on agricultural production (Jagger and Pender, 2006). A study from Nigeria examined yields of maize, sorghum and groundnuts planted in pots with composite soil samples from 3 to 12 years old exotic tree plantations, namely Azadirachta *indica*, *Prosopis* spp, *E. camaldulensis*, and a control of surface soil from outside and adjacent to the plantations. After 60 days, yields of maize and sorghum were highest under *Azadirachta indica*, whereas groundnuts produced high yields under the control and *Prosopis* spp. For the three agricultural crops studied, the mean crop yield under *Azadirachta indica*, *Prosopis* spp. *Eucalyptus* and the control were 13.99, 8.32, 6.80 and 4.76 g/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 preferred as far as agro-forestry is concerned, but if planted with agricultural crops the spacing should be wide enough to reduce competition and the harvesting cycle should be long enough to allow regeneration of nutrients. The application of fertilizer could help mitigate the negative effects.

Nutrient use efficiency

Nutrient use efficiency can be estimated as the amount of aboveground net primary production per kilogram of nutrient taken up (Binkley *et al* 1992). As with water use efficiency, compared to a range of crops, the eucalypts can achieve a high biomass production on a low nutrient uptake. According to some sources, as little as one-half to one-tenth the nutrient uptake of most agricultural tree crops are required to produce a unit biomass. As a consequence, they can be successful on poor soils, even without fertilizer. Others have observed that N-use efficiency was higher for *E. globulus* than for *Acacia mearnsii* and the N- and P-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. mearnsii* fell. In other words, the nutrient use efficiency of *Eucalyptus* increased with the decrease of the availability of the nutrient in the soil. This is well understood by farmers, as witnessed during the field visit in the central highlands of Ethiopia where they suggested that *Eucalyptus* can be planted on agriculturally marginal lands where other crops are not economically feasible. Although this may not lead to optimum tree growth rate, in the long run it allows the productive use of degraded lands which may gradually be regenerated.

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 of 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 land degradation in the tropics. Trees can influence soil erosion mainly through intercepting rainfall which dissipates its kinetic energy. The rain drops that are intercepted eventually fall to the soil surface with reduced erosive energy, depending on the size and orientation of the leaves. Large leaves produce larger size droplets which have greater impact on the soil. Accordingly, erosive energy of rain under the crowns would be least for *Casuarina* spp. with

Acacia spp (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 the eucalypts. But even they have much smaller leaves than *Anthocephalus* spp. and very much smaller leaves than *Tectona grandis*, the last of which has been widely planted in tropical plantations in Asia. Consequently Jagger and Pender (2000) concluded that there is no evidence to single out the eucalypts for special criticism with regard to soil erosion. It has been hypothesized; however, that-long term exposure to allelo-chemicals may result in increased risk off soil erosion, which may have implications for sustainable land use over time (Jagger and Pender, 2006). Regarding the reduction of 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 is more important than the species of trees planted. Plantations of eucalypts have made significant contributions to soil and water conservation in China; data from Jingdong County show that after the establishment of eucalypt plantations, the density of soil decreased by 6%, and 99% of the mud and sand movement was intercepted. Hedge rows of *Eucalyptus* can be used as windbreaks with a significant impact on wind erosion in dry land areas.

Allelopathy

Allelopathy is the release of chemicals from leaves or litter that inhibit the germination or growth of other plant species (FAO 1985), and consequently reduce the output of crops. The allelopathic effect of *Eucalyptus* is among the issues dominating the agroforestry literature. Allelophatic exudates from *Eucalyptus* tree components have shown an inhibiting effect on undergrowth vegetation regeneration and growth (Poore & Fries, 1985). Allelopathic or phytotoxic compounds are known to be mainly phenolic acids (Glass, 1976; Rice, 1984) which are degraded over time, resulting in alleviation of the effect.

Eucalyptus leaves have been reported to contain phenolic acids, tannins and flavonoids and bioassay experiments with *Eucalyptus* litter extracts and leaf leachates have shown a high level of phytoxocity (Bernhard-Reversat, 1998). Soil bioassays have shown clear inhibitory effects on germination and growth of under-storey plants, particularly soils from *Eucalyptus globulus* and *Acacia melanoxylon* stands compared to *Pinus radiata* in Spain. However, much of the work mentioned in the literature lacks experimental precision, particularly controls and sufficient replication (Jagger and Pender, 2006). Most of the studies put forward as "evidence" for eucalypts being strongly allelopathic involve laboratory studies of extracts on germination of seeds or early growth of potted plants which may not accurately represent field conditions. Soil bioassay studies have been carried out with three agricultural crops: chickpea (*Cicer arietinum*), tef (*Eragrostis tef*) and durum wheat (*Triticum turgidum*) under laboratory and field conditions in the Ethiopian highlands. According to the findings, bioactive compounds from the decomposing litter of *E. globulus* did not affect the test crop seed germination nor root growth. However, a litter extract with 5% dry matter concentration significantly impeded germination and root growth of the tested agricultural crops. On a farm field experiment, declining barley yield was observed near a *E. globulus* plantation. Greenhouse and field experiments to examine the effects of *E. camaldulensis* and *E. grandis* on maize germination, nutrition and the growth of maize in Zimbabwe gave results which suggested that germination of maize under *Eucalyptus* leaf litter depended on the quantity of leaf litter applied to the experimental plot, and that there was evidence of a positive 'fertilizer effect' from decomposing leaf litter.

Field trials which compared sites in miombo woodland and a *Eucalyptus* plantation concluded that although significant variation in soil mineral content was observed, with less magnesium and potassium in the eucalypt soils, there was little evidence to indicate that allelopathic effects were significantly inhibiting maize growth. A study in Tamil Nadu, southern India, investigated the effect of aqueous extracts of freshly fallen leaves of *E. globulus*, raised along river banks. It was observed that the growth of weeds and grasses beneath these trees seemed inhibited, and thus the authors sought to study the effect of eucalypt leaf extracts on the growth of peanut (*Arachis hypogaea*) and maize (*Zea mays*) seedlings. Leaf area, plant height, and leaf chlorophyll content of both test species were significantly inhibited by the aqueous leaf extracts. Arising from this it has been suggested that *Eucalyptus* spp. release toxic allelo-chemicals into the soil system mainly through litter decomposition products.

Results evidently 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. Although it is likely that allelo-chemicals do accumulate in the soil, they are highly soluble and rainfall is likely to leach them out and the effects of allelopathy are thus likely negatively correlated with rainfall. It has been noted that allelopathic effects are more severe in low rainfall regions prone to soil erosion than in drier regions which 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 may more often be the result of strong competition for water and nutrients than allelopathy. Farmers in the highlands of Ethiopia linked this effect to competition for water and nutrients as noted during the field visit for this study.

Effects on Biodiversity

Some authors have indicated a negative impact of forest plantations on biodiversity but several studies have compared the composition of the undergrowth vegetation in plantations and natural forests 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 land use (agriculture, savannah, or native forest), uniformity of horizontal (spatial heterogeneity) and vertical (stratification), structural diversity of the overstorey, tree species and management regimes.

Studies indicate that single species *Eucalyptus* plantations have the potential to alter the diversity of plant and animal species across landscapes and it has been found that 26-32 years old plantations of *E. saligna* in Hawaii contained 42 species in the under-storey. In contrast, others found that afforestation of savannas with *Eucalyptus* facilitated the establishment of native forests. The use of the plantations by birds and mammals was also substantial, and varied with the tree species planted. In southern China, with the establishment of *Eucalyptus* plantations on barren land, the environmental conditions improved and the number of life forms increased. It was reported that 71 bird species lived in eucalypt plantations of Guiqi County, Jiangxi Province, more than in *Pinus massoniana* plantations.

Inter-cropping the eucalypts with other species, especially leguminous plants, may have advantages in establishing plantations which may include improvement in soil fertility, the reduction of insect and pest damage, water and soil conservation, all of which were observed in intercropping *Eucalyptus* with other species in China (Zhao Tingxiang *et al* 1990). It is concluded that the establishment of eucalypt plantations under responsible management should not degrade the environment, but combining them with other species, especially leguminous plants, may improve biodiversity over a single species plantation.

Pests and diseases

Although there are examples of diseases and pests damaging plantations of exotic species, it appears that removing eucalypts from their natural enemies has generally resulted in good performance (Wingfield *et al.*, 2008). Not surprisingly, both the incidence and impact of diseases and pests in eucalypt plantations has increased over time often due to the accidental introduction of pests or pathogens from areas where the trees are native to new environments. There are also increasing numbers of examples of host-specific pathogens native to areas where the eucalypts have been planted as non-natives, which have undergone sometimes surprising host jumps. These 'new pathogens' threaten not only plantation forestry based on non-native species, but also the eucalypts and their relatives in areas where they occur naturally. Pests and pathogens seem set to challenge eucalypt plantation forestry worldwide, so in order to sustain profitable businesses based on eucalypt plantations, forestry companies will need to invest substantially in technologies to manage these pests and diseases. East African countries particularly need to learn from other countries to cope with the threats to *Eucalyptus* plantations in the region.

Disease surveys conducted on *Eucalyptus* species in East Africa, notably in Kenya, Malawi, Mozambique, Tanzania, and Zambia have found cankers caused by *Chrysoporthe* spp. *Botryosphaeria* spp. and *Coniothyrium zuluense*; leaf and shoot diseases caused by species of *Mycosphaerella* and *Cylindrocladium*; and root rot caused by *Armillaria spp.* (Roux *et al* 2005). Some of these diseases can cause serious economic losses, so that forestry companies and organizations in eastern and southern Africa will need to re-vitalize or establish breeding and selection programmes to identify disease-tolerant stock. The preliminary surveys reported here provide a basis for the establishment of an African tree health network.

A survey of the diseases of exotic trees in plantations undertaken in southern and south-western Ethiopia ascertained the occurrence and distribution of diseases of major plantation species and recommended further research. Stem cankers associated with *Botryosphaeria* sp. were common on *Eucalyptus globulus, E. saligna* and *E. citriodora* . Stem canker disease associated with a *Coniothyrium* sp. was commonly observed on *E. camaldulensis.* Leaf blotch associated with *Mycosphaerella* sp. was common on *E. globulus* in most areas where it is planted. In addition, Pink Disease caused by *Erythricium salmonicolor* on *Eucalyptus* was recorded in some plantations. This is the first general evaluation of plantation diseases in Ethiopia, which provides a foundation for future planting and disease management strategies, with a view to enhancing commercial timber production (Gezahgne et al., 2003). Moreover, results of a study and a prior survey in 2000/2001 in Ethiopia have shown that canker caused by *Botryosphaeria parva* is the most common disease of *Eucalyptus* in Ethiopia, affecting all the major *Eucalyptus* spp. including *E. globulus, E. grandis, E. saligna* and *E. citriodora* (Gezahgne *et al*. 2003). This is the first report of this fungus from Ethiopia.

Another report from Kenya indicates that an exotic pest, identified as a gall-forming wasp, the Blue Gum Chalcid *(Ophelimus eucalypti)*, is currently threatening plantations in Western Kenya. Its origin is Australia, and it has also been attacking *Eucalyptus* spp. in Morocco, Iran, Israel and Italy (Anonymous, 2003). Table 8 summarises some of the diseases and pests reported on the eucalypts.

Table 9 Some diseases and pests reported on *Eucalyptus* species

Disease type and name		**Cause**	**Signs**	**Hosts**	**Occurrence**
Viral disease	Mosaic	*Spherical virus*	White, irregular patches	*E. tereticornis, E. citriodora, E. macrorhyncha*	India, Zambia
Phytoplasma disease	Little leaf	*Phytoplasma*	Smaller leaves, pale colour & scaly	*E. tereticornis, E. citriodora, E. grandis, E. microtheca*	India, Sudan, China
Bacterial disease	Bacterial wilt	*Burkholderia solanacearum*	Leaf drop, death of stems, and reduced growth rate	*E. camaldulensis E. citriodora, E. grandis, E. saligna*	Tropical, sub-tropical and warmer temperate regions of the world
Fungal diseases	*Cylindrocladium* leaf spot & blight	*Calonectria sp.*	Leaf spots & shoot blight	Wide range of *Eucalyptus* sp.	Brazil, India, South Africa, Vietnam
	Eucalyptus rust	*Puccinia psidii*	Yellow-golden uredinial pustules on branches	Potentially all *Myrtaceae,* incl. Eucalypts	Brazil, Taiwan, south Africa

	Botryosph-aeria canker	*Botryosph-aeria sp.*	Death of tops, discolored wood	*E. camaldulens., E. globulus, E. grandis, E. saligna*	Australia, South Africa, USA
	Pink disease	*Corticium salmonicolor*	Bark cracks, terminal shoot death	*E. alba, E. grandis, E. tereticornis*	Tropical & sub-tropical Africa, Asia, America, India
Insects	Blue gum chalcid	-	Formation of galls	*E. globulus*	Australia, New Zealand
	Gum tree scale	-	Dieback	*Wide range of eucalypts*	Australia (native) New Zealand

Source: Ciesla et al. (1995)

Conclusions and Recommendations

The introduction and expansion of plantations of the eucalypts in East Africa was largely due to the loss of native forests and the consequent wood deficit, decreasing farm areas and the increasing urbanization and the mounting need for construction material. There was thus a strong demand for a fast-growing tree species.

The properties of fast growth and easy establishment in East Africa have made the eucalypts a popular tree crop for over one hundred years to meet demand for many products and services, and have created a strong local knowledge of the various species. It is usually the tree of choice for smallholders, because plantation can be established cheaply, it can be cultivated easily, it has reliable markets and the products fetch good prices all of which continue to encourage the expansion of the eucalypts in East Africa and make it one of the most widely planted exotic trees in the region.
The success of this genus in the east African landscapes has not been without problems, however, which include its popularity which complicates systematic *Eucalyptus* management to minimize environmental impact. Due to multiple uses of this tree species, growers favour single species cultivation which are not only risky in case of species-specific diseases outbreaks or insect infestations, but also exacerbate the negative effects on the environment. Despite the existence of longstanding and widespread local knowledge of *Eucalyptus* species in this region, little genetic improvement or productivity enhancement has been done. Although it is very popular among the growers, there are valid concerns over the its effects on the environment, which include aggressive water consumption and nutrient uptake which may lead to soil erosion, and to its allelopathic effects and the suppressing of biological diversity.

The wide range of literature reviewed in this study provides no reason for banning *Eucalyptus* planting altogether. A comparison of their benefits against the adverse effects they might cause shows that their planting should be continued, but in such a way that their detrimental effects are minimized and the benefits are optimized. Decisions should be made case by case, as each could be different and need separate analysis because the environmental impacts vary with site characteristics. Generally, as long as wise management is practised, including the proper matching of species to site and careful silvicultural practices are carried out, such as optimal stand density and the consideration of mixed plantation options, eucalypts can be grown safely.

The costs and benefits of planting fast-growing trees including *Eucalyptus* need careful assessment based on detailed site studies with due consideration to both environmental and socio-economic needs. The literature reviewed on the environmental impacts of the eucalypts found that these effects are complex, mixed, and dependent upon local conditions. Site factors will include the amount and availability of rainfall, soil moisture capacity, the risk of excessive runoff and erosion, the scarcity of land and biomass, and the alternative sources of timber and energy available to households. It is not advisable to make decisions about the use of the eucalypts based on consideration of only the negative or of the positive impacts, or without also considering the reasons why poor households choose to plant these trees and the economic impacts that they trees may have on livelihoods. The main factors influencing households' and communities' decisions to invest in the eucalypts or other trees are the costs and returns on their investment, including the opportunity costs and availability of land, labour and other inputs; the cost and availability of the seedlings; the rate of growth of the trees; the price (or local scarcity, if not marketed) of poles, fuelwood and other products; the discount rate of households; and the institutional factors affecting the ability of households to receive benefits, the distribution and timing of benefits and costs; and the ability to attain effective collective action (especially for community woodlots).

Wise decisions on whether to plant *Eucalyptus*, where and how to plant it and how to manage it, depend on the purpose of the planting. It is important to consider the following facts in reaching a decision: 1) The demand for wood products is increasing with growing urbanization. Potential trees that can provide the benefits given by the eucalypts have not yet been found. 2) The area of *Eucalyptus* plantation is doubling every decade, and more and more smallholder farmers are growing globally and in East Africa. This seems unstoppable progress. 3) Most of the counter argument leveled against eucalyptus is from its adopted environment than its native environment. 4) *Eucalyptus* is not the only aggressive exotic species grown in east Africa with the potential to harm the environment. Therefore, unbiased criteria should be used to compare *Eucalyptus* with other tree crops or agricultural crops.

In making a comparative analysis it is important to 1) evaluate physiological characteristics of the crops and the environmental conditions of the sites where they grow 2) identify the threshold area beyond which comparable crops can cause environmental damage 3) examine management conditions under which the crops are kept, such as single or mixed species 4) take into account the conversion efficiency of the nutrients and water consumed to useful products 5) examine the extent to which the resources (nutrients and water) are limiting 6) the preference and attitude of the producers e.g. simplicity to grow *Eucalyptus* 7) overall socioeconomic significances.

In future evaluation, the choice of eucalypt species for plantations should be based on several criteria including maximum wood production, environmental sustainability, marketability of the product, 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 their own criteria.

While the detrimental effects of *Eucalyptus* such as nutrient and water depletion can be controlled by 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 consumptions on 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 implication not only on nutrient and water consumption, but also on the performance of understorey 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 may enable the productive use of such areas. For larger scale plantations in the landscape, sufficient spacing should be provided to allow understory vegetation. Also encourage mixed cropping (possibly with leguminous trees), avoid short cutting cycles, avoid litter racking and removal of understory vegetations and encourage application of manure and other organic residues.

Conclusions based on Ethiopian knowledge

The controversies surrounding *Eucalyptus* in Ethiopia have attracted several policy debates, scientific literature and workshops, both national and regional. Two national workshops have been organized since 2000

1) *Eucalyptus Dilemma*, November 15 2000 and

2) *Eucalyptus Species Management, History, Status and Trends*, September 15-17, 2010.

The papers presented to on either side of the debate often failed to address the complexity of the issues, or lacked completeness, scientific rigour or rational assessment. For example, among the 30 papers presented to the 2010 workshop desktop and interview based studies accounted for 60% while the remainder reported field and laboratory experiments. In this literature research and interview dominated work where over 10 local level researches based themes are covered conclusions reached appear far reaching.

All papers agree that at the moment there is no other genus or species as productive, well-adapted or requested like the eucalypts. Nearly all of the papers reported that the rate of adoption, amount of goods and services and level of importance of this species are high. A village level study in central Ethiopia showed that 100% of the inhabitants grew *Eucalyptus*, 20-30% of their income is from the eucalypts and over 20 years the price of *Eucalyptus* grew 15 times. Another village study in south central Ethiopia revealed that all of the construction is with *Eucalyptus* poles, 20% of the charcoal is derived from the wood, 93% of other wood products come from the eucalypts and the genus supported 78% local market economy.

The only two studies dealing with wood property and disease aspects indicated that the wood has high quality with the potential to replace endangered tree species in Ethiopia, and the identified diseases have potential adverse effect on the growth and yield performance and wood quality. Most studies related the alleged adverse effects of *Eucalyptus* arising from poor plantation management techniques such as density, coppice management, harvesting intensity and species selection. Excessive loss of micronutrient was found to be directly proportional to intensity of biomass removal, while intercropping and undergrowth vegetation are negatively affected by high planting density. Unlike uncharacteristic nurse tree services a study here showed coffee grown under *Eucalypts grandis* has no significance difference of been size and test with natural forest. Additionally *Eucalyptus* has shown no allelophatic impact on the regeneration of an Olea specie. Similarly a study made in a green house has shown that *Eucalyptus camaldulensis* has a positive phytoremediation service to chromium based toxic chemicals. Another study has shown, *Eucalyptus globulus* perform well on degraded land with 95% seedling survival percentage at the same time provide high income. A regression analysis based study from this workshop reported that in stem wood contain 82-86% of the total *Eucalyptus* tree. Studies regarding oil extraction from eucalypts show that green leaves contain the most oil extracts and maximizing leaves production are recommendable objective.

The underlying conclusions of the papers address local communities' interest and preference, the nature of the controversies, potential for cloning and way ahead.

- *Eucalyptus* growing helps local communities to diversify their farm income, increase their farming systems productivity and sustainability. Despite the knowledge of farmers about the negative ecological impact of *Eucalyptus* they continue growing this species.
- Divided opinions exist among *Eucalyptus* stake holders. While growers prioritize Eucalyptus for its economic benefits, experts denounce it for its alleged negative ecological impact.
- Propagation by cutting can yield clones with desirable threats, however, carful screening is necessary not to favor unfavorable varieties
- The divided interest, controversy around this species call for scientific understanding and empirical data based decision making.

Recommendations

The following recommendations are drawn from environmental and socioeconomic lessons drawn from literature around the world. See figure 9 for simplified recommended guideline regarding management prescriptions to address major concerns about *Eucalyptus* plantation.

Data collection and analysis

- This study has been, of necessity, based on incomplete, outdated and often unreliable data. It is not known, for example, the area of the genus *Eucalyptus* grown as an exotic species outside its country of origin. There is an urgent need for national forest services to improve this situation, both in their own interests and to give a better region-wide view.

Management

- There is need for better education of farmers, and other stakeholders, in the selection of the best phenotypes for seed collection.

- Fewer trees per unit area should be planted, and existing plantations should be thinned to reduce the water consumption needed by eucalypts in areas where water is scarce or demanded by other crops.
- Arising from the recommendation above, there is need for research on the optimum spacing of eucalypt plantations for different purposes, to ensure soil protection and the development of understorey or ground vegetation without compromising the productivity of the trees.
- The foliage and bark of eucalypts should be left on the plantation floor after harvesting to minimize the impact of *Eucalyptus* plantations on soil nutrients
- There should be wider spacing between trees to allow ground cover or agricultural crops to develop.
- Comprehensive research is required before undertaking projects to determine impacts on soil nutrients, water, hydrology, wildlife and biodiversity
- Native forest or even secondary regrowth should not be cleared to make way for *Eucalyptus* plantations
- *Eucalyptus* could be tried in mixed species systems, using indigenous tree species and vegetation to minimize adverse impacts on biodiversity and wildlife

Socio-economics

- The introduction of a eucalypt species should be done only with the concurrence of the local community involved.
- Tree planting should not be planned in isolation of market forces and care should be taken to ensure that there is a clear understanding of tree and land tenure.
- Efforts should be made to secure land tenure for local communities in a given project area. If this is not feasible, then tree and land tenure should be clearly defined.
- Community needs in a given project area should be determined, and projects should address a number of these needs rather than a single need identified by project managers.
- Particular attention should paid to the needs of landless people, whose former access to the areas selected for reforestation could be curtailed by the planting programme.
- Clear project objectives which are not in isolation of market forces or political or community needs should be determined. Project objectives should be dynamic and flexible.
- Communities should be consulted and informed both before a project begins and during the actual implementation of the project
- Communities should participate in decision making and project implementation.

Table 10 Si mplified recommended guidelines for management prescriptions to address major concerns about Eucalyptus *plantations*

Management prescription	**Major concerns regarding *Eucalyptus* plantation**			
	Water depletion	**Soil degradation**	**Biodiversity loss**	**Undergrowth inhibition**
Species election	Choose appropriate species.	Plant appropriate species on gullies	Select nursing species.	Choose appropriate species
Planting density	Determine optimal spacing density	Promote wide spacing	Create several canopy levels	Avoid high plantation density
Planting diversity	Promote mixed plantation	Limit monocrop plantation	Avoid monocrop plantation	Promote mixed planting
Site selection	Avoid planting near water sources	Avoid vulnerable sites	Avoid planting on farmlands	Limit *Eucalyptus* in biodiversity area
Rotation period	Carefully determine rotation periods	Increase rotation period	Increase rotation period	Increase rotation period

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