Swedish University of Agricultural Sciences
Faculty of Forest Sciences

Department of Forest Products, Uppsala

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Examiner SLU: Jan-Erik Nylund

Dedication

This report is dedicated to my parents Mr. Justine Opeero and Mrs. Clementina Opeero Alokait.

Abstract

A literature review on the alternative management regimes of eucalyptus; policy and sustainability issues of smallholder eucalyptus woodlots in the tropics and sub-tropics was carried out in autumn, 2011. The aim of the study was to review alternatives to the traditional management regimes under which smallholders in these areas produce eucalyptus and policies in Kenya affecting this production. Meta study was used to collect information to assess the differences in understory plant species between eucalyptus species and other commonly used tree species. It was reviled that weeding at establishment, incorporation of rice and beans, N and P fertilization and slash residue management have the potential to increase the mean annual increment of eucalyptus species depending on site and climate conditions. However, understory species diversity was less in these alternative management regimes compared to the traditional practices. The number of understory plant species in the plantations of eucalyptus species was in general higher compared to that in stands of other commonly used plantation tree species. Thus, it cannot be concluded in line with other studies that eucalyptus does in general decrease biodiversity in the under growth as compared to other commonly used plantation tree species in the tropics and subtropics. Policies in Kenya prohibit establishment and production of trees, in particular eucalyptus, in wetlands or nearby water bodies, levy land tax promote co-generation of energy and give a special consideration to indigenous trees. Legislation and policies of different sectors related to trees and forest work to achieve and maintain forest cover of at least 10% of Kenya's total land area and work against processes and activities that endanger the environment. However, the same legislation may lead to a decrease in tree production and forest cover in Kenya as it limit farmers possibilities to plant and produce trees and in particular eucalyptus. It is argued that this will affect smallholders as small woodlots, in most cases consisting of eucalyptus, serve to cover many of their important needs. In general, it can be concluded that much as these alternative management regimes enhance productivity of eucalyptus woodlots, the challenge for the small-scale farmers is how to manage them sustainably. Therefore, forest policies that take consideration of increasing production of eucalyptus and managing biodiversity with reference to these alternative management regimes should be developed in Kenya.

Keywords: *management regimes, production, understory, eucalyptus, nitrogen- fixing tree species, policies, legislations, smallholders, tropics, sub-tropics*

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With great pleasure, I would like also to extend my sincere thanks to my family and friends, especially for their moral support, advice and encouragement offered to me in the different situations.

Moses Otuba

Table of Content

List of Acronyms

CIFOR:	Center for International Forestry Research
EAWS:	East African Wildlife Society
FAO:	Food and Agricultural Organization
FRA:	Forest Resources Assessment
GoK.	Government of Kenya
ICRAF:	International Centre for Research in Agroforestry
ICUN:	International Union for Conservation of Nature and Natural Resource
K:	potassium
KEFRI:	Kenya Forestry Research Institute
KFS:	Kenya Forest Service
KFWG:	Kenya Forest Working Group
KLR:	Kenya Law Reports
KSHS.	Kenyan Shillings
MOE:	Ministry of Energy
MOENR:	Ministry of Environment and Natural Resources
MOL:	Ministry of Lands
MOLHUD:	Ministry of Lands, Housing and Urban Development
N:	nitrogen
P:	phosphorus
SLU:	Swedish University of Agricultural Sciences
ULRC:	Uganda Law Reform Commission
UNEP:	United Nations Environment Programme
WMO:	World Meteorological Organization
n.d:	no date

Unit of Measurements

ha:	hectares
mm:	millimeter
Kg:	Kilogramme
MW:	MegaWatts
ton:	tonne
yr:	year

1 Introduction

1.1 Background of the Study

Plantation forests are man-made forests that differ greatly from natural forest ecosystems in terms of their structure and functions (West, 2006). While the area of natural forests is shrinking, that of plantation forests is expanding at a rapid rate and dominates the landscape in some regions of the world. A study conducted by Global Forest Resource Assessment 2010 reports that the global area of planted forests and trees has increased by 7% (264 million ha) between 2005 and 2010 (FRA, 2010). Most of these forests were established through afforestation i.e planting non-forested areas in recent times. China had the largest total area of plantation forests with approximately 77 million ha in 2010, followed by United States at 25 million ha, the Russian Federation (17 million ha), Japan (10 million ha), and Canada with about 9 million ha (FRA, 2010). It is therefore clear that the plantation forests are here to stay because they represent a very efficient production system for a much needed renewable resource.

The establishment and expansion of plantation forests in the tropics and sub-tropics is based mainly on exotic tree species, for example Eucalyptus and pine managed in short rotations in the tropics and sub-tropics. During harvest, large quantities of nutrients are removed gradually exhausting the soil of plant nutrients particularly in high rainfall areas. Therefore it has been claimed that these fast growing plantations are unsustainable (Nambiar, 2008; Laclau *et al*., 2010). The silvicultural challenge therefore is to design and use management regimes that target high growth rates and wood quality without compromising sustainability. It has been and still remains possible to identify practices that enhance production sustainably such as harvest residue management, weed control, soil cultivation, coppice management, thinning, pruning, and legumes intercropping among others (Mendham *et al*., 2003; Goncalves *et al*., 2004).

Residue management in fast growing plantations during inter- rotation period can influence the availability of plant nutrients in the soil and the sustainability of future rotations on highly weathered tropical soils (Tiarks and Ranger, 2008). The wood production and economic benefits of managing weeds during establishment have been demonstrated for the fast growing plantations (Silva *et al*., 1997; Wilkinson and Neilson, 1990; Little, 2002). Weeds interact with residue management, fertilizer and thinning and enhance the beneficial growth response (Nambiar and Sands, 1993; Goncalves *et al*., 2002; Goncalves *et al*., 2004). It has been suggested that weeds reduce the availability of light to small seedlings but the competition for water and nutrients depends more on soil, climate and vegetation characteristics (Goncalves *et al*., 2004). When there is a response to fertilizer, increased rates of nutrients uptake lead to an increase in the leaf area index (Smethurst *et al*., 2003) that also prolong leaf retention and increase photosynthetic efficiency (Cromer *et al*., 1993).

Despite the considerable management regimes in the tropical and sub-tropical countries and elsewhere in the world, the productivity of Eucalyptus remained low due to poor genetic stock, weed competition, water stress, low nutrient status of the soil, and threats from pests and diseases in the past 30 years (Sharma *et al*., 1985; Ghosh *et al*., 1989; Kallarackal and Somen, 1997). According to CIFOR (1999) the opportunities for increasing production for long term and the potential problems in sustaining yield are also poorly understood and yet the expectation for achieving high growth rate remains strong amongst the farmers.

Even if the intended use of eucalyptus plantation is wood production, it is important to integrate eucalyptus species in the existing systems to manage them on a sustainable basis (CIFOR, 1999). This is to maintain soil source base while improving productivity. The system should be management to improve the environment and still be economically viable to contribute to smallholders' livelihood. Often, issues concerning protection and sharing of water resources are raised in connection to eucalyptus plantation at the regional scale. The impact of eucalyptus plantation on biodiversity, soil organic matter and on soil fertility is commonly addressed at the operational unit scale (CIFOR, 1999).

Since most of silviclutural practices lead to relevant disturbances to the ecosystem (Bengtsson *et al*., 2000; Roberts, 2004;) the assessment of sustainability and biodiversity in fast growing tree plantations has become an important issue of ecosystems study (Aubert *et al*., 2003; Carnus *et al*., 2003). Fast growing forest tree plantations and, in particular those of Eucalyptus species are usually considered as having less understory vegetation than other types of forest stands or other kind of vegetation cover attributed to the allelopathetic effect, root competition, tree canopy cover and intensive site preparation prior to stand establishment (Rosa *et al*., 1986; Bernaldez *et al*., 1989; Alves *et al*., 1990, Fabiao *et al.,* 2002). The tree canopy cover usually exert a direct effect on the quantity and quality of light reaching the understory vegetation (Cutini *et al*., 1998; Thomas *et al*., 1999; Brosofske *et al*., 2001; Zobrist *et al*., 2005), decreasing the number of species, especially those which are less tolerant to shade and low soil moisture levels. On the other hand, Keenan *et* al. (1997) and Oberhauser (1997) state that some intensive forest plantations have improved the species diversity of the understory and monoculture plantations have been recommended for restoration of forest vegetation on degraded land as it allow colonization of native species (Lugo , 1997; Carnus *et al*., 2003).

According to Tisdall and Oades (1982) the understory vegetation protects the soil against erosion when the stand canopy is not closed, contributing to nutrients cycling, soil carbon content, and to the stability of soil aggregation. In addition, the natural plant cover protects young seedlings against wind and frost (Smith *et al*., 1997) and increases the landscape and environmental value of forested areas (Crowe, 1966, 1978; Forestry Commission, 1994).

Following some of these concerns and others, e.g. production, conservation, environmental and social and economic issues (FAO, 1993) of forest tree plantations, policies have been formulated within the framework of national forest policies based on the principle of natural forest conservation, sustainable utilization, watershed management, and rehabilitation of degraded forest lands, community forestry development, forest land use and allocation, promotion of sound forest industries, forestry research and education among others in the world (FAO, 1993). They form part of the broader framework of national economic and social development policies, especially those related to sustainable natural resource management.

In Kenya, the first formal forest policy was formulated in 1957 to conserve, protect and exploit forest estates in sustainable way and revised in 1968 to include also the catchment protection, and timber production with strong government control of the sector (Wass, 1995). However, the policies were not effective to meet the set targets as much of the forests were cleared for cultivation purposes, charcoal- making, grazing and settlement of landless people (Wass, 1995). This called for the presidential ban on the exploitation of indigenous timber in mid- 1980 and so the management activities within forests were largely restricted to the active management of plantation, law enforcement to control illegal extraction, licensing of forest produce such as firewood (Wass, 1995).

Consequently, the total land area cover of forests has decreased in Kenya from 16% in 1970s to 6% in 1990 (Figure1) (Institute of Economic Affairs, 2000; Consultants for Natural Resources management, n.d). The loss of forests through extraction, population pressures and climate change were estimated at close to 5,000 ha per year while that through forest fires at 15,000 ha annually (GoK, 1999; Consultants for Natural Resources management, n.d). Today, the total land area of forests in Kenya has been maintained at 6% since 1990 (Figure 1) (FAO, 2011).

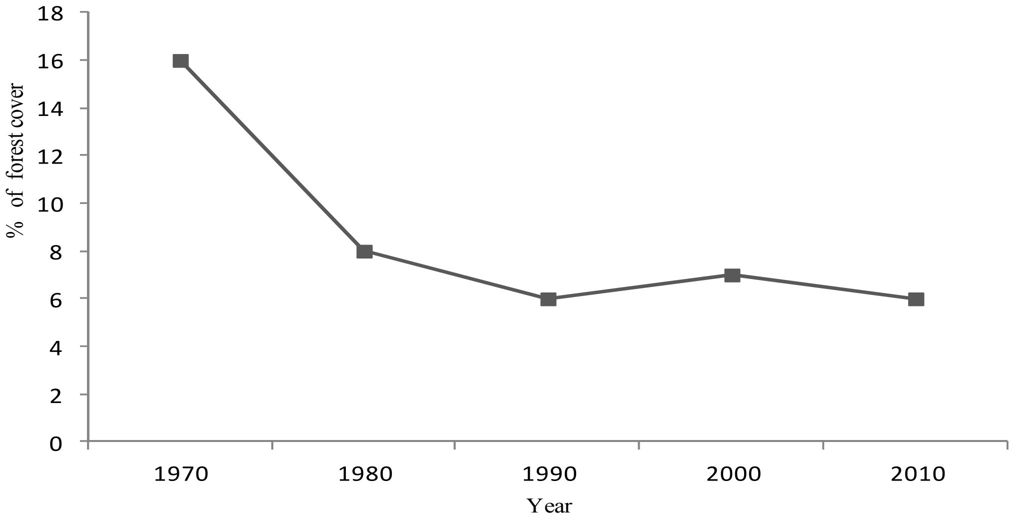

Figure 1. Trends in land area covered with forests, 1970 -2010, (Source: Institute of Economic Affairs, 2000; Consultants for Natural Resources management, n.d; FAO, 2011).

These forests comprise of indigenous and exotic tree species and are mostly found in the central highlands where rainfall is high, soils are fertile and human settlement is limited. In the arid semi areas, forests are found in the isolated mountain ranges and narrow bands along rivers (Consultants for Natural Resources management, n.d). The exotic trees that form a majority of plantation forests in Kenya are being further reduced as the sessional policy No. 1 of the forest policy gives priority to the management and conservation of indigenous forests (MOENR, 2007). The plantation forests, mainly that of eucalyptus species is also faced with a number of challenges related to their alleged incompatibility with certain aspects of environmental conservation (KFS, 2009). Of recent, there has been a lot of controversy over the effect of eucalyptus species on the hydrological cycle. It is claimed that eucalyptus trees and plantation cause the drying up of water sources, rivers and spring (KFS, 2009). As a result, planting of eucalyptus species in the water scarce areas, riparian areas, wetlands and marshy areas have been banned.

The sound development of plantation forests in Kenya therefore requires the strategies for the land use, management, socio- economic aspects, institutional arrangements for financial support and security, legislations, research support and information services (FAO, 1993). For the purpose of this study, much emphasis focuses on comparing the national policies and legislation in the different sectors affecting the smallholders' production of trees in general and Eucalyptus in particular in Kenya.

1.2 Problem Statement and Aim

The plantation forests are renewable natural resources primarily managed for growing wood for a range of purposes (CIFOR, 1999). Some of the most common tree species used for plantation forests in the tropics and sub-tropics, include Eucalyptus *hybrid, E. grandis, E. tereticornis, E. globulus, E. urophylla, E. robusta, E. nitens, Clonal Eucalyptus, Acacia mangium, Grevillea robusta, Acacia decurrens, Pinus patula, cupressus lusitanica, Leucaena leucocephala, Cordia africana, Casuarina equisetifolia* and *Juniperus procera* providing many valuable goods and services to human beings as well as to the environment in general (Pohjonen, 1989; Friis, 1995; Turnbull, 1999).

The most significant contribution is the supply of energy in form of fuel wood and charcoal and regulation of water flow. According to KEFRI (1999) and Wakhusama and Kanyi (2002), over 95% of the total energy used for domestic purposes in Kenya is provided by fuel wood and charcoal. It is also estimated that 80% of the population in Kenya use biomass energy for domestic and industrial purposes (MOENR, 2007).

The plantation forests also provide industrial wood and fibre- board, poles and posts, and timber for household use, nectar for beekeeping, oils, tannins and medicine and other non wood forest products (KFS, 2009). However, there is lack of understanding in the effect of the present policies and new legislations in the different sectors in Kenya for the smallholders. Although there are practices that can contribute to improve the sustainability and production of eucalyptus woodlots, there is a lack of an overview of these practices and their applicability to the smallholders. To bridge these gaps in knowledge, it is necessary to review and evaluate these policies and legislations and alternative management practices and their applicability to the smallholders.

The aim of this study was to review and evaluate alternative management regimes under which smallholders in the tropics and sub-tropics can grow Eucalyptus with a special focus on Kenya. Three specific objectives were formulated;

1. To review alternative management regimes of different Eucalyptus species e.g. *E. tereticornis, E. urophylla, E.globulus, E. camaldulensis, E.nitens, E.grandis*, *E. diversicolor* and *E. hybrid* in order to revile practices that can enhance the positive effects and reduce the negative effects of Eucalyptus in the perspective of smallholders, based on a comparison of these practice to a control of normal smallholder practice through a literature review.
2. To test if the number of understory species in the eucalyptus stands is less compared to that of other commonly used plantation species, nitrogen- fixing and non- nitrogen-fixing, using meta study and test of difference between matched pairs.
3. To review the new constitution, policies and legislations in the sectors of environment, energy, land and forest in Kenya that affect smallholders' production of trees in general and Eucalyptus in particular.

1.3 Justification

A comparison of different management regimes in the light of production and sustainability will contribute to build smallholders' capacity to take informed decisions in the management of small-scale eucalyptus woodlots. An assessment of understory plant species in Eucalyptus plantations compared to that in plantations of other commonly used tree species will contribute to the on-going debate on the controversy that eucalyptus plantation suppress or facilitate biodiversity in the understory in the tropics and sub- tropics.

A collective picture of policies and legislations of different sectors affecting forest and tree plantation and management is important in the design of projects and programs for poverty alleviation and development in the rural areas. In particular, it will help extension service to give the smallholders advice in accordance with the policies avoiding negative consequences or loss of opportunities for the small-scale farmers gradually making the farmers to better understand the implications of their choice of species and management in terms of production levels, negative and positive environmental effect in the light of the policies. (Hendrickson *et al*., 2006).

2 Study layout

2.1 Data Collection and Data Analysis

Literature review was used to survey alternative management regimes of eucalyptus and to investigate the influence of policies and the new legislations in the sectors of environment, energy, land and forest on the smallholders' production of trees, specifically eucalyptus in Kenya. Meta study was applied to compare the under growth in eucalyptus stands with that in other commonly used plantation species in the tropical and subtropical areas.

The table of contents of high profile forestry and sustainable development electronic journals were surveyed using Swedish University of Agricultural Sciences, SLU library databases mainly Google Scholar, AGRIS and Web of Knowledge (Appendix 1). The Center for International Forestry Research, CIFOR online library was as well used to collect the data especially on the alternative management regimes of Eucalyptus species and comparison of Eucalyptus species with the nitrogen-fixing species and some commonly used non- nitrogen-fixing species.

The review samples were further expanded by searching the reference lists of the selected articles. Some of information not included in the published electronic journal sources such as company reports, thesis, media publications and utterances, international shapers, government policies and conference papers, were consulted from other websites through Google link (Ridley, 2008). Forestry and sustainable development related articles published between 1979 and 2011 were included in this paper.

The Excel spreadsheet was used to compute the quantitative data collected for the alternative management regimes of eucalyptus species and the comparison of eucalyptus species with the nitrogen- fixing tree species and the commonly used non- nitrogen- fixing tree species (Jensen *et al*., 1997).

The alternative management regimes of *Eucalyptus tereticornis, E. urophylla, E.globulus, E. camaldulensis, E.nitens, E. diversicolor* and *E.grandis* were examined based on mean annual increment, MAI and understory plant species. The difference in mean annual increment, ΔMAI (%) between the treatment and traditional practice and the difference in number of understory plant species, ΔUPS (%) between eucalyptus and other commonly used plantation species were calculated from;

$$\Delta MAI\ (\%) = (MAI_2\ (m^3/\ ha\ /\ yr) - MAI_1\ (m^3\ /\ ha/\ yr)\ /\ (MAI_1\ (m^3\ /\ ha/\ yr))\ x\ 100\% \quad (1)$$

$$\Delta UPS\ (\%) = (UPS_2 - UPS_1)\ /\ UPS_1)\ x\ 100\% \quad (2)$$

Where ΔMAI (%); change in mean annual increment between a treatment and a normal practice (a control), ΔUPS (%); change in number of understory plant species between a treatment and a normal practice (a control), MAI_2 (m^3 / ha / yr); mean annual increment at harvest in the eucalyptus plots with treatments, MAI_1 (m^3 / ha / yr); mean annual increment at harvest in the eucalyptus plots without treatments (a control), UPS_2; number of understory plant species in the eucalyptus plots with treatments, $UPS_{1;}$ number of understory plant species in the eucalyptus plots without treatments (control).

In the Meta study data bases, literature was screened for work where the undergrowth in the eucalyptus stand was compared with that of another commonly used plantation species in the same experiment. Twenty-four such comparisons were found. The following eucalyptus species were included; *Eucalyptus urophylla, E. camaldulensis, E. saligna, E. globulus, E. grandis,* and *E. robusta.* The other commonly used tropical / sub-tropical plantation species included were both nitrogen-fixing tree species; *Casuarina equisetifolia*, *Leucaena leucocphala*, *Cordia Africana* and non- nitrogen-fixing tree species; *Juniperus procera, Pinus patula, cupressus Lusitania*.

To test the difference in the number of undergrowth between the **e**ucalyptus stand (μ_e) and that of other **s**pecies (μ_o), a test of difference between population means of matched pairs (Newbold 1991:377-380) was used. Thus, the 24 comparisons were considered as matched pairs. The sample mean of the difference was calculated through

$$\bar{y} = \frac{1}{n} \sum_{i=1}^{n} y \qquad (3)$$

The null hypotheses (H_0) were tested; that the difference (Y in the population) in the number of understory plant species in eucalyptus stand compared to that of other commonly used plantation species are equal or lower compared to other commonly used plantation species;

$$H_0 = \mu_{es} - \mu_{os} = Y_0 \quad \text{or} \quad H_0 = \mu_{es} - \mu_{os} \leq Y_0 \qquad (4 \text{ and } 5)$$

against the hypothesis (H_1) that the number of understory species in the eucalyptus stand is higher;

$$H_1 = \mu_{es} - \mu_{os} \geq Y_0 \qquad (6)$$

Using the student *T-test* and decision rule;

$$\text{Reject } H_0 \text{ if } \frac{\bar{y} - Y_0}{S_\mu \sqrt{n}} > t_{n-0.005,\alpha} \qquad (7)$$

Where the sample variance is calculated from

$$S^2_\mu = \frac{1}{n-1} \sum_{i=1}^{n} y_i^2 - n\bar{y}^2 \qquad (8)$$

The actual values are presented in Appendix 2.

Furthermore, literature review was used to compile the information on the policies and legislations in the sectors of environment, energy, land and forest in Kenya affecting the smallholders' production of trees in general and Eucalyptus in particular.

2.2 Limitation, Reliability and Validity

It proved impossible to find a sufficient number of articles with a uniform set of parameters describing the ecological conditions. Therefore, studies that have been included lack some of the ecological parameters that were initially set to be included, now appearing as missing values in the result tables limiting a wider application of the results.

There were also few articles published related to the policies and new legislations in the different sectors in Kenya that affect smallholders in the production of trees in general and eucalyptus in particular. The data compiled in Table 3 of the number of understory species cannot be considered as an independent random sample limiting the conclusions that can be derived from the test.

3 Alternative management regimes of Eucalyptus species

3.1 Management effects on volume production

3.1.1 Weeding

There is a common belief that eucalyptus can grow at any site without weeding. However, it has been proven in many tropical and sub-tropical countries that intensive weed control of eucalyptus wood lots is highly needed for their optimum growth and volume production. Of the included studies, complete weeding significantly improved ($p \leq 0.01$, $p \leq 0.05$) the mean annual increment (MAI) of *Eucalyptus tereticornis* while strip weeding did not significantly improve MAI relative to the control treatment (Table 1). *Eucalyptus tereticornis* produced an additional MAI of 87% and 394 % in plots completely weeded compared to plots not weeded in the second rotation in India and first rotation in Tanzania respectively (Table 1).

This indicates that weeding at establishment can be used as a practice for small-scale farmers to increase productivity of their eucalyptus woodlots. There is always less or no cost incurred in weeding eucalyptus woodlots since labor is from the family members. These results are in agreement with findings of Gonclaves *et al.* (2004) that weeding through cultivation always improve anchorage by the root system, aeration or access to water and nutrients by plants. This implies that weeding increases biomass of eucalyptus woodlots for small-scale farmers. On the other hand, weeding through cultivation usually form clods of various dimensions and are larger when soil is dry. As a result the disordered piling up of clod generates air holes that impede the proper soil- root contact, increasing the chance of water and nutrient stress (Gonclaves *et al.*, 2004). On the other hand, weeding decreases biodiversity which may increase erosion and loss of fertility as well as disrupt indurate layers of soil profile, hence affecting the sustainability of the practice.

3.1.2 Intercropping with legumes

Mucuna, pueraria and stylosanthes are tropical annual legumes found in Africa, India and Caribbean. Just like any other leguminous plant, the three legumes also play a role of fixing nitrogen into the soil and fertilizing it. Studies have been conducted on the effects of intercropping them with eucalyptus wood lots. In this study, the mean annual increment of *Eucalyptus tereticornis* intercropped with the legumes of mucuna, pueraria and stylosanthes generally varied depending on the altitude, soil type, soil texture and mean annual rainfall. There was no significant difference between the mean annual increment of *E. terecticornis* in the plots planted with mucuna, pueraria and stylosanthes and that of the control treatment on altitude 120 m and rainfall 200 mm. However, there was a significant improvement ($p \leq 0.01$) in mean annual increment as measured at 7 years of *E. tereticornis* in the plots planted with only pueraria and stylosanthes compared to that of the control on altitude 150m and rainfall of 2000mm at the age of 7 years (Table 1). At the age of 4 years, the results show that the three legumes improved ($p \leq 0.05$) the MAI of *E. tereticornis* compared to control treatment on both altitudes included and the different rainfall regimes included (Table 1).

E. tereticornis planted with pueraria and stylosanthes in sandy loam, clay loam soils and mean annual rainfall of 2000 mm had a mean annual increment of 23% more compared to the plots planted without legumes. However, *E. tereticornis* planted with pueraria and stylosanthes in clay soils with a mean annual rainfall of 2700 mm and 2000 mm produced a MAI in the range of 1 to 12% less compared to the plots planted as the pure stands (Table 1).

In this sense, it may not be avail option for small-scale farmers that focus on the productivity of the eucalyptus. This result is supported by other findings where legume cover crops have reduced the growth of the tree crop species (Cogliastro *et al*., 1990; Alley *et al*., 1999; Malik *et al*., 2001). Other studies have also found little effects of cover cropping on the production of eucalyptus (Little, 2002). The degree of suppression of growth is dependent on the competition for available resources, generally water (Ofori and Stern, 1987). Pueraria and Mucuna can cause physical suppression as they have a climbing habit and require pruning around the tree base to prevent them from smothering the tree crop. However, if the total production is considered including, wood and grass for fodder together with the alternative of weed that would otherwise suppress the production of the eucalyptus the intercropping of herbaceous fodder legumes may be a viable option for the smallholder with livestock, particularly for those using zero-grazing of dairy cows.

Also, the effects of legume crops in early phase of the plantation growth may be useful mechanism to enhance soil N supply and optimize between N supply and N uptake. The beneficial effects of intercropping eucalyptus with leguminous trees such *Acacia measrsii, A. holosericea* and *Albizia falcataria* have also been reported and are potential option for improving N fertility (DeBell *et al*., 1997; Forester *et al*., 2004; Xu *et al*., 2004). Intercropping eucalypts with the legumes can reduce rate of soil erosion as it stabilize the soil and increase infiltration. In this case, legumes can also improve the environmental sustainability of the smallholder woodlots.

3.1.3 Intercropping with beans and rice

Intercropping of agricultural crops such as beans and rice with eucalyptus wood lots in the tropics and sub-tropics has been recognized as a potential agroforestry alternative for small-scale farmers. However, accurate biological and technical information is required for this system to be socially accepted. Therefore, in this study, the MAI of *Eucalyptus urophylla* and *Eucalyptus camaldulensis* in plots planted with beans and rice shows a significant improvement ($p \leq 0.05$) over the control treatment (Table 1). *E. urophylla* and *E. camaldulensis* had an additional mean annual increment of 74% and 140% respectively in the plots planted with rice over that of the control (Table 1).

This therefore, showed an increase in their MAI, implying that small-scale farmers can be advised to intercrop eucalyptus species with the beans and rice to realize higher eucalyptus yield. The beans and rice can also be used as food and source of income for small-scale farmers, thereby improving their livelihoods. Therefore, intercropping eucalypts with rice and beans would be an economically and socially preferable management regime for small-scale farmers in the tropics and sub-tropics. Leiva (1994) also found similar results of the height increment of *Eucalyptus globulus* when intercropped with maize and beans after one year in Guatemala. In Brazil, Pinto *et al.* (2005) found that sugarcanes improved the growth of *Eucalyptus grandis*. Nissen *et al.* (1999) found that belowground competition between 9-month *Eucalyptus torelliana* and close cabbage row was only for moisture not nutrients.

3.1.4 Fertilizers

Mineral fertilizers are regularly used in large-scale industrial eucalypt growing, but less so by small-scale farmers, who see better use of their fertilizer –if any is available – growing food crops. Interestingly, an experiment in China produced a clear difference between planted and coppiced *E. urophylla* in the response to NPK fertilizer in terms of MAI. Planted *E. urophylla* did give a significant ($p \leq 0.001$), positive response to NPK application, while the coppice rotation did not (Table 1). *E. urophylla* planted in ultisol soils produced a MAI of 100% and

293% more while that of coppice *Eucalyptus urophylla* in the same soil type had its mean annual increment reduced by -9% and -13% in the plots applied with the low and high NPK fertilizer treatments respectively compared to the plots established without NPK fertilization in the second rotation (Table 1).

It means that NPK fertilizers improved MAI of eucalypts of re-established seedlings while the effect on the coppicing rotation often proves to be considerably decreasing the need to apply fertilizers during the coppice rotation of Eucalyptus wood lots. The well developed root systems of the coppice rotation probably helped the trees to utilize soil nutrients better than the smaller root systems of trees established from seedlings. There is also a possibility that coppice Eucalyptus could have used nutrients remaining in the root system from previous rotation. The coppice rotation makes the use of fertilizer redundant by improving profitability and reducing the negative environmental effects of fertilizers, e.g. eutrophication of water bodies. As P fertilizer can improve the MAI of eucalypts, it is an option that could be tested by small-scale farmers to increase productivity of their eucalyptus wood lots, although most of them often use it for only agricultural crops. The response also agree with findings of McLaughlin (1996) showing an improvement in the growth of eucalyptus following application of P in plantations in Southern China. It also supports a general suggestion that P is often the nutrient that controls biomass increment and productivity in most eucalyptus plantation soils (McLaughlin, 1996). However, excess use of P may have adverse environmental effects (Griffith, n. d).

Only the plots treated with N fertilizer 550 Kg / ha showed significant improvement ($p \leq 0.05$) in terms of MAI of *Eucalyptus nitens* compared to the control treatment. Similarly, only the plots treated with P fertilizers of 200 and 40 Kg / ha gave a positive response ($p \leq 0.05$) in terms of MAI of *Eucalyptus urophylla* and *Eucalyptus globulus* respectively relative to the control treatment. The remaining plots treated with N and P fertilizers did not show a significant response over the control treatment (Table 1). The MAI in the first rotation of *Eucalyptus nitens* planted in Australia increased with 27%, 33, 32% and 32% in the plots treated with N fertilizer of 300, 600, 1200 and 1600 Kg / ha respectively compared to the control.

This shows that the productivity of eucalyptus in these plantations increased as a result of available N in soil being supplied by the fertilizer. Therefore, small-scale farmers may use fertilizers in order to increase of their eucalyptus woodlots. Studies carried out by Makino and Osmond (1991) and Boussadia *et al*. (2010) also show that availability of N in the soil often results in marked increase in plant photosynthesis in many crops, including trees. On the other hand, excess use of this fertilizer is expensive for small- scale farmer in terms of accessing it and also leads to N losses by leaching with negative impacts on the environment (Boussadia *et al*., 2010). Therefore, use of this management regime may not be available alternative in small-scale farmer perspective.

Whereas the plots fertilized with NPK, harrowed and both harrowed and fertilized significantly improved ($p \leq 0.001$) the mean annual increment of *Eucalyptus globulus* in Portugal, those in the Australia were not significantly different compared to the control treatment. The plots of *Eucalyptus globulus* applied with the combination of harrowing and fertilization and only NPK fertilizer had its mean annual increment increased by 21% and 4% respectively compared to the control with the exception of the plots applied with harrowing only in the first rotation in Portugal.

This study therefore shows that the use of NPK alone and in combination with harrowing increased the productivity of eucalypts in the included experiment, indicating that these are options with a potential to improve the profitability of smallholders' woodlots. However, the production increase of the treatment depends on the site and climate conditions. In an experimental trial in which optimum fertilizer application of a 6- year period only slightly increased tree growth (Pereira *et al.,* 1994). Similarly, the results were observed in Mediterranean climate conditions in which tree productivity is strongly affected by water availability and at lower extent by the nutrients (Pereira *et al*., 1994). This suggests that there is little benefit or even loss to use NPK and/or harrowing in low rainfall areas and on soils with poor water retention. Small-scale farmers may also face problem to raise cash and or to access NPK. Farmers with excess plant and animal residues can use them to improve soil nutrient and organic matter levels – serving as alternative to inorganic fertilizer (NPK). Excess use of NPK and harrowing may also cause problems of erosion and loss of topsoil, including the added fertilizer, causing further problems where it ends up, e.g. eutrophication of water bodies (Fabiao *et al*., 2002). Studies have shown that the process of eutrophication leads to excessive plant growth that in turn will cause deficiency of oxygen for the fish and gradually make the open water to a swamp.

Plots treated with the medium and high effluent irrigation in Australia had insignificant positive effect, increasing MAI of *Eucalyptus grandis* by 14% and 19% respectively compared to the control. Plots treated with low effluent irrigation in the first rotation affected the MAI negatively, still not significant (Table 1). Therefore, effluent irrigation is yet another option that could be considered by small-scale farmers who have water available and easily accessible for irrigation in order to increase productivity of their eucalyptus wood lots. This is supported by the fact that application of effluent to plants in the areas without sufficient nutrients usually improves their growth and productivity. This result is in agreement with findings of Polglase *et al.* (1994) that the greater the nutrient application the faster the development of leaf area, stand volume and biomass accumulation.

3.1.5 Slash retention

Slash retention as a silvicultural practice in most tree plantations in the world, including those of eucalyptus wood lots in tropics and sub-tropics is used to increase its productivity. In Australia, slash influenced eucalyptus production of the second rotation such that plots with the slash residues retained (from the first rotation harvesting) and distributed uniformly across the sandy clay soils caused a significant ($p \leq 0.01$) reduction of 10% in terms of MAI of planted *E. globulus* compared to the control. With the quantity of slash residues doubled and distributed uniformly across the soil, the MAI of *E. globulus* increased significantly ($p \leq 0.01$) in the range of 14 to 52% depending on soil conditions relative to the control (Table 1).

The MAI of second rotation *Eucalyptus hybrid* planted in Congo increased significantly ($p \leq 0.05$) with 36% and 82% in the plots with slash residues retained (form the first rotation) and distributed uniformly, and in the plots with the quantity of slash doubled, distributed uniformly and burnt according to the standard procedures compared to the control, respectively (Table 1). In Brazil, the MAI of second rotation *Eucalyptus grandis* increased with 57% (not significantly) compared to the control in the plots with slash residues retained and distributed uniformly across, and slash residues burnt according to standard plantation practice (Table 1).

This suggests that the increase in MAI of eucalypts could have been due to the additional nutrients provided by the slash residues when subjected to retention, and burning.

Table 1. Compilation of change in Mean Annual Increment, ΔMAI of Eucalyptus species under different management regimes

Age years	species	location	rotation / establish-ment	altitude m.a.s.l	soil type / soil texture	mean annual rainfall mm	Type of treatment	standing volume m^3/ha	TBP ton/ha	MAI m^3/ ha/ yr	ΔMAI %	LoS	ABP ton/ha/yr	Ref
3	E. tereticornis	Tanzania	First, planted	-	Sandy clay loam	860	Plots with no weeding applied	8	4.5	2.5	0	control	1.5	1
							Plots with clean weeding applied	37	22.5	12.5	394	*	7.5	1
7	E. tereticornis	India	Second, planted	120	Ferralsols, clay	2700	Plots with no weeding applied	60	36.0	8.6	0	control	5.1	11
							1 m strip weed control	64	38.4	9.1	6	n.s	5.5	11
							Plots with complete weeding applied	112	67.2	16.0	87	**	9.6	11
				150	Ferralsol Sandy loam	2000	Plots with no weeding applied	36	21.6	5.1	0	control	3.1	11
							Plots with 1 m strip weeding applied	48	28.8	6.9	33	n.s	4.1	11
							Plots with complete weeding applied	90	54.0	12.9	150	**	7.7	11
				120	Ferralsols, clay	2700	Plots without legumes	98	58.8	14.0	0	control	8.4	11
							Mucuna grown as an intercrop (incorporated)	105	63.0	15.0	7	n.s	9.0	11
							Pueraria grown as an intercrop (incorporated)	86	51.6	12.3	-12	n.s	7.4	11
							Stylosanthes grown as an intercrop (incorporated)	90	54.0	12.6	-8	n.s	7.7	11
				150	Ferralsol, Sandy loam, clay loam	2000	Plots without legumes	80	48.0	11.4	0	control	6.9	11
							Mucuna grown as an intercrop (incorporated)	80	48.0	11.4	0	n.s	6.9	11
							Pueraria grown as an intercrop (incorporated)	98	58.0	14.0	23	**	8.3	11
							Stylosanthes grown as an intercrop (incorporated)	98	58.0	14.0	23	**	8.3	11
4	E. tereticornis	India	Third, planted	120	Clay	2700	Plots without legumes	100	60.0	25.0	0	control	15.0	8
							Mucuna grown as an intercrop (incorporated)	105	63.0	26.3	5	*	15.8	8
							Pueraria grown as an intercrop (incorporated)	98	58.8	24.5	-2	*	14.7	8
							Stylosanthes grown as an intercrop (incorporated)	98	58.8	24.5	-2	*	14.7	8
4	E.terecticornis	India	Third, planted	150	Clay	2000	Plots without legumes	100	60.0	25.0	0	control	15.0	8
							Mucuna grown as an intercrop (incorporated)	94	56.4	23.5	-6	*	14.1	8
							Pueraria grown as an intercrop (incorporated)	99	59.4	24.7	-1	*	14.9	8
							Stylosanthes grown as an intercrop (incorporated)	106	63.6	26.5	6	*	15.9	8
1.3	E.urophylla	Brazil	First, planted	670	Oxisol	1300	Plots without rice and beans	10	5.6	7.5	0	control	4.3	3
							Rice grown as an intercrop	13	7.3	9.8	74	*	5.6	3
							Bean grown as an intercrop	17	9.7	13.1	31	*	7.5	3
1.3	E.camaldulensis	Brazil	First , planted	-	Oxisol	1300	Plots without rice and beans	5	4.9	3.9	0	control	3.8	4
							Rice grown as an intercrop	12	11.8	9.2	140	*	9.1	4
							Bean grown as an intercrop	8	7.8	6.2	60	*	6.0	4
7.5	E. urophylla	China	Second, planted	20-50	Ultisol	2178	Plots without nitrogen fertilizers	14	8.0	1.9	0	control	1.1	13
							Low fertiliser applied with (N 76.7, P 16.0 and K 53.4) kg / ha	28	14.0	3.7	100	***	1.9	13
							High fertiliser with (N 153.3, P 32.0 and K 106.7) kg / ha	55	31.4	7.3	293	***	4.2	13
7.5	E. urophylla	China	Second, coppice	20- 50	Ultisol	2178	Plots without nitrogen fertilizers	70	39.9	9.3	0	control	5.3	13
							Low fertiliser applied with (N 76.7 , P 16.0 and K 53.4) kg / ha	64	36.5	8.5	-9	n.s	4.9	13
							High fertiliser applied with (N 153.3, P 32.0 and K 106.7) kg / ha	61	34.8	8.1	-13	n.s	4.6	13
7.9	E. nitens	Australia	First planted	430	Brown kurosol, Clay loam	1444	Plots without nitrogen fertilizer	110	77.0	13.9	0	control	9.8	12
							Nitrogen fertilizer applied with 300 Kg / ha	140	98.0	17.7	27	ns	12.4	12
							Nitrogen fertilizer applied with 550 Kg / ha	105	73.5	13.3	-5	*	9.3	12
							Nitrogen fertilizer applied with 600 Kg / ha	146	102.2	18.5	33	ns	12.9	12
							Nitrogen fertilizer applied with 1200 Kg / ha	145	101.5	18.4	32	ns	12.8	12

							Nitrogen fertilizer applied with 1600 Kg / ha	145	101.5	18.4	32	ns	12.8	12
3	E.urophylla	China	First, planted	30- 50	Oxisol, Sandy clay loam	1870	Plots without phosphorus fertilizers	45	25.7	15.0	0	control	8.6	14
							Phosphorus fertilizer applied with 20 Kg / ha	60	34.2	20.0	33	ns	11.4	14
							Phosphorus fertilizer applied with 50 Kg / ha	68	38.8	22.7	51	ns	12.9	14
							Phosphorus fertilizer applied with 200 Kg / ha	70	39.9	23.3	56	*	13.3	14
3	E. globulus	China	First, planted	2200	Ultisol, sandy clay,	995	Plots without phosphorus fertilizers	45	29.5	15.0	0	control	9.8	14
							Phosphorus fertilizer applied with 40 Kg / ha	70	49.9	23.3	56	*	16.6	14
							Phosphorus fertilizer applied with 120 Kg / ha	67	43.9	22.3	49	ns	14.6	14
							Phosphorus fertiliser applied with 360 Kg / ha	80	52.5	26.7	78	ns	17.4	14
12	E. globulus	Portug al	First, planted	140	Dysric cambisols Sandy loam, Clay loam	607	Plots without NPK fertilization and without harrowing	212	144.0	18.3	0	control	12.0	7
							Plots fertilized with NPK	228	149.9	19.0	4	**	12.5	7
							Plots harrowed	217	142.2	18.1	-1	**	11.9	7
							Plots both harrowed and fertilized	264	173.5	22.0	21	**	14.5	7
8	E.globulus	Portug al	First, planted	140	Dystric cambisol and Regosol, sand	757	Plots without NPK fertilization and without harrowing	219	143.7	27.4	0	control	18.0	2
							Plots fertilized with NPK	229	150.2	28.6	4	ns	18.8	2
							Plots harrowed	265	173.8	33.1	21	n.s	21.7	2
							Plots both harrowed and fertilized	217	142.4	27.1	-1	ns	17.8	2
3	E. grandis	Austra lia	First, planted	-	Red chromosol Sandy clay-loam,	570	Plots without effluent irrigation	45	35.8	14.9	0	control	11.9	10
							Plots irrigated with low effluent irrigation	40	31.8	13.2	-11	n.d	10.6	10
							Plots irrigated with medium effluent irrigation	51	41.0	17.1	14	n.d	13.7	10
							Plots irrigated with high effluent irrigation	53	42.5	17.7	19	n.d	14.2	10
6	E. globulus	Australia	Second, planted	-	Rhodic Ferraso, loamy sand, clay	1023	Slash residue removed physically	220	144.3	36.7	0	control	24.1	9
							Slash residues retained at double the normal quantity and uniformly distributed across	250	164.0	41.7	14	**	27.3	9
					Hapalic podzol, sand,clay	825	Slash residue removed physically	42	27.6	7.0	0	control	4.6	9
							Slash residues retained and distributed uniformly across	38	24.9	6.3	-10	**	4.2	9
							Slash residues retained at double the normal quantity and distributed uniformly across	64	42.0	10.7	52	**	7.0	9
							Slash residues burnt according to standard plantation practice	58	38.1	9.7	38	**	6.4	9
7	E. hybrid	Congo	Second, Planted		Ferralic Arenosols, Sandy, clay,	1200	Slash residues removed physically	90	93.6	12.9	0	control	13.4	6
							Slash residues retained and distributed uniformly across	140	145.6	20.0	36	*	20.8	6
							Slash residues retained at double the normal quantity and distributed uniformly across	164	170.6	23.4	82	*	24.4	6
							Slash residues burnt according to standard plantation practice	125	130.0	17.9	39	*	18.6	6
6.4	E. grandis	Brazil	Second, planted	750	Haplic ferralsol, Sandy clay loam, clay, loamy sand	1597	Slash residues removed physically (control)	176	141.0	27.5	0	control	22.0	5
							Slash residues retained and distributed uniformly across	277	221.4	43.2	57	n.d	34.6	5
							Slash residues burnt according to standard plantation practice	277	221.4	43.2	57	n.d	34.6	5

TBP: Total Biomass Production, ABP: Annual Biomass Production, MAI: Mean Annual Increment, - ; Missing information
LoS; Level of Significance, *; $p \leq 0.05$, ** ; $p \leq 0.01$, ***; $p \leq 0.001$, n.s ; not significant, n.d; not determined , [1]Ahimana and Maghembe (1987),[2]Carneiro *et al*. (2008), [3]Ceccon (2008), [4]Ceccon (2005) ,[5]Gonclaves *et al*. (2008), [6]Laclau *et al*. (2010) [7]Madeira (2011), [8]Mendham *et al*. (2004), [9]Mendham *et al*. (2003), [10]Myers *et al*. (1996), [11]Sankaran *et al*. (2008), [12]Smethurst *et al*. (2003), [13]Xu *et al*. (2008), [14]Xu *et al*. (2001

According to Sankaran *et al*. (2000) eucalyptus plantations produce large quantities of biomass that can be a significant store for nutrients and most of them are concentrated in the bark and wood of harvest residues**.**

Therefore, retention of harvest residues during rotation phase has shown improvement in the growth of pine (Smith et al., 2000; Tiarks *et al*., 2000 and eucalypt (Jones *et al*., 1999) plantations. The retention of harvest residues can improve soil moisture (O'connell and Grove, 1999) as well as improve the growth of seedlings. On the other hand, the residue management treatment may differ in their effects on soil nutrients supply. Burning of materials will produce an initial release of P and cat-ions in plant available forms and it stimulates growth of the tree. Residues also immobilize N and hence reduce the losses of N due to leaching during the initial phase of decomposition by removing N from the pool of plant available N (Aggangan *et al*., 1999; Corbeels *et al*., 2003). This can cause N deficiency during the early stages of tree growth. Slash residue management may be an alternative for the small-scale farmers who do not have other sources of fertilizer our manure. .

3.2 Understory biodiversity under different management regimes of eucalyptus

In Portugal, the number of the understory plant species decreased compared to the control (no treatment) with 7%, 37% and 43% in the plots planted with first rotation *Eucalyptus globulus* treated with NPK fertilizers only, harrowing only and the combination of harrowing and fertilization respectively (Table 2).

This actually suggests that the number of understory plants generally declined with different management regimes as compared to normal / traditional management. However, only harrowing and the combination of harrowing and fertilization had statistically secured lower number of plant species compared to the control, suggesting a long term negative effect of harrowing on species diversity in the under growth. These results agree with the findings of study by Fabiao *et al*. (2002) concluding that there is always greater species richness in the understory vegetation of eucalyptus plantation with less disturbances. Similarly, there is a common assumption that species richness is negatively affected in the forest plantations with major disturbances (Neary *et al*., 2001). Therefore, from the perspective of biodiversity and soil conservation harrowing and NPK fertilization may not be advisable under some site and climatic conditions. Also, from the perspective of the smallholders inorganic fertilizer is usually not accessible to them.

Similarly in Australia, the number of the understory plant species was reduced as compared to the control by 43 % and 64% in the plots of first rotation *Eucalyptus diversicolor* treated with P of 30 and 200 Kg / ha respectively (Table 2). Also, in Portugal the number of understory plant species decreased in range of -9% and -37% in the plots of *Eucalyptus globulus* treated with broadcasting slash over soil only. The number of understory plant species also decreased within same range in plots of eucalyptus treated with combination of broadcasting slashes over and concentrating woody residues over the plots with slash removed in the second rotation (Table 2).

The slash residue management regimes caused a decline in the number of undergrowth in the eucalyptus plantations. The results are similar to the findings of Fabiao *et al*. (2002) who also found a negative influence of slash on the number of understory species. Fabiao also found that change in the species composition appears to be related to environmental changes at the understory level following canopy closure (Fabiao *et al*., 2002).The use of heavy machinery may also increase soil compaction, mainly through alternation of soil porosity (Lenhard, 1986). The displacement of boles and heavy accumulation of slash on soil surface may also have negative effect on reestablishment and survival of the understory vegetation (Smith *et al*., 1997). Even though retention of slash decrease species diversity in the under growth it improve soil fertility. Removal of slash from site to prevent fire hazards and to ease the execution of operation during stage of a stand leads to the exportation and displacement of nutrients contained in the plant biomass and consequently, negatively affecting long-term soil-fertility (Nyland *et al*.,1979; Abbot and Crossley, 1982; Burger and Prichett, 1984; Smith *et al*.,1997). From the perspective of the small-scale farmer, all parts of the eucalyptus tree is useful, including leaves and bark, making an immediate loss from the harvest if some parts of the tree is left as slash. This should be compared to a potential production increase that will accrue after several years. Smallholders normally live from hand to mouth and will not be motivated to lose something that is available now against a potential gain years ahead.

3.3 Understory biodiversity under eucalyptus and other plantation species

There was in average 12.3 understory plant species more under the eucalyptus plantation compared to that under the other studied tree species (significant difference ($P \leq 0.005$) (Table 3). The test value was calculated to 4.244 against the $t_{n\text{-}0.005\alpha} = 2.807$, hence the null hypothesis of equal or lower number of under story species in eucalyptus stands compared to other commonly used plantation species was rejected at the 0.005 significance level.The difference in the number of understory plant species on the plantation of eucalyptus species and those on the plantations of other commonly used tree species were highest (36) on the altitude between 2200 and 2700 m above sea level (Table 3), The largest positive difference (36) in favour of eucalyptus was found between *E. globulus* and *C. lusitanica* as well as the largest negative difference (-22) (Table 3).

On the altitude between 1200 and 2200m above sea level the total number of species was in general lower as well as the general difference. At this altitude, the largest difference in favour of eucalyptus was found between *Eucalyptus grandis* and *Cupressus lusitanica* (15), followed by *Eucalyptus globulus* and *Cupressus lusitanica* (13) and the smallest difference was found between *Eucalyptus globulus* and Pinus patula (1), and *Eucalyptus saligna* and *Pinus patula* (2) (Table 3). This indicates that the differences general were larger and the understory flora was more diverse on the higher altitudes probably due to a better water balance (precipitation – evapotranspiration).

This also suggests that the environmental conditions at the forest floor such as air, soil water and soil temperature were more favourable for the seed germination, seedling survival and growth of the understory plant species in the plantation of eucalyptus species compared to those in the plantations of other commonly used tree species. These results are in contrast to the findings that Eucalyptus species inhibit the understory herbaceous and woody species growth by producing allelochemicals (Basanta *et al*., 1989; Madeira *et al*., 1989). Similarly, findings of study on influence of overstory composition on understory colonization contradict with this study in that there were more species richness and density on the Leucaena plantations followed by Eucalyptus and finally Casuarina (Parrotta, 1995). On the other hand, the results also support findings of a study of Leucaena *leucocephala* and eucalyptus species by Suresh and Vinaya Rai (1988) where they found little or no influence of the leaf litter chemistry of eucalyptus species on understory regeneration through allelopathic interference. This was in an area with relatively high rainfall which reduces competition between trees and understory plants for water and nutrients with low mobility and also the allelopathic effects by leaching of toxic compounds (Michelsen *et al*., 1996). Similar studies state that the choice of tree species may affect the number of understory woody colonization in terms of their attractiveness as roosting habitat for seed- dispersing birds and bats (Desbussche *et al*., 1982; Manders and Richardson, 1992; Mitra and Sheldon, 1993).

Table 2. Compilation of Change in number of the understory plant species, ΔUPS (%) on the plantations of Eucalyptus species under different management regimes

Year of experiment	Species	Location	Altitude (m. a. s. l)	Rotation / Establishment	Soil type / Texture	Mean Annual rainfall (mm)	Type of treatment	Number of understory species	ΔUPS (%)	Ref
1997- 1998	E.globulus	Portugal	140	First, Planted	Dystric cambisol and Regosol, sand	757	Plots not harrowed and not fertilized with NPK	67	0	1
							Plots fertilized with 42.0, 27.6 and 52.5 Kg / ha of N, P and K respectively	62	-7	1
							Plots harrowed	42	-37	1
							Plots harrowed and fertilized with NPK	38	-43	1
1999- 2004	E.globulus	*Portugal*	140	First, Planted	Dystric cambisol and Regosol, sand , clay	757	Plots not harrowed and not fertilized with NPK	46	0	1
							Plots fertilized with 42.0, 27.6 and 52.5 Kg / ha of N, P and K respectively	38	-17	1
							Plots harrowed	28	-39	1
							Plots harrowed and fertilized with NPK	26	-43	1
1981- 1983	E.diversicolor	Australia	-	First, Planted	Chromic luvisols,	>900	Plots without phosphorus	14	0	4
							Plots with phosphorus applied with 30 Kg / ha	8	-43	4
							Plots with phosphorus applied with 200 Kg / ha	5	-64	4
1993- 1997	*E.globulus*	Portugal	30	Second, Coppice	Eutric cambisol	607	Plots with slash removed	73	0	2
							Plots with slash broadcasted over the soil	56	-23	2
							Plots with slash broadcasted over the soil woody residues concentrated between tree rows	62	-15	2
							Plots with slash incorporated into the soil by harrowing	58	-21	2
1998- 2004	*E.globulus*	Portugal	30	Second, Coppice	Eutric cambisol	607	Plots with slash removed	85	0	2
							Plots with slash broadcasted over the soil	56	-34	2
							Plots with slash broadcasted over the soil woody residues concentrated between tree rows	62	-27	2
							Plots with slash incorporated into the soil by harrowing	58	-32	2
1994-1996	*E.globulus*	Portugal	30	Second, Coppice	Eutric cambisol, Silt, clay	607	Plots with slash removed	38	0	3
							Plots with slash broadcasted over the soil	19	-50	3
							Plots with slash broadcasted over the soil woody residues concentrated between tree rows	24	-37	3
							Plots with slash incorporated into the soil by harrowing	41	7	3
1997-1999	*E. globulus*	Portugal	30	Second, Coppice	Eutric cambisol Silt clay	607	Plots with slash removed	57	0	3
							Plots with slash broadcasted over the soil	49	-14	3
							Plots with slash broadcasted over the soil woody residues concentrated between tree rows	43	-25	3
							Plots with slash incorporated into the soil by harrowing	52	-9	3

-;missing value, [1]Carneiro *et al*., (2008), [2]Carneiro *et al*. (2007) ,[3]Fabiao *et al*. (2002), [4]Grove (1988)

The difference in the number of understory plant species on the plantations of eucalyptus species and those on the plantations of other commonly used tree species varied depending on the location. This indicate that the number of understory plant species in the plantation of eucalyptus species and that in the plantations of other commonly used tree species depends on the site conditions, e.g. altitude, temperature, soil type and amount of rainfall. The variation may also be attributed to the management systems for example conifers are managed for timber production on long rotation while eucalyptus is managed on a shorter rotation. The nature of crown and extent of litter accumulation differ in the plantation stands. The coniferous stands produce thick crown and more litter accumulation than eucalyptus that reduces germination and growth of understory species. This is also in agreement with other studies; that species richness, density and growth characteristics of colonizing woody species vary considerably between different plantation species, even among closely located stands. Some of the factors that may contribute to differences are tree species attributes (Lugo, 1992; Guariguata *et al*., 1995; Parrotta, 1995; Fimbel and Fimbel, 1996).

Other site factors that may contribute to variation in number of understory plant species in plantations is the soil substrate quality, altitude and radiation index (Gerontidis, 2000), plantation age (Geledenys, 1997; Obserhauser, 1997; Zhaung, 1997), plantation management intensity, degrees of protection from fire and other disturbances (Brown and Lugo, 1994; Obserhauser, 1997; Powers *et al*., 1997; Zhauang, 1997), litter mass and depth (Lugo, 1992; Parrotta, 1995, Harrington and Ewel, 1997 and canopy characteristics (Fimbel and Fimbel, 1996; Harrington and Ewel, 1997). Other studies also report that decrease in the number of colonizing woody species in the understory of plantation stand normally occurs with the increasing overstory stand and leaf area index and basal area in Hawaii (Harrington and Ewel, 1997).This implies that smallholders in the tropics and sub-tropics require specific management advice appropriate to their locality in order to foster the growth of understory plant species.

Table 3. Comparison of understory plant species on plantations of Eucalyptus species and those on plantations of other commonly used tree species

Altitude (m.a.s.l)	Rainfall (mm)	Soil type	Eucalyptus	Number of species	Spp comparison	Number of species	y	y^2	Ref
1200-2200	600-900	-	saligna	27	Pinus patula	18	9	81	2
			globulus	19	Pinus patula	18	1	1	2
			saligna	27	Cupressus lusitanica	16	11	121	2
			globulus	19	Cupressus lusitanica	16	3	9	2
			saligna	23	Pinus patula	21	2	4	3
			grandis	26	Cupressus lusitanica	11	15	225	6
			globulus	24	Pinus patula	21	3	9	6
			saligna	23	Cupressus lusitanica	11	12	144	6
			grandis	26	Pinus patula	21	5	25	6
			globulus	24	Cupressus lusitanica	11	13	169	6
2200-2700	>900	-	globulus	46	Cupressus lusitanica	68	-22	484	9
			saligna	66	Pinus patula	49	17	289	9
			globulus	46	Pinus patula	49	-3	9	9
			saligna	66	Cupressus lusitanica	68	-2	4	9
		Ferrasols	saligna	63	Cordia africana	51	12	144	4
		Ferrasols	saligna	63	Cupressus lusitanica	28	35	1225	4
		Ferrasols	saligna	63	Pinus patula	32	31	961	4
			globulus	30	Cupressus lusitanica	10	20	400	1
			globulus	57	Cupressus lusitanica	21	36	1296	7
			globulus	57	Juniperus procera	31	26	676	7
		-	globulus	57	Cupressus lusitanica	21	36	1296	5
			globulus	57	Juniperus procera	31	26	676	5
			robusta	20	Casuarina equisetifolia	9	11	121	8
			robusta	20	Leucaena leucocephala	20	0	0	8

Mean was statistically significant ($P \leq 0.005$, student t –test), -: Missing information,
[1]Abiyu *et al.,* (2011), [2]Feyera *et al*., (2002), [3]Kindu *et al*., (2006), [4]Limenih *et al*., (2004), [5](Lisanework and Michelsen 1993b; Michelsen et *al*., 1993), [6]Michelsen *et al*., (1996), [7](Michelsen *et al.,* 1993; Lisanework and Michelsen, 1994), ,[8]Parrotta (1995), [9]Senbeta *et al.,* (2002)

4 Policies and legislations in Kenya affecting tree and forest production

The Environment Act (article 42, paragraph 1(d)) prohibit the introduction of any part a plant specimen, whether alien or indigenous, dead or alive in any river, lake or wetland (Table 4).This means that the local forestry service may not allow the small-scale farmers to plant trees in the around lakes, ponds, wetlands and any other standing water body. This is explained in the KFS (2009) guideline that trees especially eucalyptus should not be planted in wetland, marshy areas, riparian areas (areas around lakes, ponds, swamps, estuary and any other body of standing water). It is also stated that large proportions of areas in Kenya that are either irrigated or receive less than 400 mm of rainfall should not be planted with eucalyptus species. This suggests that the land area where eucalyptus can be planted is limited particularly to small-scale farmers.

Similarly in Ethiopia, the Regional government of Tigray banned Eucalyptus tree planting on farmlands in 1999 in order to increase food production and to reduce the negative environmental impacts associated with eucalyptus (Jagger and Pender, 2000). The farmers in this region are only allowed to plant eucalyptus trees in the community woodlots and on the community wastelands and steep hillsides.

Despite the existence of these policies in Ethiopia, Amare (2010) reports that small-scale farmers hardly establish and manage their Eucalyptus trees on the degraded lands since they are aware of suitable sites for specific species. In the same study, the findings state that there is poor growth of Eucalyptus trees on the degraded hills established by the government (Amare, 2010). In South Africa, eucalyptus plantations has also been removed from the riparian zones (ICRAF, 2006) thus encouraging the natural forests and grasses, which use less water to regenerate. Similar concerns and proposed actions are under consideration in Uganda and Rwanda (Jagger and Pender, 2000; Nduwamungu *et al*., 2007; Oballa *et al*., 2005).

This policy was developed following an allegation that eucalyptus consumes high amount of water and therefore causes drying up of water bodies. However, there are alternative management regimes that these farmers could use to reduce this problem such as planting trees farther apart or thinning existing plantation of eucalyptus wood lots (Davidson, 1995). Therefore, there is a need for policy makers to amend this policy in line with these alternative management regimes so that they are tailored to better stimulate eucalyptus growing by small-scale farmers. Otherwise, this policy will be rendered irrelevant to small-scale farmers.

The Land Article 64, paragraph 1 states that an appropriate land taxation system to mobilize revenue and discourage land speculation on public land would be established. The Land Article 77, paragraph 1 (b) and (e) also state that leasehold interests out of public, community or private land as long as the terms of the lease is less than the residual terms (99 years) would be established (Table 4). This indicate that after 99 years, small-scale farmers would be required to renew the terms of leasehold for the continued growing of the trees in such kind of land.

This is in agreement with MOLHUD (2009) that leasehold is a means of land ownership to promote the public to access land and its duration should not exceed 99 years. Similar studies of Mayers and Bass (2004) and FAO (2009) also report that today many companies are becoming more interested to investing in plantation forests because of global practical and land tenure advantage. Investment like tree planting takes long before profits are accrued and therefore needs secure land tenure arrangement. The use of leaseholds by both private persons and government is not also commonly practiced despite its existence in the constitution and does not provide security of the long- term investment by the leasees (Consultants for Natural Resources management, n. d).

Therefore, small-scale farmers in Kenya who risk into acquiring leasehold land for tree planting are bound to loss since there is no security of the land. In addition, the small-scale farmers are not likely to get the leasehold land for tree planting because the policy is not implemented, hence reducing the production of trees. On the other hand, land privately owned by small-scale farmers as freehold may be secured enough for long-term investment like tree planting as it can be used as collateral for borrowing money from financial institutions. This shows that communal land may be the only way for the small-scale farmers to increase the area for production of trees, including eucalyptus wood lots.

The land policy also enforces an effective and appropriate progressive land taxation system to mobilise revenue and discourage land speculation on public land. This finding agrees with the land policy in Uganda stating that unutilised or underutilised land shall be taxed to induce land utilization and deter speculative accumulation of land (MOLHUD, 2009). This policy does not favour poor small scale farmers who cannot pay taxes on public land progressively during tree growing, therefore reducing the overall production of trees. The relatively rich small- scale farmers who may be able to pay taxes on public land, have the opportunity to increase the production of trees in Kenya.

Article 6.3.2 paragraphs 1 and 2 of Energy Act promote co-generation of power through undertaking appropriate studies. The article 6.4, paragraph 1 (i) and (ii) of Energy Act also promote production of power through collecting hydrological data and undertaking pre-feasibility and feasibility studies on small hydro, including wind regimes and solar installation and utilization of municipal wastes. The same article, paragraph 1 (vii) and (xi) further promote the development of appropriate local capacity for manufacture, installation, maintenance, and operation of basic renewable technologies such as bio- digesters, solar water heating systems and hydro turbines and growing of appropriate trees for production of feedstock for manufacture of biodiesel (Table 4). These energy policies might lead to decline in the production of eucalypts since there are no incentives provided to the small-scale farmers and yet wood and other biomass contributes about 68% to the total primary energy production at national level.

Wood is also expected to remain the main source of energy for the foreseeable future in Kenya (MOE, 2004). As small- scale farmers cannot participate in the production of energy using municipal wastes, solar and hydro sources, the energy policy in Kenya is unlikely to motivate farmers or individuals to plant more trees or forest. The energy sector together with policy makers therefore, should review this policy such that all tree species, including eucalyptus in particular are promoted by small- scale farmers. Studies on calorific value (energy value) of different eucalyptus species and other tree species can be conducted to promote bio-energy production. . In this sense, more eucalyptus wood lots will be grown by small- scale farmers as well as motivate production of bio-energy since the raw material can easily be accessed.

In the sector of forests, the Forest Act (article 1.4, paragraph 1.4.3) promote the growing of indigenous trees rather than the exotic trees, eucalyptus inclusive. This policy may affect small- scale farmers negatively with an interest to produce eucalyptus species. The Forest Act (article 1.6 and paragraph 1.6.1) promote a mechanism to ensure that forests and woody vegetation on local authority land is managed sustainably to satisfy the local forest needs and conserve biological diversity (Table 4). As eucalyptus is believed to inhibit the undergrowth, therefore local forest service may prohibit or discourage the small- scale farmers who want to plant the eucalyptus species.

This is in agreement that many indigenous tree species do meet local requirements better than exotic species (FAO, n. d). In Tanzania, local people often prefer indigenous species for a variety of uses such as charcoal, furniture, housing material and medicine (FAO, n. d).

However, the growing of exotic species by small-scale farmers in Kenya is expanding at a high rate, particularly eucalyptus species because of their fast growth, survival characteristics in the marginal environment and generally yields more return than other tree crops (KFS, 2009). The total area currently under Eucalyptus plantations in the country is about 100,000 ha and it is expected to increase in future due to high demand for the transmission poles for rural electrification, construction, fuel wood, carbon sequestration, and mitigating effects of climate change (FAO, 1985; Ball, 1995; Binkley and Stape, 2004; FAO, 2009; Oballa *et al*., 2010). The policy concerning indigenous tree species may be of minor importance to small-scale farmers as they highly value exotic tree species.

This policy is a result of many indigenous trees becoming extinct in the country and yet they provide some useful services and products compared with exotic trees. To solve this conflicting issue, small-scale farmers can be motivated to practice mixed cultivation of indigenous and exotic trees rather than monoculture system. In this way, the policy would be tailored to stimulate eucalyptus growing by the small-scale farmers.

The Environment Act (article 69, paragraph 1(b) of new constitution, 2010 set a target that at least 10% of total land area in Kenya should have tree cover. This is to increase the forest cover which has been declining over space and time considerably in Kenya (EAWS / KFWG, 2001, Consultants for Natural Resources management, n.d). Presently, Kenya is internationally considered to be a low forest cover country with less than 10% of its total land area classified as forest (MOENR, 2007). The government can however, achieve this level of forest cover through promoting farm forestry, intensify dryland forest management and involve private sector in the management of industrial plantations. It can also achieve this by promoting community participation in forest management and conservation. Consequently, small-scale farmers can as well contribute to increase the production of trees as they may attain market intelligence for their products, better technical knowledge and support for management (MOENR, 2007).

Paragraph 1 g of same article state that processes and activities that are likely to endanger the environment should be eliminated (Table 4). This shows that since eucalyptus is believed to consume much water and likely to reduce the water table, the environmentalists may discourage the small scale farmers from planting eucalyptus species. This result agrees with a report by ULRC (2006) that environment shall be managed, protected and preserved from abuse, pollution and degradation.

Table 4. Policies and legislations in the sectors of environment, land, energy and forest in Kenya

Sector	Article	Paragraph	Policy statement	Ref
Environment	42	1(d)	No person shall introduce any part of a plant specimen, whether alien or indigenous, dead or alive in any river , lake or wetland	1
Land			Government shall;	5
	64	1	1. Establish an appropriate land taxation system to mobilize revenue and discourage land speculation on public land	5
	77	1(b)	2. Establish a mechanism for creating leasehold interests out of public, community or private land as long as the terms of the lease is less than the residual terms	5
	77	1(e)	3. Ensure that duration of all future lease will be 99 years or less and subject to revocation if they do not approved development conditions	5
Energy			Government shall;	3
	6.3.2	1	1. Promote co-generation to generate 300MW by the year 2015 and other commercial establishments where opportunities exist	3
		2	2. Undertake appropriate studies on co- generation	3
	6.3.2			
	6.4	1 (i)	3. Continue to collect hydrological data and undertaking pre- feasibility and feasibility studies on small hydro, including wind regimes and solar installation	3
	6.4	1(ii)	4. Promote feasibility studies on the utilization of municipal wastes as a source of energy	3
	6.4	1(vii)	5. Promote the development of appropriate local capacity for manufacture, installation, maintenance, and operation of basic renewable technologies such as bio- digesters, solar water heating systems and hydro turbines	3
	6.4	1(xi)	6. Promote growing of appropriate trees for production of feedstock for manufacture of biodiesel	3
Forest			Government shall;	4
	1.4	1.4.1	1. Develop a mechanism to ensure that private sector manages plantations through appropriate incentives like land leases, agreements and concessions	4
	1.4	1.4.3	2. Broadened species base through special consideration of indigenous species as well as the requirement of market	4
	1.6	1.6.1	3. Develop a mechanism to ensure that forests and other woody vegetation on local authority land will be sustainably managed to satisfy local forest based needs and conserve biological diversity	4
			Legislation statement	
Environment			The state shall ;	2
	69	1 (b)	1. Work to achieve and maintain a tree cover of a least 10% of the land area of Kenya	2
	69	1(g)	2. Eliminate processes and activities that are likely to endanger the environment	2
Land			Parliament shall enact legislation to;	2
	63	1	1. Provide more power to community land owners based on ethnicity and culture	2
	63	4	2. Community land shall not be disposed of or otherwise used except in terms of legislation specifying the nature and extent of the rights of members of each community individually and collectively	
	68	1	3. Prescribe minimum and maximum land holding acreage in respect of private land	2
	68	2	4. Regulate the manner in which land may be converted from one category to another	2

[1]GoK (1999) [2]KLR (2010), [3]MOE (2004), [4]MOENR (2007), [5]MOL (2007)

A study of WMO (1997) reports that burning of coal, oil, natural gas as well as deforestation and other agricultural practices as some of the human activities that have altered the composition of gases in the atmosphere in ways that contribute to negative climate change, hence endangering environment. However, the rate at which small- scale farmers produce trees at present may be reduced as a result of some parts of the new legislations, specifically those related to tree planting and management of eucalyptus in the wetlands

The Land Act (article 63, paragraph 1) of new constitution 2010, provide more power to community land owners based on ethnicity and culture. Paragraph 4 of same article states that community land shall not be disposed, or otherwise used unless legislation specifies the nature and extent of rights of the members. The implications of new legislation on community land may as well affect tree planting activities and management by small-scale farmers in the similar manner. Article 68, paragraphs 1 and 2 of land act also prescribes the minimum and maximum size of land acreage a private individual can own and regulate the manner in which land can be converted from one form of use to another (Table 4).

The regulation on land conversion is applicable to the public land and community land in Kenya. The use of land and land based resources are based on the principle of sustainability, intergenerational equity, prevention, precautionary, and public participation (Akech, 2006). With reference to public land in Kenya, Environmental Impact Assessment is normally carried out in the context of precautionary principle before there is change in land-use (Aketch, 2006). Therefore, the small-scale farmers in this case do not have the capacity to be able to participate in tree planting and management activities on public land since the law requires an approval by government authority with a condition that an environment impact assessment is conducted. Moreover, this process sometimes is associated with bureaucratic procedures.

5 Conclusion and recommendations

From the survey of different studies, it can be concluded that the kind of alternative management regimes to be applied for eucalyptus species to enhance the positive effects and reduce negative effects attributed to eucalyptus varies depending on the location, rotation period, altitude, soil type and mean annual rainfall.

Weeding plantations of eucalyptus woodlots has a potential to improve productivity since there is less competition for soil water and nutrients. Better soil aeration and increase infiltration capacity may also contribute to productivity after weeding. Weeding is a practice that can be used by smallholders if labor is available. However, it reduces plant biodiversity as well as increasing soil erosion.

Intercropping eucalyptus species with legumes did not show a positive response in terms of tree production in any of the included cases suggesting that intercropping of legumes may not be the best way to enhance eucalyptus production. However, for small-scale farmers the production of legumes may be useful as a more immediate source of fodder for their animals and forage for bees.

Intercropping eucalyptus with rice and beans enhanced eucalyptus production in the cases included in this study. This is particularly an option to be considered for smallholders as it contributes to food production apart from wood.

Fertilizers generally improved the productivity of eucalyptus woodlots. Nevertheless, excess use of fertilizers by small-scale farmers, especially nitrogenous fertilizers may lead to negative environmental effects and is under normal circumstances not affordable to smallholders. Therefore, fertilization must, however, be sufficient to provide only an optimal final yield and desired product quality.

It can also be concluded that the use of slash residues has the potential to improve the production of eucalyptus. This suggests that slash residues added nutrients and improve moisture holding capacity of the soil. It shows that slash residue management can contribute to the sustainability of the system as it can decrease the rate at which nutrients are exhausted from the soil. On the one hand, in the included studies, slash residues suppressed the undergrowth in the eucalyptus stands indicating that this practice may increase soil erosion apart from decreasing biodiversity.

The result of the meta study indicate that the impact of eucalyptus on the under growth plant diversity is on average more favorable compared to other commonly used trees in the tropics and sub-tropics. Therefore, it cannot be concluded in line with most previous studies that eucalyptus decrease biodiversity in the under growth as compared to other commonly used tree species in the tropics and sub-tropics. Hence, a negative effect on the under growth cannot be used as an argument to stop smallholders from cultivating eucalyptus.

The production of trees in general and eucalyptus in particular is unlikely to increase as the policies in the different sectors in Kenya give priority to the management and conservation of wetlands, indigenous trees, as well as co- generation of power using municipal wastes, solar system and hydro turbines. Therefore, small-scale farmers particularly those who own land in the wetlands or near any water body cannot be permitted to grow trees in such areas. As the short rotation period and ease of establishment that eucalyptus can offer was part of farmers' investment decision to plant trees it is likely that farmers will be less motivated to plant trees if eucalyptus no longer can be part of the investment considerations probably for a majority of the Kenyan farmers with eucalyptus woodlots. If the aim to increase the forest cover stands the present policies needs to be reviewed with alternative management systems.

It is also recommended for small-scale farmers to plant *Acacia measrsii* and *Albizia falcataria* as alternative tree species to eucalyptus for improving soil fertility, providing timber and other products since they are fasting growing trees.

In general, it can be concluded that much as these alternative management regimes may enhance productivity of eucalyptus woodlots, the challenge for small- scale farmers is how to manage them sustainably. Therefore, forest policies that take consideration of increasing production of eucalyptus and managing biodiversity with reference to these alternative management regimes should be developed in Kenya. More studies on eucalyptus can also be conducted with other management regimes not included in this study.

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Appendices

Appendix 1. Journals

1. Agriculture water management
2. Agroforest System
3. Biochemistry
4. Biology and fertility of soil
5. Ethiopian society of soil science
6. Forest Ecology and management
7. Indian Forester
8. Journal of Applied Ecology
9. Journal of Dry lands
10. Journal of sustainable development
11. Journal of tropical forest science
12. Journal of vegetation science
13. New forests
14. Plant and soil
15. Restoration Ecology
16. Small- scale forest economics, management and policy
17. Tree physiology
18. Tree Structure and functions

Appendix 2. Hypothesis testing using student's t-test

	Euc	other	diff	
1	27	18	9	81
2	19	18	1	1
3	27	16	11	121
4	19	16	3	9
5	23	21	2	4
6	26	11	15	225
7	24	21	3	9
8	23	11	12	144
9	26	21	5	25
10	24	11	13	169
11	46	68	-22	484
12	66	49	17	289
13	46	49	-3	9
14	66	68	-2	4
15	63	51	12	144
16	63	28	35	1225
17	63	32	31	961
18	30	10	20	400
19	57	21	36	1296
20	57	31	26	676
21	57	21	36	1296
22	57	31	26	676
23	20	9	11	121
24	20	20	0	0
	949	652	297	8369

N	24
Mean	12.375
variance	204.0707
St dev	14.28533

H_0 (testing the null hypothesis) 4.243855

$t_{23/0.005}$= 2.807

Hence the null hypothesis of equality of population means can be rejected at the 0.5% level of significance

i.e the probability is very low that the number of under growth species is lower under the other tree species included in the test compared to that of eucalyptus

Publications from
The Department of Forest Products,
SLU, Uppsala

Rapporter/Reports

1. Ingemarson, F. 2007. De skogliga tjänstemännens syn på arbetet i Gudruns spår. Institutionen för skogens produkter, SLU, Uppsala
2. Lönnstedt, L. 2007. *Financial analysis of the U.S. based forest industry*. Department of Forest Products, SLU, Uppsala
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