Evaluation of Tree Nursery Management Practices in Two Agro-ecological Zones of Central Ethiopia

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Dedicated to my "wife Erste Tesfaye

&

daughters; Menbere, Tihitina and Beshadu Belay"

for their confidence on my thoughts and decisions

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Abstract

The causes of deforestation in the highland and lowland zones of central Ethiopia are the population growth that leads to an increase in the demand for agricultural and grazing lands, wood for fuel, charcoal production and construction. Settlements in the forest sites are resulted in the conversion of forest lands into agricultural and other land use systems. The deforested areas can be changed through reforestation and natural regeneration. Hence, various developmental organizations involved in the production of planting stocks of different trees and shrub species in the nurseries of lowland and highland zones of central Ethiopia. The success of producing quality stocks is not clear and known. Therefore, the evaluation of nursery stock quality of selected nurseries and tree species is important to understand the factors that exhibit success and failure, in order to improve and develop the appropriate nursery management practices for the two agro-ecological zones of central Ethiopia. Three nurseries were selected from lowland and highland zones of central Ethiopia. The selected tree species were *Acacia albida*, *Eucalyptus camaldulensis* and *Grevillea robusta* from lowland zone and *Acacia mearnsii*, *Eucalyptus golobulus* and *Hagenia abyssinica* from highland zone. Results showed that the tree species from lowland and highland tree nurseries responded differently to the mean shoot height, mean root length, mean root collar diameter and shoot and root dry weight. In Bushoftu and Godino nurseries, the *Eucalyptus camaldulensis* nursery stock showed significant differences in mean shoot height, mean root length and mean root collar diameter. In Bekate and Garmama the nursery stock of *Acacia mearnsii* did not show significant differences in the mean root length. In Bekate, Garmama, and Menagesha nurseries the *Eucalyptus globulus* did not show significant differences in the mean root length and also in Bekate and Menagesha, the *Eucalyptus globulus* nursery stock did not show significant differences in the mean root collar diameter. According to the tree species in the other tree nurseries significant differences ($p \leq 0.05$) have been found for mean shoot height, mean root length and mean root collar diameter. Differences in shoot and root dry weights values have been found too. Based on the results of nursery management practices, nursery stock parameters and stock quality criteria, the growth of most of the studied tree species in Garmama nursery from the highland zone of central Ethiopia is relatively better than in other nurseries. Similarly, the studied tree species in Modjo nursery from the lowland zone of central Ethiopia have shown promising nursery stock quality as compared to the other nurseries. Based on the discussion of the analysis of the parameters for stock quality test recommendations for further research are given.

Keywords: Nursery management, Seedling quality, *Acacia albida, Acacia mearnsii, Eucalyptus camaldulensis, Eucalyptus globulus, Grevillea robusta, Hagenia abyssinica*

Kurzfassung (German language)

Die Bewirtschaftungspraktiken in drei Baumschulen der agroökologischen Zonen in Zentral-Äthiopien wurden analyiert. Dabei wurden die qualität von Containerpflanzen an ausgewählten parametern für Akazie .albida, Eukalyptus camaldulensis und Grevillea robusta vom Tiefland und Akazie mearnsii, Eukalyptus globulus und Hagenia abyssinica vom Hochland untersucht. Die resultate dieser Arbeit zeigten signifikante unterschiede für die mittlere Spross –und Wurzellä nge, den mittleren Wurzelhalsdurchmesser und das Trockengewicht von Spross- und Wurzel für die untersuchten Pflanzen in den Baumschulen. In den Baumschulen von Bushoftu und Godino zeigte Eukalyptus camaldulensis Unterschiede im Wachstum der Spross –und Wurzellänge sowie dem Wurzelhalsdurchmesser. In den Baumschulen von Bekate und Garmama hat Akazie mearnsii keine signifikanten unterschiede bezüglich der Wurzellängle. Für Eukalyptus globulus zeigten sich bei bekate, Garmama und Menagesha keine signifikanten Unterschiede in der Wurzellänge und keine signifikanten Unterschiede im Wurzelhasdurchmesser für die Baumschulen Bekate und Menagesha . Jedoch zeigten alle anderen untersuchten Pflanzen in nden Baumschulen signifikante Unterschiede für die mittlere Spross- und Wurzellänge, den mittleren Wurzelhalsdurchmesser und das Trockengewicht von Spross- und Wurzel. Basierend auf den Resultaten der Wachstumsparameter kann festgehalten werden, dass die untersuchten Pflanzen der Baumschule in Garmama verhältnismäßig besser abschneiden als die Pflanzen in den anderen Baumschulen im Hochland. In ähnlicher Weise weisen auch die Pflanzen der Baumschule Modjoein vielversprechenderes Wachstum verglichen mit den Pflanzen der anderen Baumschulen in der Tieflandzone auf. Die Bedeutung von Spross- und Wurzelschnitt sowie die Zusammensetzung des Substrats für das Wachstum der Pflanzen wird diskutiert. Basierend auf der Analyse ausgewählter Qualitätskriterien für die Bewirschaftung von Baumschulen werden Empfehlungen für zukünftigen Forschungsaktivitäten gegeben.

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Abbreviations

A.	Acacia
AEZ	Agro-Ecological Zone
ANOVA	Analysis of Variance
cm	centimetre
DMRT	Duncan Multiple Range Test
DFSC	Danida Forest Seed Center
E.	Eucalyptus
FAO	Food and Agricultural Organization of the United Nation
H.	Hagenia
GDP	Gross Domestic Product
gm	gram
G.	Grevillea
GTZ	German Technical Cooperation
ICAF	International Center for Research in Agroforestry
IFS	International Foundation for Science
IUFRO	International Union of Forest Research Organization
MoA	Ministry of Agriculture
NCS	National Conservation Strategy
RMRS-P	Rocky Mountain Research Station-Proceedings
SPSS	Statistical Packages for Social Sciences
UNEP	United Nations Environmental Protection
USDA	United States Department of Agriculture
VITA	Volunteers in Technical Assistance

1 Introduction

1.1 Natural Resources Management in Ethiopia

Ethiopia occupies the interior of the eastern Horn of Africa stretching between 3° N and 15° N latitude and 33° E and 48° E longitude, with the total area of 1.13 million km^2 (Anonymous, 1988, cited in MoA & GTZ, 2001). Ethiopia is largely an agrarian country with over 90% of its population living in rural areas. The subsistence agricultural sector engages nearly 85% of the work force. Agriculture is the cornerstone of the economy of the country contributing about 53% of the GDP and accounts for more than 90% of all exports. It is the ninth largest country in Africa, while its population of about 74 million (Anonymous, 1996, cited in MoA and GTZ, 2001), with about three percent annual growth, makes it the third most populated country in the continent. The average population density in Ethiopia is about thirty four persons per square kilo meter and these ranges between 8 and 95 persons per square kilo meter (Anonymous, 1988, cited in MoA & GTZ, 2001).

Ethiopia is the country of great geographical diversity with high and rugged mountains, flat-topped plateaux, deep gorges of incised river valleys and rolling plains. Over time, erosion, volcanic eruptions, tectonic movements and subsidence have occurred and continued throughout millennia to accentuate the unevenness of the surface (Anonymous, 1988, cited in MoA & GTZ, 2001). Altitude range from the highest peak, Ras Dejen of 4620 m. above sea level and down to the depression of the Kobat Sink (Afar Depression), about 110 m below sea level. Most of the country consists of high plateaux and mountain ranges with precipitous edges dissected by numerous streams, which are tributaries of the major rivers. The rift valley separates the western and south-eastern highlands, and the highlands on each side give way to vast semi-arid lowland areas in the east and west, especially in the south of the country. The physical conditions and variations in altitudes have resulted in a great diversity of climate, soil and vegetation.

The central lowland and highlands of Ethiopia are heavily populated and characterized by smallholder cereal-livestock farms. Increasing population pressure has led to an increased demand for more forest products and agricultural land resulting in the destruction of the natural vegetation, overgrazing and expanding of farming activities into marginal and more fragile ecosystems. Since no or insufficient production inputs are applied on these soils, average yields tend to stagnate or to decline.

In Ethiopia, the natural resources and the general biological and social environments have been badly degraded over the past several years. This was mainly due to the renewable resources and development initiatives falling behind in the race to keep up with the rise in consumption levels and demands for better standards of living from a rapidly increasing population (NCS, 1999). The forest resource, as an element of environment, is not an exception. Indiscriminate clearing of the forest for construction, fuel wood, charcoal production, cultivation, overgrazing and exploitation without replacement reduced the high forest areas down to less than three percent of the total land area of the country. The situation has been exacerbated as more area has been turned to agricultural production. The high rate of deforestation and the ruthless exploitation of forest could be resulted in serious ecological and socio-economic problems. Large areas of the country are now exposed to heavy soil erosion and only relic patches of natural forests are located in the south-east, south and south-west of the country. The scarcity of fuel and construction wood is so chronic that it almost affects every household across the country. Moreover, as the result of loss of vegetation, large areas of the country are now exposed to severe soil degradation (Bishaw, 2003). It is estimated that fertile topsoil is lost at a rate of one billion cubic meters per year (FAO, 1981; UNEP, 1983; Constable, 1985; Kuru, 1990 and Yirdaw, 1996 cited in Bishaw, 2003), resulting in a massive land and environmental degradation and serious threat to sustainable agriculture and forestry. The level of deforestation is so severe that if the problem continues unabated, the remnant forests are also expected to be destructed within a short period of time.

The major cause of deforestation in Ethiopia is the increasing population growth which has resulted in extensive forest clearing for agricultural use, overgrazing, and exploitation of existing forests for fuel wood, fodder and construction materials. The current rate of deforestation in the country has to be estimated to be 160-200 thousand ha (Bishaw, 2003). The lack of appropriate land-use and forest policy and corresponding law also aggravated the rate of deforestation in the country. On the other hand, new settlements in forested areas are increasing from time to time and hence resulted in the conversion of forested areas into agricultural and other land use systems. At present, the few remaining high forests are threatened by pressure from investors who are converting the moist evergreen montane forests into other land-use systems such as coffee, tea and flower plantations.

The lowland and highland parts of the central agro-ecological zones of Ethiopia have been covered by dense vegetation consisting of several tree species. This does not always true, since some parts of the region are characterised by harsh climates and stony or saline soils with scarce vegetation on them, as in some parts of the Afar triangle in the northeast, and very good climates in the south and south western part of the lowland central zones. The status of the vegetation in the central Ethiopia now is different from the past due to agricultural expansion, over-grazing and exploitation. According to FAO (1992) and Kojwang (1996), the major factor of environmental degradation and loss of natural cover is the lack of forest management plans. Depletion of vegetation cover on the land is the basic cause of soil erosion by water and wind (FAO, 1989). Removal of the vegetation has brought about desiccation, increased soil erosion by wind and rainwater, and shortage of wood and wood products. Consequently, the destruction of the ecosystem has resulted in recurrent drought leading to agricultural failure.

To alleviate the existing problem of the country, the governmental, non-governmental and interested groups or individuals involved in tree planting or afforestation programmes (http:/www.menschenfuermenschen.de/Projekte, August 01, 2007). Most forestry operations are undertaken in rural Ethiopia and a large number of human resources are required for forest nursery operations and afforestation. This is a major source of income for the rural communities living around the tree nurseries.

These days, governmental, non-governmental institutions and interested few individuals produce a huge number of trees and shrub seedlings in the nurseries of the highland and lowland agro-ecological zones of the central parts of the country. The successes of these nurseries to produce quality seedlings are not well known. The evaluation of nursery management practices is important to understand the influential factors that cause success and failure and to improve and develop good nursery practices for the two agro-ecological zones of the central Ethiopia using selected tree nurseries and species.

1.2 Tree Nursery Management Practices in Ethiopia

Reforestation is one of the most important strategies to reduce the current wood, feed and soil degradation problems in the country. Tree planting practices in Ethiopia encompass or cover all the agro-ecological zones of the country. Official Ethiopian statistics does not give complete information on tree nurseries, but the number has to be assumed with several thousands (according to author's experience). However, there are seedling production constraints such as high mortality rate due to low quality of seedlings. There is also limited information on nursery management practices and inappropriate shipment of tree seedlings from nursery site to planting areas (Figures: 1, 2, 3, and 4).

Figure 1: *Acacia mearnsii* nursery stock, raised in polythene tubes/ bags, is ready for the market (planting). The preparation for shipment is usually done as "hand work".

Figure 2: Common shipment of *Acacia mearnsii* seedlings from nursery site to planting area.

Figure 3: Inappropriate interim storage of *Eucalyptus globulus* seedlings before out planting.

Figure 4: Inappropriate shipment of *Eucalyptus globulus* seedlings using track from nursery site to planting areas

According to Riley and Steinfeld (2005), the common factors that influence nursery management practices are: seedbed preparation; substrate or soil mixture; seed sources and seed treatments; sowing depth; sowing date; mulching or shading and watering; root pruning; weeding; culling or sorting of seedlings. These nursery stock quality parameters should be used in Ethiopia to produce good quality seedlings of different tree species. But these parameters are not common for nursery managers, not even in the state nurseries. So far, the efforts of international development organizations like the World Agro-forestry Centre and its regional sub-organizations did not yet reach the success which they deserve. Free available publications dealing with nursery management like Jaenicke 1999, and Wightman 2000, for example, did not reach those who are managing the highland and lowland nurseries of central Ethiopia. Moreover, some of the forest tree nurseries of highland and lowland zones of central Ethiopia have no well documented information on nursery management practices suitable for the tree species of regional importance. Finally, quality standards for high quality nursery crop are urgently needed which include the nursery-afforestation site interaction (the target seedling concept: Landis 2002).

The tree nurseries under this study are also producing seedlings of different tree species only based on the experiences of the staff working in the nurseries for long duration. All the forest tree nurseries of the two selected agro-ecological zones of central Ethiopia raise seedlings of different tree species from year to year and distribute them to the end users for out planting in the field for various objectives. According to the observations of the author's long time experiences, most of the out planted tree species were poor and low in regard to survival and growth rate. The main reasons for the low survival and growth rate of the out planted seedlings could be the lack of appropriate nursery management practices and also the lack of the knowledge of tree seedling quality requirements.

The evaluation of nursery management practices in the two agro-ecological zones of central Ethiopia could be considered to be the base to start the research on evaluation of nursery management practices in this country.

1.3 Objectives

1.3.1 General objective

The general objective of this study is:

- To evaluate nursery stock quality of some selected forest tree nurseries from two agro-ecological zones of central Ethiopia based on the seedlings' metric traits and selected quality indictors for a set of tree species,
- To provide a first description of the Ethiopian nursery management practice, and
- To develop suggestions for future research considerations in order to improve the common nursery practice.

1.3.2 Specific objectives

The specific objectives of this study are:

- To evaluate nursery stock quality based on mean shoot height, root length, root collar diameter, shoot and root dry weights of *Acacia albida*, *Eucalyptus camaldulensis* and *Grevillea robusta* seedlings in the three nurseries of the lowland agro-ecological zones of the central Ethiopia
- To evaluate nursery stock quality based on mean shoot height, root length, root collar diameter, shoot and root dry weights of *Acacia mearnsii*, *Eucalyptus globulus* and *Hagenia abyssinica* seedlings in the three nurseries of the highland agro-ecological zones of the central Ethiopia
- To find relations between nursery management practices and growth performances.

1.4 Hypothesis

The main hypotheses of the study are:

- The tree nurseries in the lowland and highland agro-ecological zones of the central Ethiopia apply different management practices, respectively;
- The nursery stock characteristics of each single tree species are similar across the respective agro-ecological zone of central Ethiopia; and
- The tree nursery management practices in the lowland and highland agro-ecological zones of the central Ethiopia have an influence on the growth performances of seedlings of the tree species.

2 Forest Nursery Management Practices – a Review

2.1 Tree Nursery Management Practices

For hundreds of years, tree seedlings have been raised in out door, bare root nurseries and out planted in the field with reasonable success (Duryea and Landis, 1984). In the 1950's and 1960's, however, interest in raising and out planting container grown seedlings on a large scale arose in North-America and elsewhere to shorten the production period and make more efficient use of genetically improved seed (Duryea and Brown, 1984). The hypothesis in using container was the automation and acceleration of production and planting and there were some spectacular biological failures (Duryea and Brown, 1984). Physiologists recognize the opportunity to utilize controlled environments for growing seedlings adapted to specific sites (Jaenicke, 1999). In the 1970's intense research on seedling physiology made possible reliable container seedling production and virtual field success (Duryea and Brown, 1984).

Successful plantation establishment depends on the use of seedlings whose morphological and physiological characteristics meet targets associated with favorable growth and survival under an anticipated range of site conditions (Davis and Jacobs, 2005). Moreover, successful seedling production requires a functional nursery root system which is capable of supplying adequate water and nutrients to meet seedling demands after out planting (Rose and Haase, 2005).

Forest tree nurseries are the place of which seedlings of various tree species are produced. By establishing forest tree nurseries, foresters give the suitable conditions for seeds to germinate uniformly, and seedlings to grow vigorously (Mansur and Sukendro, 2003). There must be several requirements or considerations to be fulfilled for the selection of nursery sites, i.e. they should be closer to the permanent source of water; the nurseries should have workers; the areas of the nurseries are relatively flat; they should have good accessibility; they have to be free of extreme condition (very hot, very cold, strong wind, dry or flooding etc.); and if possible the nurseries should be close to the planting sites. A permanent water supply is the determinant factor for the continuous production of tree seedlings in the nursery. Careful considerations could be needed before the establishment of forest tree nurseries. In general, in Ethiopia as well as in other parts of the world, tree seedling production could be conducted during the dry season to be ready for planting in the following rainy seasons. Therefore, the fluctuation of water flow in the river or canal and water availability in the lake or pond needs to be observed before the establishment of tree nurseries.

Forest tree nursery management practices include the silvicultural activities which could be carried out in the tree nurseries. These silvicultural activities are sowing of seeds, watering, mulching, shading, weeding, root pruning, shoot pruning (sometimes when the seedlings are too long), culling or grading the seedlings and finally distributing the seedlings for out planting in the field (Daniels and Simpson, 1994; Rose and Haase, 2005). Based on the type of trees or shrub seedling production, the forest tree nurseries are divided into bare-root and container types.

2.1.1 Bare root Nursery

Knowledge on interaction between nursery management practice and plant performance (plant quality) was created from bare root nursery experiments.

Bare root plants are cultivated in open ground, uprooted mechanically, sorted by size, packaged in tufts and delivered at the location of the plantation with their roots usually bare. The production of these plants usually begins with a sowing on nursery seed beds, outdoors. The sowing will be more or less dense according to the species; a sowing that is too dense will harm the development of the roots, the stems and the leaves: the plants will end up being pockmarked and badly lignified.

In bare root nurseries, it is possible to produce tree seedlings with maximum root development and growth. Each nursery, however, has its own unique combination of climate, soils, species, and stock types for which site specific cultural practices are necessary (Riley and Steinfeld 2005). It is also suggested that the production of planting stock with a large, vigorous root system and a shoot-to-root ratio to match the needs of the out planting site is a key element in successful seedling establishment. Forest tree seedlings with good lateral root formation throughout the entire root system have been shown to have higher survival and growth rates than the tree seedlings with poor root systems, or those with few lateral roots (Hermann 1964; Lopushinsky

1976; Rose et al. 1991 cited in Riley and Steinfeld, 2005). Good seedling root development in the tree nurseries is simply decisive for seedling survival.

Understanding of the tree seedlings root physiology and the effects of tree nursery cultural practices on the overall tree seedling physiology is a means to improving seedling quality at a production nursery and producing a target seedling that matches better to the requirements of out planting sites (Duryea, 1984).

According to Riley and Steinfeld (2005), tree nursery management practices can affect seedling root and shoot development which includes; soil cultivation and amendments; timing of sowing; seedling spacing and seedbed density; timing and depth of root culturing, such as undercutting and wrenching; timing of transplanting and alternative stock types.

Transplanting the tree seedlings onto a bigger surface area could give them the space to develop properly. This does not only enhance the development of the tip and the roots, but also prepares the seedlings for their final transplantation: they could therefore be able to adapt better to the more hostile environment that awaits them.

The sowing dates for obtaining a target seedling is dependent on the soil types and climate conditions of the nursery site. A delay in tree seed sowing may adversely affect seedling size at the end of the growing season, expose very young seedlings to summer seedbed heat and moisture stresses, and affects timing of dormancy in the fall. As a general rule, sowing is best done as early as possible to get plantable size of seedlings at the time of out planting. Early seed sowing can have a major role in the prevention of damping-off seedlings and root diseases by taking advantage of soil temperatures that are warm enough to start seed germination, but cool enough to restrict the lethal activity of damping-off and disease caused by Fusarum spp. (Jankinson and Nelson 1986; Filer and Peterson 1975 cited in Riley and Steinfeld 2005).

Both spacing within and between rows of seedlings of bare root seedlings significantly affected shoot height, root collar diameter, root dry weight and shoot dry weight, but not the root to shoot ratio (Cicek, et al., 2007). They also observed that wider spacing produced larger seedlings, but only the wider spacing within rows significantly increased fine and coarse root mass.

Seedbed densities in bare root nurseries vary widely depending on the type of tree species and stock type (Riley and Steinfeld, 2005). Tree nursery cultural practices such as root pruning which disturb the root systems of seedlings are common practices in most bare root nurseries. Tree seedling root culturing is implemented in the seedbed to alter various aspects of seedling morphology. The tree seedling root culturing is most commonly used to stop seedling height growth, decrease shoot-to-root ratios, improve root fibrosity, and the precondition of seedlings for planting (Duryea, 1984).

Root pruning in bare root nurseries is useful to create tree seedlings with more fibrous root systems that make easier to pull seedlings from the ground during lifting operations and easier to root prune in the packing operations. Without horizontal root pruning or wrenching, taproots can grow several feet deep, making lifting very difficult (Riley and Steinfeld, 2005) and they have also expressed that unpruned seedlings are difficult to prune in packing operations; taproots at 20 and 30 cm from the cotyledon scar, the most commonly requested root pruning lengths, often have calipers between 3 and 6 mm.

2.1.2 Container Nurseries

Containerised plants are common in forestry of the developed countries. Seedlings are cultivated in different types of plastic containers according to species afforestation conditions. The substratum in which the seedlings are raised in Europe is mostly a mixture of peat, sand, and sometimes of ground bark (Van Lerberghe and Balleux, 2001). The advantage of peat can improve the water holding capacity and the bark can also improve the bulk density and drainage (Riley and Steinfeld, 2005). The plants could be delivered with their substratum, and generally in their containers which need to be removed before the plants are planted.

Landis et al. (1990), report that the containerized tree seedlings have a better survival rate, are easier to plant, have more immediate growth response benefits, and are easier to produce and plant than bare root seedlings. Therefore, many tree nurseries have changed from bare root to containerized seedling production and the demand for container produced planting stock or tree seedlings continues to increase every tree planting season.

The existing tree seedling production techniques in forest tree nurseries involve sowing of seeds in containers and on seedbeds. Germinated seedlings can be transferred or transplanted into containers as well as collected wildlings are useful for further cultivation in containers. In comparison of the huge variety of different hard and soft wall containers, which are available all over the world, polyethylene bags are easily available. At the other hand, they have some disadvantages like limited life span and the risk of root deformation. It is commonly observed that this method produces tree seedlings having a deformed taproot, which can affect the overall root development (Cedamon, et al., 2005). Smallholder tree farmers have historically used low quality tree seedlings in their woodlots, probably due to the type of nursery containers and nursery cultural treatments applied to the planting stock. Overgrown seedlings at the time for planting out, due to the problem of matching seedling readiness with the time of demand, often lead to low quality seedlings with root deformation or J-rooting (Mangaoang and et al., 2005). The lack of adequate knowledge in tree seedling production techniques may hinder the tree nursery operators in the production of high quality seedlings.

The containers used for tree propagation methods can be made in various forms, sizes, type, volume, shape and from different materials. These materials are polystyrene, polyethylene, polythene tubes, fiber or paper. The type of containers used could depend on the type of tree seedlings to be raised and the purpose of the tree seedlings needed and the size of the tree seedlings (Van Eerden and Gates, 1994).

A better alternative to polybags as potting containers is root trainers (Cedamon, 2005). Root trainers are usually rigid containers with internal vertical ribs which direct roots straight down to prevent sideways growth. The containers could be set on frames above the ground to allow natural air-pruning of roots as they emerge from the containers. The latest developments also encourage natural air pruning. Seedlings grown in root trainers have more vigorous and rapid root growth than seedlings grown in polybags and the survival rates at out planting and in the long term are much higher (Cedamon, 2005). Plants grown in root trainer systems could often ready for planting out when they are substantially smaller than those from conventional polybags. This helps to reduce requirements for space and potting mix in the nursery and transport costs to the field (Jaenicke, 1999).

There is variation in early root development between newly planted bare root and container seedlings. Rose and Haase (2005) approved that reforestation foresters note that container seedlings often initiate roots sooner and produce more roots than bareroot seedlings during the first spring after out planting.

The container seedlings could be out planted with the nursery soils existing in the container and less growth medium immediately surrounding the roots, which may lead to more rapid root development because of greater organic matter and increased water-holding capacity compared to bare root seedlings. The difference in nursery management practices and also the result in root characteristics between stock types, differences in root development following out planting could likely to exist but have yet to be adequately quantified.

Polybags could be the containers most generally used in the tree nurseries of the developing countries. The common problem with polybags is that the tree seedling roots tend to grow in spiral once they hit the smooth inner surface, which inevitably lead to plants with restricted growth, poor resistance to stress and wind-throw and even early dieback due to ensnarled root masses or pathogens (Jaenicke, 1999). However, another problem may be arising when seedling roots reach the bottom of the bag, where they may be deformed or enter the soil. However, the most common problem with all containers is the type of substrate used (Jaenicke 1999). In developing countries the most commonly used substrates are soil and sand based mixtures which are unsuitable for the development of an extensive fibrous root system (Jaenicke, 1999).

2.2 Tree Seedling Quality

The most important goal of forest tree nursery managers is to produce high quality tree seedlings. Mattsson (1996) defined seedling quality as "fitness for purpose" and attributes for assessing seedling quality are grouped in "material attributes" that can be rapidly assessed by any number of direct or indirect methods and "performance attributes" that are assessed by subjecting whole seedlings to certain environmental regimes and evaluating their growth response. Tree seedling quality is a term used to describe the extent to which a tree seedling may be expected to successfully survive and grow after out planting (Duryea 1985; Mattsson 1996). Tree seedling quality is heavily dependent on factors such as tree species, tree nursery culture, storage methods, planting site conditions and genetics. A quality tree seedling can be defined as one that will succeed once out planted in the field (Jacobs, et al. 2004; Wilson and Jacobs, 2006). For many decades, various measurements of morphological and physiological characteristics have been used as a tool to predict field performance of tree seedlings and their ability to tolerate mechanical and environmental stresses. A primary goal of seedling quality assessment has been to quantify levels of morphological and physiological attributes that result in an accurate assessment of tree seedling conditions and potentials for vigorous growth and development. Evaluation of the different techniques used in tree seedling quality assessment, particularly with physiological analysis has also been of major importance (Wilson and Jacobs, 2006). Research carried out on the nursery cultural treatments and procedures that result in optimal levels of these parameters have been of prime importance as has the evaluation different methods of assessment. The tree seedlings stock qualities are based on morphological characteristics of the plants and environmental conditions are highly significant for plant performance also (Stape et al., 2001). Tree seedling performance is dependent on physiological short-term effects related to survival and long-term effects of genotype/root morphology related to tree development. Good tree seedling qualities are the basis for tree planting success. The genetic improvement of trees can be obtained through the use of improved seeds and clones. Other forest establishment improvements including planting site preparation, fertilization, pest and weed control (Simoes et al. cited in Stape et al., 2001). The main morphological attributes used to address stock quality are: single leadered stem, height, root collar diameter, leaf area, health, leaf hardening, stem suberization and straightness of tree seedling, root activity and morphology, and adequate container/substrate consistency and moisture (Simoes 1987; Guerreiro and Colli 1984, cited in Stape et al., 2001)). Tree seedling shoot height and root-collar diameter are widely used to assess the quality of nursery seedlings, and in many cases these variables have been correlated with seedling survival and/or growth after out planting (Thompson 1985; Bayley and Kietzka 1997; Jacobs et al. 2005 cited in Davis and Jacobs 2005).

Among the two main aspects of the tree seedling qualities the first aspect is the genetic quality or the source of the tree seed and the second component of tree seedling quality is its physical condition when it leaves the nursery for out planting (Wightman, 2000). The quality of tree seedlings produced in the nursery depends mainly on the seeds used (seed sources). The quality of seeds sown in the nursery is of crucial importance in the production of quality tree seedlings.

And tree seeds are the most basic input of any afforestation and reforestation programme. It is, therefore, necessary to pay proper attention to quality issues when procuring and subsequently storing tree seed until sowing in the nurseries.

Tree nursery seedbed density, shading, pricking out techniques, seedling size at planting, watering and fertilizing before and after planting out, have significant and long-lasting effects on the seedling qualities.

Tree seedling stock quality testing is considered to be a world wide program of a vital component of forest regeneration. According to Mohammed (1996), the stock quality test consists of stock quality control during seedling production at the tree nurseries and planting stock quality assessment prior to planting. The successful tree planting can be established by planting appropriate quality of tree seedlings. The quality tree seedlings could be planned and prepared to plant in different planting sites. Tree seedlings may seem to be different from each other but they all have a well-developed root system with many root tips from which new roots can emerged. Tree seedlings with well developed roots can show a good growing performance and high survival rate in areas with adverse environments, such as moisture stress, dry weather, flooded, saline or nutrient-deficient sites (Jaenicke, 1999). Mohammed (1996) showed that there can be a variety of reasons for incorporating stock quality test into a seedling production or planting program. These include determination of the timing of nursery operations; improvement of nursery, shipping, and planting procedures; culling of nonviable stock; matching of planting stock to site; and prediction of survival and growth in the field.

Tree seedling quality concept is widely used in forestry and it is given a considerable attention in the world of afforestation and reforestation (Jaenicke, 1999). The seedling quality concept is important because tree seedlings for afforestation cannot receive the same care as of that may be given to individual ornamental or fruit trees.

Tree seedling quality depends upon the ability of seedlings to produce new roots after out planted in the field (Janeicke, 1999), the speed with which seedlings get anchored in the ground, the ability to start assimilating and growing after planting out, because of having a well-developed root system, the sun-adapted foliage, having large root collar diameter and a balanced shoot to root ratio.

Seedling quality is determined by the two properties of tree seedlings such as physical features and condition. Evaluating both types of properties are critical to insure quality and successful planting and seedling establishment.

Several physical (morphological) features are used to assess or describe seedling quality, such as shoot height, root length, root collar diameter, and lateral root abundance. Unless altered during the handling and/or planting process, these physical features remain the same from the time of the seedlings are lifted at the nursery until they are planted and begin to grow. For this reason, seedlings should be inspected for acceptable physical features as soon as they are received from the nursery. One of the most important physical features that are vital to seedling survival is the relationship between the size of the root mass and the size of the foliage. Tree seedlings with far more foliage than roots (top-heavy seedlings) have a transpiring surface out of proportion to the absorbing capacity of the roots. Simply put, the foliage of top-heavy seedlings can transpire water out of the seedling faster than the roots can absorb water in to the seedling and as a result, seedlings can out and die. A last possibility for correcting the quality of a nursery batch is grading and culling before planting out in the field.

2.2.1 Shoot Quality Parameters

Seedlings shoot height is the physical or visually determinable attributes of a seedling. Out of several morphological characteristics, seedling shoot height is often used as indicator of seedling quality and predictor of field response (Rose et al. 1990; Dey and Parker, 1997), as it is relatively simple to measure (Racey 1985; Thompson 1985) and as it correlates with field success (Kaczmarek and Pope, 1993a; Dey and Parker, 1997). Tree seedling height at the time of out planting can greatly influences growth rate in the field (Duryea and Landis, 1984). It is the most attribute used to determine the sturdiness of seedlings (the ratio between seedling height and root collar diameter). The northern red oak (*Quercus rubra L.*) seedlings with root collar diameter greater than 8 mm and shoot heights greater than 50 cm were more competitive than smaller stock when planted on a variety of sites (Johnson 1992; Pope, 1993). Moreover, initial shoot height has provided inconsistent ability to predict seedling field performance for some species (Chavasse, 1977; Thompson and Schultz, 1995).

2.2.2 Root Quality Parameters

The seedling root quality is at least as important as the shoot quality in predetermining the survival and growth rates of the tree. The root quality depends amongst others, upon soil material. Root mass and root volume (Burdett 1979, cited in Thompson, 1985), root length and root area index (Morrison and Armson 1968, cited in Thompson, 1985), are common measurements of the root quality. Root mass and root volume do not give an accurate representation of the root fibrosity because seedlings with many fine roots may weigh or displace the same amount as one with a large tap root. Root mass is often correlated to seedling root collar diameter (Ritchie 1994, Mullin and Christl 1981, cited in Thompson, 1985) and thereby to survival and initial growth. Although root mass correlated to growth and survival of container loblolly pine seedlings, root collar diameter and stem weight were all better predictors (McGilvray and Barnet 1982, cited in Thompson, 1985).

Thompson (1985) founded that a quality seedling as one that possesses a large root system comprised of a high percentage of fibrous roots. The fibrous roots resulted in a large surface area for absorption of water and nutrients from the soil. Stone (1955) (cited in Davis and Jacobs 2005) determined that seedling physiological condition which is expressed by root growth potential at out planting could indicate potential for root and shoot growth and as this variable largely determined the capacity of the seedlings to mitigate drought stress.

The root system morphology can be different extensively depending on the species and the stock types. The container seedlings are out planted with the nursery soil or growth medium immediately surrounding the root, which may lead to more rapid root development because of greater organic matter and increased water holding capacity compared to bare root seedlings (Rose and Haase, 2005). The root system length and area provide a quantitative description of seedling root systems and can also be measured non-destructively (Davis and Jacobs, 2005).

2.2.3 Shoot to Root Ratio

Among the several tree seedling quality characteristics, the measurements of the shoot to root ratio is difficult to observe and/or requires destructive sampling methods (Jaenicke, 1999). The shoot to root ratio is an important predictor for tree seedling survival and growth rate. It relates the transpiring area (shoot) to the water absorbing area (roots) (Thompson, 1985). It is usually measured by determining the root and shoot dry weights. Jaenicke (1999) reported that a healthy tree seedling or plant can have (1:1 up to 1:2) shoot to root ratios.

2.2.4 Root Collar Diameter Growth

The tree seedlings root collar diameter growth is the morphological characteristics of seedlings used to assess the quality of tree seedlings and has also been correlated with seedlings survival and growth after out planted in the field. Jaenicke (1999) investigated that a less rigorous, but non-destructive, index is the 'sturdiness quotient' which compares seedling shoot height (in cm) over seedling root collar diameter (in mm). According to Jaenicke (1999), small ratios of sturdiness show a sturdy plant with a higher expected chance of survival, especially on windy or dry sites. Jaenicke (1999) also suggested that a sturdiness ratio of tree seedlings which is greater than six is not recommendable.

3 Material and Methods

3.1 Description of Nurseries Analyzed under this Study

The field data assessment was conducted from beginning of July 2006 until the end of September 2006. It was implemented in the two agro-ecological zones of Central Ethiopia, which are closer to the City of Addis Ababa. Among the three tree nursery sites of the highland agro-ecological zones of the central Ethiopia, Garmama tree nursery site was located in the northern direction of Addis Ababa at the distance of 40 kilo meters and Menagesha tree nursery site and Bekate tree nursery sites were located in the western direction of Addis Ababa at the distances of 30 kilo meters and 60 kilo meters, respectively. The altitude range of the highland tree nursery sites is from 2000m up to 3000m a.s.l., the annual mean temperature varies from 12.5°C to 18 °C and the mean annual rainfall ranges between 900 and 2000 mm (Table 1).

Although all the three tree nursery sites of the lowland agro-ecological zones of the central Ethiopia, such as Bushoftu tree nursery site at 40 kilo meters, Godino tree nursery site at 50 kilo meters and Modjo tree nursery site at the distance of 70 kilo meters were located in the eastern direction of Addis Ababa. The altitude range of the lowland tree nurseries sites is from 1200m up to 2000m a.s.l., the average temperature is 16°C to 27.5°C and the mean annual rainfall ranges from 650 mm upto1000 mm (Table 1).

Table 1: Meteorological Data of the Study Nurseries from Different Ecological Zones of Central Ethiopia and Sowing Date for the Nursery Crop Analyzed.

N0.	Nursery Site	AZE	Tree Species	Sowing Date	Mean Rainfall	Temperature Range	Altitude Range
1	Bushoftu	Lowland	*A. albida* *E. camaldulensis* *G. robusta*	08-03-2006 20-02-2006 30-01-2006	650-1000mm	16°C-27.5°C	1200-2000m
2	Godino	Lowland	*A. albida* *E. camaldulensis* *G. robusta*	05-03-2006 15-02-2006 23-01-2006	650-1000mm	16°C-27.5°C	1200-2000m
3	Modjo	Lowland	*A. albida* *E. camaldulensis* *G. robusta*	02-03-2006 22-02-2006 28-01-2006	650-1000mm	16°C-27.5°C	1200-2000m
4	Bekate	Highland	*A. mearnsii* *E. globulus* *H. abyssinica*	10-12-2005 15-02-2006 15-12-2005	900-2000mm	12.5°C-18°C	2000-3000m
5	Garmama	Highland	*A. mearnsii* *E. globulus* *H. abyssini*	15-12-2005 12-02-2006 08-12-2005	900-2000mm	12.5°C-18°C	2000-3000m
6	Menagesha	Highland	*A. mearnsii* *E. globulus* *H. abyssini*	12-12-2005 10-02-2006 10-12-2005	900-2000mm	12.5°C-18°C	2000-3000m

3.2 Description of tree species used under this study

3.2.1 *Acacia albida* (Del.) A. Chev.

Common names: Grar (Amharic), Apple-Ring Acacia (English)
Family: *Fabaceae (Mimosoidea)*
Genus: *Acacia*
Species: *albida*

The natural distribution of *Acacia albida* extends through northern Africa, from Senegal to Ethiopia, and southwards through East Africa to the Transvaal and Lesotho. The largest concentration of the species occurs on the sandy alluvial soils of the Jebel Mara (altitude of about 2500 m.a.s.l) drainage system in the Sudan, where pure stands are found in belts often a mile wide (Wickens 1969 cited in FAO, 1977). It is well grown and distributed in the lowland parts of the agro-ecological zones of the country. Growing *A. albida* as a permanent tree crop, on farmlands with cereals, vegetables and coffee underneath or in between, is an indigenous agro-forestry system in Ethiopia.

Acacia albida is one of the largest trees in the genus Acacia, reaching 30 m in height and 1.5 m in diameter (FAO, 1977). The bole of *A. albida* forms up to one third of height of a tree; bark dull grey, fissured when old, crown dense; tree puts out leaves during dry season and sheds them during rains.

The natural regeneration of *A. albida* from seed origin may be limited because of heavy seed predation and high seedling mortality (Wickens, 1969 cited in FAO, 1977).

The regeneration of *A. albida* by vegetative means is often more successful in nature and suckers may develop from the mother tree. Vegetative reproduction is the main means of natural regeneration where the natural stands produce viable seed.

According to (VITA, 1977 cited in Duke, 1983) "*Acacia albida* is highly valued in conservation efforts. It is the only species which loses its leaves during the rainy season; therefore, farming under these trees is not only possible but profitable." It is held sacred by the Africans of the Transvaal. In the lowlands and dried parts of Ethiopia the pods of *A. albida* is used as goat and camel food. The gum that exudes spontaneously from the trunk is sometimes collected like gum arabic. The timber of *A. albida* is though straight grained, close, and weighty and it is also soft, fibrous and unsuitable for agricultural implements (Watt & Breyer-Brandwijk, 1962). The pods and foliages of *A. albida* are highly regarded as livestock fodder. When most of other trees are leafless, peasants gather or collect and store pods of *A. albida* to feed the livestock or lop the foliage in the dry season. According to Duke (1983) and the author's observation the local communities also eat the boiled seeds of *A. albida* in the times of scarcity of food.

3.2.2 *Acacia mearnsii* De Wild.

Common names: Mimosa (Amharic), Black Wattle (English)

Family: *Fabaceae (Mimosoidea)*

Genus: *Acacia*

Species: *mearnsii*

Acacia mearnsii is native to Southeast Australia (Victoria to New South Wales and Southern Queensland) and Tasmania. It was introduced to Ethiopia and cultivated widely in the highland parts of the country for afforestation.

The tree or large shrub of *A. mearnsii* grows up to 6-10 m tall, sometimes reaches 25 m and with a diameter up to 60 cm (Duke, 1983 and DFSC, 2000). The bark of *A. mearnsii* is brownish-black, hard and fissured. The young branches of *A. mearnsii* are found with hairs. *A. mearnsii* has no thorns. The leaves of *A. mearnsii* reach the length of 8-12 cm and they are fern like (Duke, 1983 and DFSC, 2000).

The propagation of *Acacia mearnsii* by seed origin could be easy. The seeds retain their viability for several years (Duke 1983). For germination, the seeds of *A. mearnsii* are treated with boiling water and allowed to cool (Duke, 1983). This cracks the hard outer coat and facilitates germination. Seeds may be broadcast or sown in rows on any barren site. They can also be sown in containers. Normally two seeds are sown and surplus seedlings transplanted to empty pots. Seedlings are ready for out planting after about 4 months when they reach the length of 20 cm tall. Vegetative propagation of *A. mearnsii* is also possible using 10-15 cm cuttings with leaves (Duke, 1983).

Acacia mearnsii is used to produce high quality tannin, paper pulp, and wood for construction, firewood and charcoal (DFSC, 2000). Sometimes *A. mearnsii* is used for erosion control on poor sloping, soils unsuitable for agriculture, windbreaks and soil improvement. Densely packed plantations of *A. mearnsii* are effective in preventing further erosion on steep slopes (Duke, 1983). The use of tannin for production of waterproof wood adhesives is expanding (DFSC, 2000). *Acacia mearnsii* could be used to add nitrogen and organic materials to improve the soil and it is also a good source of green manure. Nowadays, *A. mearnsii* has to be recognized as aggressive colonizer that became a weed in some parts of the central highlands of Ethiopia.

3.2.3 *Eucalyptus camaldulensis* Dehnh.

Common names: Key bahir zaf (Amharic), River Red Gum (English)

Family: *Myrtaceae*

Genus: *Eucalyptus*

Species: *camaldulensis*

Eucalyptus camaldulensis is a common and widespread tree along water courses over much of mainland Australia. It is frequently a dominant component of riparian communities, and is an iconic and important species of the Murray-Darling catchments, both ecologically and economically. *E. camaldulensis* has important attributes such as tolerance to a wide range of soil type and PH and rapid growth and high wood yield for timber and fuelwood (Bhati and Singh, 2003).

Eucalyptus camaldulensis is one of the Eucalyptus species introduced or imported from Australia to Ethiopia and it shows promising grows in the lowland areas of the country where the moisture stress exists. Due to its natural adaptation to both temperate and tropical climates with winter and summer rains, *E. camaldulensis* is the most widely planted species in arid and semi-arid regions of the country (Ethiopia).

In Ethiopia, the wood of *Eucalyptus camaldulensis* has been used for construction materials, flooring, farming, fencing, plywood and veneer manufacture, firewood and charcoal production.

The seedlings of *Eucalyptus camaldulensis* are vulnerable to heat stress and immersion during the establishment phase. The seedlings cope with heat stress by developing roots giving good penetration into the sub-soil and accessing soil moisture. The seedlings also develop resilience early, allowing them to shed leaves in times of moisture stress and recover from auxiliary buds when moisture is again available (Dexter, 1978).

The seedlings of *E. camaldulensis* develop adventitious roots and aerenchymatous tissue to deal with anoxia resulting from immersion (Heinrich, 1990). Complete immersion, unless brief, is likely to kill seedlings; lower leaves of small saplings die if submerged for long periods (Roberts and Marston, 2000). The seedlings of *E. camaldulensis* increase tolerance to flooding with age. Two-month old seedlings can survive water logging for one month (Marcar, 1993), while seedlings 50-60 cm tall can survive extended flooding of 4-6 months and complete immersion for a few weeks by shedding leaves (Dexter, 1978). The competition of *E. camaldulensis* with weeds is very poor when it is young.

3.2.4 *Eucalyptus globulus* Labill.

Common names:Nech Bahir zaf (Amharic), Bluegum Eucalyptus (English)

Family: *Myrtaceae*

Genus: *Eucalyptus*

Species: *globulus*

According to Skolmen and Ledig, (1990), Blue gum Eucalyptus, also called Tasmanian blue gum, is one of the world's best known eucalyptus tree species. It is the "type" species for the genus *Eucalyptus* in California, Spain, Portugal, Chile, and many other locations.

Eucalyptus globulus was imported or introduced from Australia to Ethiopia as early as in the 1890s to solve the scarcity of the wood shortages of the country and has been successfully established throughout the country (Yirdaw, 2001). Consequently, Ethiopia has one of the longest histories of forest plantation development in Africa. At present, forest plantations in the country consist mainly out of *Eucalyptus* to an extent of about 93% of the total plantation area (Yirdaw, 2001). The plantation area of *E. globulus* is steadily increasing in Ethiopia. Eucalyptus is found to be well distributed around Addis Ababa and in all the highland parts of the country, as it became the main source of construction wood and of energy for the urban and rural people.

The newly germinated seedlings of *E. globulus* have inverse heart-shaped cotyledons, borne epigeously (Skolmen and Ledig, 1990). They also tried to elaborate the stems of *Eucalyptus globulus* seedlings, especially those grown in the shade, are usually square in cross section, often for as much as 3 to 5 m of stem length. These square stems usually have prominent ridges or "wings" at the corners. Juvenile leaves, which are opposite and broadly lanceolate, 9 by 9 cm, may persist for more than a year (Skolmen and Ledig, 1990). Trees in coppice stands, 6m or more in height, are often entirely in the juvenile leaf form. These juvenile leaves bear a bluish gray, waxy bloom and are the reason for the common name of the tree: blue gum.

Nursery-grown seedlings of *E. globulus* in containers reach plantable size, about 30 to 40 cm high in 3 to 4 months (Skolmen and Ledig, 1990). *Eucalyptus globulus s*eedlings can be established in planted with bare roots, but success is highly dependent on favorable wet weather after planting. *Eucalyptus globulus* seedlings are, therefore, usually grown in container and planted with a root ball. *Eucalyptus globulus* seedlings are not frost resistant. Due to the sensitivity of seedlings of *E. globulus* to frost, there will be seedling damage as the results of too much frost in the forest tree nursery.

Eucalyptus globulus has achieved the highest height growth at an age of 64 months in the central highlands of Ethiopia as compared to other indigenous and exotic tree species (Kindu, et al., 2006).

Nowadays, *Eucalyptus globulus* becomes one of the world's most valuable windbreak trees species because of its wind firmness and the unpalatable nature of its seedlings to grazing animals. Because of its ability to sprout along the stem, it can be hedged, thereby making effective sight and sound barriers along highways. The wind breaks of *E. globulus* are the most effective with an understory or adjacent planting of smaller trees and shrubs (Woodbridge, 1924).

The *Eucalyptus globulus* is a major source of fuel wood in Ethiopia and also in many other countries of the world primarily because of its ability to coppice after cutting. The wood burns freely, leaves little ash, and produces good charcoal (FAO, 1979). The tree shows promising characteristics for use as industrial fuel wood in order to substitute oil as source of energy (Skolmen and Ledig, 1990).

Eucalyptus globulus is much used for pulpwood, particularly so because its bark, acceptable in most pulping processes, adds greatly to the yield. It is used mostly for bleached products made by sulfate, sulfite, or bisulfite processes (FAO, 1979).

Other uses of *Eucalyptus globulus* include the extraction of essential oils from the leaves, honey production from the flowers (that are also good pollen sources), plantings for erosion control, and roadside plantings to provide a noise and headlight buffer (FAO,1979).

The wood of *Eucalyptus globulus* is heavy and shrinks greatly in drying and it is not suitable for lumber production. Sawing of logs is difficult and the quality of lumber is poor because of growth stress problems. The main uses of *E. globulus* are for mining timber, fence posts, and poles (Turnbull and Pryor, 1978).

3.2.5 *Grevillea robusta* A. Cunn. ex R. Br.

Common name: Silk oak (English)

Family: *Proteaceae/Protea*

Genus: *Grevillea*

Species: *robusta*

Grevillea robusta is native to coastal eastern Australia from the Clarence River, New South Wales, to Maryborough, Queensland, and is now naturalized in Hawaii and southern Florida (Francis, 1951, and Sreets, 1962). It is also introduced in Ethiopia since few years ago. *Grevillea* *robusta* is a medium to large tree commonly planted as an ornamental in many warm-temperate and semitropical climates. It has been established as a forest tree in some countries like Ethiopia and shows promise as a fast-growing timber tree.

Seed germination is epigeal. Seedlings are grown in flats (seed beds of bare root nursery) or containers in nurseries. Methods vary among the countries where silk oak is cultivated. In some countries 4 to 6 week-old wildings are lifted and potted and later replanted (Fenton, Roper and Watt, 1977). Plants are grown elsewhere to 45-cm height in large baskets so that they can compete when out planted (Y.R.A. and Rao, 1961). They also indicated that in Hawaii, seedlings in individual containers can be grown to a plantable size of 20 cm height and 4 mm caliper in 12 to 14 weeks.

In some parts of the African countries like Kenya, Ethiopia and others, *G. robusta* can be grown with agricultural crops and used as a tree species of agroforestry systems. The cultivation of maize combined with *G. robusta* agroforestry system covers about 750 000 ha in the highland area of Kenya (Muchiri, 2002). The majority of farmers usually grow maize for their own consumption. *Grevillea robusta* is the dominant component of the tree vegetation cover in the maize combined with *G. robusta* agro-forestry system in Kenya and is usually grown to produce timber, poles and firewood for sale. Yet, most families are entirely dependent on *G. robusta* as fire wood for cooking and warming. Because the trees are not felled before they attain a size that can produce timber, about 80 percent of the firewood is harvested when *G. robusta* is pruned and pollarded, and the remainder when suppressed trees are removed and large trees are harvested. *Grevillea robusta* is planted either in rows (alley cropping) or in less regular spatial arrangements (intercropping). In Kenya (Muchiri, 2002), *G. robusta* is intercropped with maize, beans, bananas, coffee, etc. and sometimes *G. robusta* is planted in pure stands (wood-lots) but the most common practice is to plant along the boundaries of a land parcel belonging to one family. The latter practice has resulted in conflicts among farmers because a dense row of large trees reduces the crops yield and tree growth of the neighbour farmer.

Grevillea robusta is a popular ornamental tree because of its fernlike foliage even in areas where it does not flower abundantly. In more tropical climates its showy flowers cause it to be widely used.

In Ethiopia, people started to use *G. robusta* as a windbreak and shade trees between the plantation of coffee and tea. *Grevillea robusta* is an important honey tree in India where it is also regarded as a good fuelwood producer (S.S and Sagwal, 1984).

The tree produces an attractively figured, easily worked wood, which was once a leading face veneer in world trade, where it was marketed as "lacewood." The wood contains an allergen that causes dermatitis for many people (Roger and Skolmen, 1990).

3.2.6 *Hagenia abyssinica* (Bruce) J.F. Gmel

Comon names: African Redwood (English), Kosso (Amharic language / Ethiopia)

Family: *Rosaceae*

Genus: *Hagenia*

Species: *abyssinica*

Hagenia is a mono-specific genus belonging to the family Rosaceae. The only species, *H. abyssinica* was once abundant in the semi-humid mountain woodlands of Ethiopia with the altitudinal range between 2450 and 3250 m (Hedberg, 1989 cited in Feyissa, et al., 2005). At present, the tree is sparsely distributed in mountainous central, central-west and southeastern parts of Ethiopia (Negash, 1995 cited in Feyissa, et al., 2005). Furthermore, this species is found also in Kenya, Tanzania, Uganda, Sudan, Congo, Malawi, Burundi and Rwanda (ICRAF, 2007)

Hagenia abyssinica is a slender tree which grows up to 20 m tall, with a short trunk and thick branches. First, *Hagenia abyssinica* was described in Ethiopia and also found in East Africa. This tree is often dominant in the woodland zone just above the mountain bamboo. *Hagenia abyssinica* grows at an altitude range of 2000 to 3000 m a.s.l. and needs a mean annual rainfall of between 1000 and 1500mm (ICRAF, 2007). *Hagenia abyssinica* is sometimes deliberately left in farmland or derived grassland and may be occasionally planted where it occurs naturally because of its medicinal properties.

Hagenia trees have either male or female flowers. Flowering and seeding can be observed throughout the year with a break in the months with the coldest temperatures. Pretreatment of seeds is not necessary and seeds germinate within 10-20 days of sowing with a germination rate of 40-60%. Trees can also be regenerated from seedlings or wildings (Hedberg, 1989 cited in Feyissa, et al., 2005). According to author's observation the seedlings of *Hagenia abyssinica* usually stay in the nursery for about more than eight months before out planting.

Hagenia abyssinica could be used as good sources of firewood and charcoal. Wood of *Hagenia abyssinica* is dark red, medium soft but not durable; it is used for furniture, poles, flooring, carving and cabinet making.

According to the reports of Bekele-Tesemma, Birnie and Tengnas (1993), the roots are cooked with meat and the soup drunk for general illness and malaria, while the dried and pounded female inflorescence is used as an anthelmintic (especially for tapeworm). They found that bark may be pounded, added to cold water and the liquid drunk as a remedy for diarrhoea and stomach-ache. This could be a strong medicine that must not be taken in large quantities; it is sometimes taken as an abortifacient. *Hagenia abyssinica* could be found as one of the most recommended tree species for erosion control. Trees are employed in soil-conservation activities and also serve as shade or shelter tree. The *Hagenia abyssinica* is a fire-resistant species which can be used as a firebreak. *Hagenia abyssinica* constantly sheds leaves, providing mulch and green manure to the soil (Bekele-Tesemma, Birnie and Tengnas, 1993).

3.3 Materials

Ecological site conditions vary to a remarkable extent in Ethiopia, which is mostly due to the remarkable variation in elevation of the land. Hence, a different set of tree species was selected for analyzing the quality of nursery stock in the two different ecological zones of central Ethiopia (see chapter 3.1). Each set represents important species for afforestation purposes and consists out of one species of the genus Acacia, one species of the genus Eucalyptus, and one further timber species. Amongst the species of each of the sets, one species is native to Ethiopia. The tree species which were chosen in the lowland zones of central Ethiopia were *Eucalyptus* *camaldulensis, Acacia albida* (indigenous tree species in Ethiopia) and *Grevillea robusta* (Table 1) and also the tree species selected in the highland zones of central Ethiopia were *Eucalyptus globulus, Acacia mearnsii* and *Hagenia abyssinica* (indigenous tree species) (Table 1).

All the tree species were raised in soft wall containers (colourless polythene tubes) with a diameter of 8 cm and a length of 12 cm. The polythene tubes for seedling production are open on both sides and simply placed on the naked ground of the nursery batch. The ripened container stock was used for quality analysis.

3.4 Methods

Three tree nursery sites from different three districts of the lowland agro-ecological zones of the central Ethiopia with common different three tree species such as *Eucalyptus camaldulensis, Acacia albida* and *Grevillea robusta* were systematically selected and used for field data assessment. In the same way, three tree nursery sites from different three districts of the highland agro-ecological zones of the central Ethiopia with common different three tree species such as *Eucalyptus globulus, Acacia mearnsii* and *Hagenia abyssinica* were also systematically selected and used for field data collection.

The following morphological features for determination of the seedling quality (see chapter 2.2.) were measured: shoot height, root length, root collar diameter, shoot dry mass as well as root dry mass. The instruments used during field data collection were measuring tape or ruler for measuring shoot height and root length, vernier caliper for measuring root collar diameter and sensitive electronic balance for measuring the shoot and root dry weights. All parameters were measured accurately to cm and mm (length and diameter) for each single plant. The dry weight was determined accurately to gm and ngm (nano gram) for a bundle of ten seedlings, whereby shoot dry mass was separately measured from root dry mass. Each bundle of shoots and roots was dried at 68° C for 48 hours in the National Seed Laboratory of the Ethiopian Forestry Research Center.

Furthermore, the sturdiness ratio (shoot height to root collar diameter ratio, see chapter 2.2.3.) were calculated for each single seedling. The shoot to root ratio was calculated using the total shoot- and root-weight of a ten-seedling bundle.

The current and reliable information on the management activities of the selected nurseries from the two agro-ecological zones of central Ethiopia was observed. The general information on the nursery and the management activities of all nursery sites were assessed using semi structured interview methods (Wells, 1992). A questionnaire was prepared for the interview (Appendix 31), which was done by talking to each of the nursery foremen during the visit of the respective nursery.

3.4.1 Data Collection

Sampling of seedlings was carried out at random, using a sample size of 100 seedlings per species and nursery. Thus, a total number of three hundred seedlings species were selected and measured in each nursery. Consequently, the total number of measured tree seedlings for the set of three tree species per agro-ecological zone was nine hundred, so that altogether 1800 seedlings were analyzed in this study.

According to shortage of funds, only one sub-sample of 10 seedlings was taken at random for each of the species at each nursery in order to measure shoot and root mass.

3.4.2 Data Analysis

The seedling shoot height, root length, root collar diameter growth and the shoot and root dry weights of the experimental tree species were subjected to One Way Analysis of Variance (ANOVA) using Statistical Packages for Social Sciences (SPSS) 10.0 for window for significant differences, P=0.05, independently. Independent analyses were executed for *Acacia albida*, *Eucalyptus camaldulensis* and *Grevillea robusta* for lowland study tree nursery sites and for *Acacia mearnsii*, *Eucalyptus globulus* and *Hagenia abyssinica* for highland study tree nursery sites of the central Ethiopia. Duncan Multiple Range Test (DMRT) was used for mean separation at alpha=0.05, using statistical analysis system, SPSS. Correlation analysis was run to check to what extent the parameters were associated. The correlation of species by seedling shoot height, by root length, by root collar diameter growth and species by shoot dry weight and by root dry weight in different tree nurseries were analyzed employing SPSS 10.0 package for window.

4 Results

4.1 Results from the Interview with Nursery Foremen

4.1.1 Soil Substrates for Container Filling

The field observation from each nursery foreman of all experimental tree nurseries from the highland and lowland agro-ecological zones of the central Ethiopia indicated that all used the same type of container fillings. These fillings were local soil, animal manure and sandy soil.

The ratios of the filling mixtures used among the nurseries were different (Table 2), with one exception. The ratios of the filling mixtures used in the highland tree nurseries of Garmama and Menagesha were identical using two parts (50%) of local soil, one part (25%) of animal manure and one part (25%) of sandy soil. But in Bekate nursery, the ratios of the soil mixtures used were four parts (57%) of local soil, two parts (29%) of animal manure and one part (14%) of sandy soil (Table 2).

The ratios of the filling mixtures amongst the lowland tree nurseries are completely divergent and indicated as follows (Table 2): Two enterprises, Godino and Modjo, use the same proportion of local soil (50%), but a contrasting proportion of animal manure and sandy soil (Table 2): 17%/33% in the case of Godino and 30%/20% in the case of Modjo, respectively. Moreover, Bushoftu nursery uses the highest ratio of local soil (60%) and at the same time one of the lowest proportion of animal manure (20%) compared to the remaining nurseries analyzed in this study

Table 2: Filling substrate ratio used by nurseries of two different zones of central Ethiopia

Tree nursery	AEZ	Filling substrate ratio [parts (%)]		
		Local soil	Animal manure	Sand soil
Bushoftu	Lowland	3 (60)	1 (20)	1 (20)
Godino	Lowland	3 (50)	1 (17)	2 (33)
Modjo	Lowland	5 (50)	3 (30)	2 (20)
Bekate	Highland	4 (57)	2 (29)	1 (14)
Garmama	Highland	2 (50)	1 (25)	1 (25)
Menagesha	Highland	2 (50)	1 (25)	1 (25)

4.1.2 Forest Tree Seed Sources

The tree nurseries of this study use different seed sources for the production of seedlings of tree species and shrubs. According to the information obtained from the nurserymen tree seeds were obtained through direct collection as well as from different local seed suppliers. Some of the tree nursery sites can collect the tree seeds from different trees available near to and around the tree nursery sites. The tree nurseries use different tree seeds sources for seedling production; however, some of these seed lots do not fulfill the legal (national) requirements of seed sources.

4.1.3 Sowing Date

The sowing dates of all the experimental tree species of the lowland and highland zones of the central Ethiopia are given as follows. *Acacia mearnsii* was sown in December 2005, at Bekate, Menagesha and Garmama nursery sites of highland zone of central Ethiopia. The difference of sowing dates between Bekate and Menagesha and Bekate and Garmama are two and five days, respectively (Table 3). *Eucalyptus globulus* was sown in February 2006, at Menagesha, Garmama and Bekate nursery sites of highland zone of central Ethiopia. The difference of sowing dates between Menagesha and Garmama and Mnagesha and Bekate are two and five days, respectively (Table 3). *Hagenia abyssinica* was sown in December 2005, at Garmama, Menagesha and Bekate nursery sites of highland zone of central Ethiopia. The difference of sowing dates between Garmama and Menagesha and Garmama and Bekate are two and seven days, respectively (Table 3).

The *Acacia albida* was sown in March 2006, at all three nursery sites of lowland zone of central Ethiopia. The difference of sowing dates between Modjo and Godino and Modjo and Bushoftu are three and six days, respectively (Table 4). *Eucalyptus camaldulensis* was sown in February 2006, at all three nursery sites of lowland zone of central Ethiopia. The difference of sowing dates between Godino and Bushoftu and Godino and Modjo are five and seven days, respectively (Table 4). *Grevillea robusta* was sown in January 2006, at Godino, Modjo and Bushoftu nursery sites of lowland zone of central Ethiopia. The difference of sowing dates between Godino and Modjo and Godino and Bushoftu are five and seven days, respectively (Table 4).

Table 3: Sowing date of tree seeds in nurseries of highland zone of Central Ethiopia

Nursery sites		**Tree species**	
	Acacia mearnsii	*E. globulus*	*Hagenia abyssinica*
Bekate	10-12-2005	15-02-2006	15-12-2005
Garmama	15-12-2005	12-02-2006	08-12-2005
Menagesha	12-12-2005	10-02-2006	10-12-2005

Table 4: Sowing date of tree seeds in nurseries of lowland zone of central Ethiopia

Nursery sites		**Tree species**	
	Acacia albida	*E. camaldulensis*	*Grevillea robusta*
Bushoftu	08-03-2006	20-02-2006	30-01-2006
Godino	05-03-2006	15-02-2006	23-01-2006
Modjo	02-03-2006	22-02-2006	28-01-2006

4.1.4 Sowing Depth

From the general interview made with all the study nursery foremen, the sowing depth of seeds of trees and shrub species depend on the experiences of the staff working in the forest tree nurseries. The sowing depth of seeds can differ within the seeds of one tree species and from tree species to species. Based on the results of interviewed made with the nursery foremen, the sowing depth of seeds of each of the studied tree species of the lowland and highland zones of central Ethiopia is not identified.

4.1.5 Nursery Cultural Treatments

According to the interviewed information from the nurserymen, root pruning is one of the nursery cultural practices which are carried out in the study nurseries of the two agro-ecological zones of central Ethiopia. The root pruning practices disturb the root systems of tree seedlings in the study nursery sites of the highland and lowland zones of central Ethiopia. The root pruning (root culturing) was done to control the growth of roots out of the polythene tube and in to the ground of the batch. According to the interviewed information from the study nursery sites, the root culturing was implemented in the seedling bed to alter various aspects of seedling morphology. If the shoot height of tree seedlings is too long shoot pruning/pollarding is a common practice in the study nurseries of the highland and low land zones of central Ethiopia, but was not applied for the plant materiel of this study. The interviewed information can be used to know the soil cultivation, weeding and culling are the most common nursery cultural practices of the study nursery sites. Figures 5 to 8 gives some impressions from the studied nurseries.

4.1.6 Educational Level of Nursery Staff

The level of education has its own impacts on the understanding and implementation of the activities take place in the tree nurseries. Based on the field observation obtained through field assessments of all the six experimental tree nursery sites, the educational levels of the nursery foremen of the highland and lowland agro-ecological zones of the central Ethiopia are different. The educational levels of the nursery foremen of the tree nursery sites of Bekate, Garmama and

Menagesha were grade 11, grade 10 (both: senior secondary school uncompleted) and grade 8 (junior secondary school), respectively (Table 5). However, the educational level of the nursery foreman of Godino tree nursery site is diploma in general forestry (college level) but the educational levels of the nursery foremen of Bushoftu and Modjo tree nursery sites are grade 10 (senior secondary school uncompleted) and grade 8 (junior secondary school), respectively (Table 5).

Table 5: Educational level of the nurserymen of the tree nurseries of highland and lowland zones of central Ethiopia

Nursery site	**AEZ**	**Level of education**
Bekate	Highland	Grade 11
Garmama	Highland	Grade 10
Menagesha	Highland	Grade 8
Bushoftu	Lowland	Grade 10
Godino	Lowland	Diploma in Forestry
Modjo	Lowland	Grade 8

Figure 5 : Nursery workers are in the process of sorting, weeding and root pruning of the containerized seedlings of different tree species in one of the highland study nurseries.

Figure 6: Sorting out the containerized seedlings of *Grevillea robusta* for shipment in one of the lowland study nurseries.

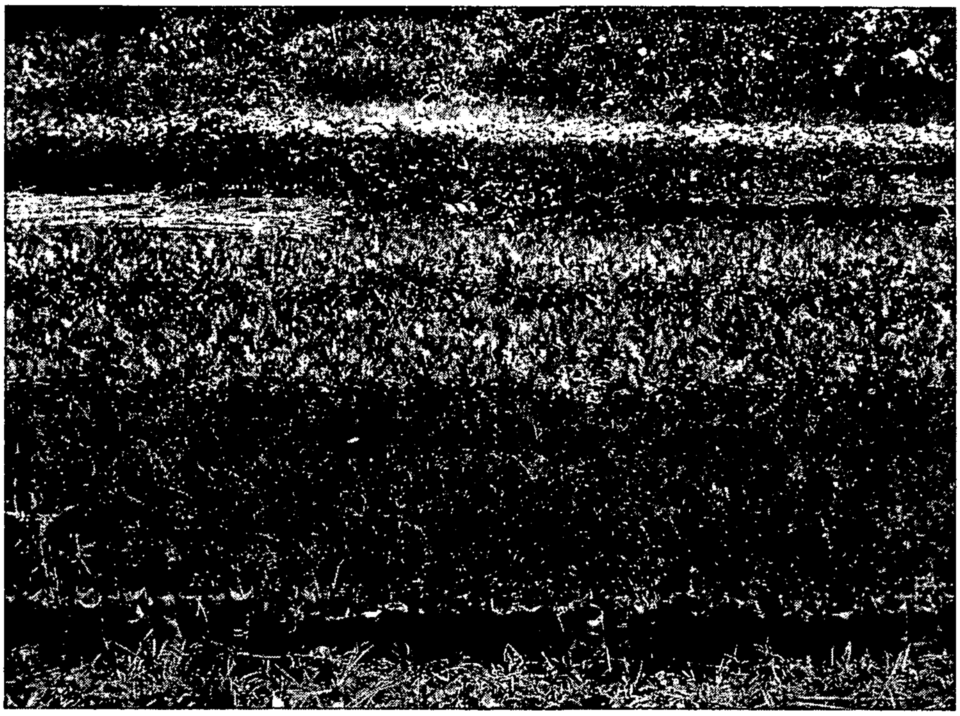

Figure 7: The containerized seedlings of *Grevillea robusta* (middle batches) and *Acacia albida* (front batch) are ready for shipment from one of the lowland study nurseries to out planting areas.

Figure 8: The nursery workers are working in one of the highland study nurseries, consisting of containerized seedlings of different tree species.

4.2 Results from Seedling Growth

4.2.1 Results from the Highland Agro-ecological Zone of Central Ethiopia

4.2.1.1 Shoot Height

The seedlings mean shoot height of *Acacia mearnsii* at the experimental tree nursery sites of Bekate, Garmama and Menagesha showed significant differences at $p \leq 0.05$ (Table 6). This was also the case for *Hagenia abyssinica* (Table 6). Only for *Eucalyptus globulus* it was observed that two nurseries, Bekate and Menagesha, produce seedlings of comparable size, whereas Garmama raised significantly taller plants. All together, Menagesha produced generally smaller plants than the remaining nurseries and Garmama has grown the tallest plants in two out of three cases.

Table 6: Mean shoot height (cm) of different nursery stock sampled at the highland zones of central Ethiopia

Name of species	Nursery site		
	Bekate	Garmama	Menagesha
Acacia mearnsii	68.46[a] (± 13.75)	49.58[b] (± 12.95)	23.52[c] (± 5.45)
Eucalyptus globulus	22.32[b] (± 1.79)	43.97[a] (± 13.20)	19.60[b] (± 4.23)
Hagenia abyssinica	19.33[b] (±4.29)	26.94[a] (± 7.19)	17.64[c] (± 3.11)

Numbers in parenthesis are standard deviations. Different letters indicate significant differences (Duncan Multiple Range Test; $p \leq 0.05$) (for detail see appendices 1, 4 and 7).

4.2.1.2 Shoot Dry Weight

The seedlings shoot dry weight values of *Acacia mearnsii and Eucalyptus globulus* achieved the highest values at Garmama tree nursery site, Bekate tree nursery site was the next best, and the third in the rank was the Menagesha tree nursery site where the least seedling shoot dry weight value was attained (Table 7). The seedlings shoot dry weight values of *Hagenia abyssinica* indicated the highest value at Menagesha tree nursery site, Bekate tree nursery site was the next best in performance and the third in the rank was the Garamama tree nursery site where the least seedlings shoot dry weight value was obtained (Table 7).

Table 7: Shoot dry weight of different nursery stock sampled at the highland zones of central Ethiopia

Tree species	**Nursery site**		
	Bekate	Garmama	Menagesha
	total per 10 seedlings [gm]	total per 10 seedlings [gm]	total per 10 seedlings [gm]
Acacia mearnsii	34.772	39.160	6.820
Eucalyptus globulus	11.939	25.444	8.735
Hagenia abyssinica	8.573	6.346	12.310

4.2.1.3 Root Length

The mean values of the highland seedlings' root length of *Hagenia abyssinica* showed significant differences at $p \leq 0.05$ Table 8). No difference of the mean root length was observed for *Eucalyptus globulus* seedlings from the different nurseries either. Only the *Acacia mearnsii* seedlings of the Menagesha nursery showed a significantly lower mean root length than the remaining nurseries.

Table 8: Mean root length (cm) of different nursery stock sampled at the highland zones of central Ethiopia

Name of species	Nursery site		
	Bekate	Garmama	Menagesha
Acacia mearnsii	12.63[a] (±2.47)	13.08[a] (±3.18)	11.10[b] (±1.67)
Eucalyptus globules	11.33[a] (±2.86)	11.34[a] (±1.80)	10.79[a] (±1.62)
Hagenia abyssinica	10.73[b] (±1.75)	11.73[a] (±1.70)	10.07[c] (±1.58)

Numbers in parenthesis are standard deviations. Different letters indicate significant differences (Duncan Multiple Range Test, p≤0.05) (for detail see appendices 2, 5 and 8).

4.2.1.4 Root Dry Weight

The seedlings root dry weight values of *Acacia mearnsii and Eucalyptus globulus* accomplished the highest values at Garmama tree nursery site, Bekate tree nursery site was the next best, and the third in the rank was the Menagesha tree nursery site where the least seedling root dry weight values were attained (Table 9). The seedlings root dry weight values of *Hagenia abyssinica* indicated the highest value at Bekate tree nursery site, Garamama tree nursery site was the next best in performance and the third in the rank was the Menagesha tree nursery site where the least seedlings root dry weight values were obtained (Table 9).

Table 9: Root dry weight of different nursery stock sampled at the highland zones of central Ethiopia

Tree species	Nursery site		
	Bekate	Garmama	Menagesha
	Total per 10 seedlings [gm]	Total per 10 seedlings [gm]	total per 10 seedlings [gm]
Acacia mearnsii	3.846	6.647	1.165
Eucalyptus globulus	3.191	4.193	1.311
Hagenia abyssinica	3.129	2.318	2.110

4.2.1.5 Root Collar Diameter

The seedlings mean root collar diameter of *Acacia mearnsii* and *Hagenia abyssinica* from the tree nursery sites of Bekate, Garmama and Menagesha showed significant differences at the level of $p \leq 0.05$ (Table 10).

Analyzing the root collar diameter of the *E. globulus* seedlings revealed that the seedlings of Bekate and Menagesha were comparable and only the Garmama seedlings were significantly bigger (Table 10).

Table 10: Mean root collar diameter (cm) of different nursery stock sampled at the highland zones of central Ethiopia

Name of species	Nursery site		
	Bekate	Garmama	Menagesha
Acacia mearnsii	0.392^{a} (±0.13)	0.313^{b} (±0.13)	0.224^{c} (±0.08)
Eucalyptus globules	0.177^{b} (±0.08)	0.214^{a} (±0.20)	0.167^{b} (±0.06)
Hagenia abyssinica	0.317^{b} (±0.11)	0.358^{a} (±1.00)	0.242^{c} (±0.06)

Numbers in parenthesis are standard deviations. Different letters indicate significant differences (Duncan Multiple Range Test, $p \leq 0.05$) (for detail see appendices 3, 6 and 9)

4.2.2 Results from the Lowland Agro-ecological Zone of Central Ethiopia

4.2.2.1 Shoot Height

Out of the seedlings of tree species of *Acacia albida*, *Eucalyptus camaldulensis* and *Grevillea robusta,* which were produced at Modjo, Bushoftu and Godino tree nurseries of the lowland agro-ecological zone of central Ethiopia, *A. albida* and *G. robusta* have shown significant differences between the seedlings mean shoot height at a significance level of $p \leq 0.05$ (Table 11). Mean shoot height values of *E. camaldulensis* were similar among Godino and Bushoftu nurseries, but *Eucalyptus* seedlings from Modjo nursery were significantly taller than the plants from both of the remaining nurseries.

Table 11: Mean shoot height (cm) of different nursery stock sampled at the lowland zones of central Ethiopia

Name of species	Nursery site		
	Bushoftu	Godino	Modjo
Acacia albida	21.46^{b} (±4.28)	19.45^{c} (±3.51)	43.81^{a} (±7.62)
Eucalyptus camaldulensis	29.60^{b} (±5.58)	28.62^{b} (±4.36)	50.64^{a} (±5.97)
Grevillea robusta	11.32^{c} (±1.58)	16.22^{b} (±2.70)	27.52^{a} (±4.83)

Numbers in parenthesis are standard deviations. Different letters indicate significant differences (Duncan Multiple Range Test, $p \leq 0.05$) (for detail see appendices 10, 13 and 16)

4.2.2.2 Shoot Dry Weight

The seedlings shoot dry weight analysis of *Acacia albida, Eucalyptus camaldulensis,* and *Grevillea robusta* achieved by far the highest values from Modjo tree nursery. Godino nursery products showed medium level dry weight for all species, whereas the Bushoftu nursery stock exhibited the lowest values of shoot dry weight for all tree species except *E. camaldulensis.*

Table 12: Shoot dry weight of different nursery stock sampled at the lowland zones of central Ethiopia

Tree species	**Nursery site**		
	Bushoftu	Godino	Modjo
	Total per 10 seedlings [gm]	Total per 10 seedlings [gm]	total per 10 seedlings [gm]
Acacia albida	3.141	8.907	42.997
Eucalyptus camaldulensis	14.182	13.493	26.480
Grevillea robusta	2.240	7.866	24.171

4.2.2.3 Root Length

The seedlings mean root length of *Grevillea robusta* revealed significant differences ($p \leq 0.05$) among Bushoftu, Godino and Modjo tree nursery products of the lowland agro-ecological zone of central Ethiopia (Table 13). The analysis of *Acacia albida* seedlings resulted in a comparable mean root length of Modjo and Bushoftu seedlings, respectively and in a significantly shorter than the mean root length of the Godino plants. Furthermore, the *Eucalyptus camaldulensis* nursery stock from Modjo showed significantly longer roots than the stock of the remaining two nurseries, Bushoftu and Godino.

Table 13: Mean root length (cm) of different nursery stock sampled at the lowland zones of central Ethiopia

Name of species	**Nursery site**		
	Bushoftu	Godino	Modjo
Acacia albida	10.31^{b} (±1.33)	13.47^{a} (±2.58)	10.74^{b} (±1.55)
Eucalyptus camaldulensis	11.36^{b} (±1.42)	11.83^{b} (±2.91)	13.50^{a} (±2.13)
Grevillea robusta	8.76^{c} (±0.99)	10.73^{b} (±1.76)	11.81^{a} ((±1.84)

Numbers in parenthesis are standard deviations. Different letters indicate significant differences (Duncan Multiple Range Test, $p \leq 0.05$) (for detail see appendices 11, 14 and 18)

4.2.2.4 Root Dry Weight

Root dry weight values of *Acacia albida, Eucalyptus camaldulensis* and *Grevillea robusta* reached absolutely the highest values at Modjo tree nursery. Godino tree nursery site was the next best, and the third in the rank was the Bushoftu tree nursery site where the lowest root dry weight values were attained for all species except *Grevillea robusta* (Table 14).

Table 14: Root dry weight of different nursery stock sampled at the lowland zones of the central Ethiopia

Tree species	**Nursery site**		
	Bushoftu	Godino	Modjo
	Total per 10 seedlings [gm]	total per 10 seedlings [gm]	Total per 10 seedlings [gm]
Acacia albida	2.107	7.938	14.411
Eucalyptus camaldulensis	2.860	3.107	6.424
Grevillea robusta	4.392	2.245	5.136

4.2.2.5 Root Collar Diameter

The seedlings mean root collar diameter of *Acacia albida* and *Grevillea robusta* from the three nursery sites of Modjo, Bushoftu and Godino showed significant differences at the level of $p \leq 0.05$ (Table 15). Analysing the mean root collar diameter of the *Eucalyptus camaldulensis* seedlings revealed that the seedlings of Bushoftu and Godino were comparable and only the Modjo seedlings were significantly bigger (Table 15).

Table 15: Mean root collar diameter (cm) of different nursery stock sampled at the lowland zone of central Ethiopia

Name of species	Nursery site		
	Bushoftu	Godino	Modjo
Acacia albida	0.145[c] (±0.04)	0.197[b] (±0.07)	0.373[a] (±0.08)
Eucalyptus camaldulensis	0.264[b] (±0.09)	0.263[b] (±0.05)	0.306[a] (±0.07)
Grevillea robusta	0.125[c] (±0.04)	0.282[b] (±0.05)	0.341[a] (±0.08)

Numbers in parenthesis are standard deviations. Different letters indicate significant differences (Duncan Multiple Range Test, $p \leq 0.05$) (for detail see appendices 12, 15 and 18)

4.3 Results from the Seedling Quality Indicators

4.3.1 Shoot to Root Ratio

The seedlings shoot to root ratio (shoot dry weight to root dry weight) of *Eucalyptus globulus* showed differences in values between the three nursery sites of Bekate, Garmama and Menagesha (Table 16). The seedlings shoot to root ratio of *Acacia mearnsii* showed comparable values between Garmama and Menagesha tree nurseries but attained larger values at the tree nursery of Bekate. Likewise, the seedlings of *Hagenia abyssinica* showed comparable values at Bekate and Garmama tree nurseries; however, it attained larger value at Menagesha tree nursery of the highland zones of central Ethiopia (Table 16).

Table 16: Shoot to root ratio of different nursery stock sampled at the highland zones of central Ethiopia

Name of species	Nursery site		
	Bekate	Garmama	Menagesha
Acacia mearnsii	9.04	5.89	5.85
Eucalyptus globulus	3.74	6.07	6.66
Hagenia abyssinica	2.74	2.74	5.83

The seedlings shoot to root ratio of *Acacia albida,* and *Grevillea robusta* showed obvious differences in values between the three tree nurseries of the lowland zone of central Ethiopia (Table 17). Only the *Eucalyptus camaldulensis* nursery stock exhibited nearly comparable values for all three nurseries under observation (Table 17).

Table 17: Shoot to root ratio of different nursery stock sampled at the lowland zones of Central Ethiopia

Name of species	Nursery site		
	Bushoftu	Godino	Modjo
Acacia albida	1.41	1.12	2.98
Eucalyptus camaldulensis	4.96	4.34	4.12
Grevillea robusta	0.51	3.50	4.71

4.3.2 Sturdiness Ratio

Computing the mean sturdiness ratio (shoot height to root collar diameter ratio) of *Acacia mearnsii* seedlings showed that the seedlings of Bekate and Garmama were comparable and only the Menagesha seedlings showed a significant smaller ratio from the highland zone of central Ethiopia (Table 18). Analyzing the mean sturdiness ratio of *Eucalyptus globulus* showed that the seedlings of Bekate and Menagesha were comparable and only the Garmama seedlings were significantly larger (Table 18). Likewise, analyzing the mean sturdiness ratio of *Hagenia abyssinica* seedlings showed that the seedlings of Garmama and Menagesha were comparable and only the Bekate seedlings were significantly smaller ratio (Table 18).

Table 18: Mean sturdiness ratio (shoot height: root collar diameter) of different nursery stock sampled at the highland zones of central Ethiopia

Name of species	**Nursery site**		
	Bekate	Garmama	Menagesha
Acacia mearnsii	18.98[a] (±5.92)	17.91[a] (±6.38)	11.87[b] (±5.11)
Eucalyptus globulus	13.21[b] (±4.77)	24.47[a] (±7.81)	13.02[b] (±4.43)
Hagenia abyssinica	6.69[b] (±2.22)	8.04[a] (±2.53)	7.94[a] (±2.84)

Numbers in parenthesis are standard deviations. Different letters indicate significant differences (Duncan Multiple Range Test, $p \leq 0.05$) (for details see appendices 19, 20 and 21)

The mean sturdiness ratio of *Acacia albida* and *Grevillea robusta* from the three nursery sites of Bushoftu, Godino and Modjo showed significant differences at the level of ($p \leq 0.05$) among all three nurseries from the lowland zone of central Ethiopia (Table 19). Analyzing the mean sturdiness ratio of the *Eucalyptus camaldulensis* seedlings revealed that the seedlings of Bushoftu and Godino were comparable and only the Modjo seedlings had a significantly higher ratio (Table 19).

Table 19: Sturdiness ratio (shoot height: root collar diameter) of different nursery stock sampled at the lowland zones of central Ethiopia

Name of species	**Nursery site**		
	Bushoftu	Godino	Modjo
Acacia albida	15.51[a] (±3.96)	10.51[c] (±2.83)	12.22[b] (±3.57)
Eucalyptus camaldulensis	12.06[b] (±3.16)	11.29[b] (±2.5)	17.33[a] (±4.17)
Grevillea robusta	9.76[a] (±2.44)	5.84[c] (±1.17)	8.39[b] (±1.69)

Numbers in parenthesis are standard deviations. Different letters indicate significant differences (Duncan Multiple Range Test, $p \leq 0.05$) (for detail see appendices 22, 23 and 24).

4.3.3 Shoot Height to Root Length Ratio

The mean values of the seedlings shoot height to root length ratio of *Acacia mearnsii* showed significant differences between the Bekate, Garmama and Menagesha tree nurseries of the highland zones of central Ethiopia (Table 20). However, the *Eucalyptus globulus* and *Hagenia abyssinica* seedlings performed more or less similar ratio values in the three nurseries of the highland zone of central Ethiopia (Table 20).

Table 20: Shoot height to root length ratio in the three nurseries of the highland zone of central Ethiopia

Name of species	**Nursery site**		
	Bekate	Garmama	Menagesha
Acacia mearnsii	5.48[a] (±0.89)	3.92[b] (±1.11)	2.15[c] (±0.57)
Eucalyptus globulus	1.90[b] (±0.65)	3.85[a] (±0.95)	1.82[b] (±0.31)
Hagenia abyssinica	1.81[b] (±0.31)	2.32[a] (±0.60)	1.77[b] (±0.30)

Numbers in parenthesis are standard deviations. Different letters indicate significant differences (Duncan Multiple Range Test, $p \leq 0.05$) (for detail see appendices 25, 26 and 27)

The mean values of the shoot height to root length ratio of *Acacia albida* and *Grevillea robusta* stock from the lowland zone of central Ethiopia showed significant differences at the level of ($p \leq 0.05$) between all three nurseries: Bushoftu, Godino and Modjo (Table 21). Analyzing the shoot height to root length ratio of *Eucalyptus camaldulensis* seedlings revealed that the seedlings of Bushoftu and Godino were comparable and only the Modjo seedlings were significantly larger in ratio (Table 21).

Table 21: Shoot height to root length ratio in the three nurseries of the lowland zone of central Ethiopia

Name of species	Nursery site		
	Bushoftu	Godino	Modjo
Acacia albida	2.11[b] (±0.49)	1.48[c] (±0.33)	4.14[a] (±0.84)
Eucalyptus camaldulensis	2.63[b] (±0.52)	2.53[b] (±0.63)	3.83[a] (±0.66)
Grevillea robusta	1.30[c] (±0.19)	1.54[b] (±0.31)	2.36[a] (±0.45)

Numbers in parenthesis are standard deviations. Different letters indicate significant differences (Duncan Multiple Range Test, $p \leq 0.05$) (for detail see appendices 28, 29 and 30).

4.4 Discussion

4.4.1 Shoot Characteristics of the Nursery Stock in Highland and Lowland Zones of Central Ethiopia

Based on the results of the analyzed field data, the seedlings shoot characteristics of the study tree species in selected highland and lowland nurseries of central Ethiopia were observed.

In the highland agro-ecological zones of central Ethiopia, the mean shoot height of the nursery stock differed significantly between the nurseries for all three tree species under observation with one exception: *Eucalyptus globulus* stock from Bekate and Menagesha nurseries were comparable (Table 6). Simply the same pattern of results was from the analysis of the shoot characteristics in the nursery stock of the lowland agro-ecological zone of central Ethiopia (Tables 11, 12). The mean shoot height of the nursery stock differed significantly between the nurseries for all three tree species under observation with also one exception: again the *Eucalyptus* stock, here the species of the lowland tree set (*Eucalyptus camaldulensis*), was comparable for two nurseries: Bushoftu and Godino (Table 11). This may be a hint, that there is already “some traded” information, how to handle the *Eucalyptus* shoot in the nursery. This result were somehow not expected, according to the hypothesis of the research that the nursery stock characteristics of each single tree species are similar across the respective agro-ecological zones of central Ethiopia. However, as there is no common hand book of good nursery practices in the highland and lowland zones of central Ethiopia the nursery foreman act according to their experience (see chapter 4.1.6). So, the growth performance of comparable tree species under observation is more or less a result of the implementation of local expert knowledge then based on an operational handbook of good nursery practice.

A similar result was obtained from the shoot dry weight analysis of the seedlings, which also revealed remarkable stock size differences among the three nurseries (Table 7). Unfortunately, the dry weight values do not match the shoot height results in all cases, which may basically be the result of the insufficient and small sample size (Tables 6, 7). On the other hand it has to be stated, that unsoundness of shoot dry weight values compared to the respective shoot height can also be the result of different nursery management. As all the study nurseries use the same size of polythene tube containers, every single plant has the same size of growing area. If so, than a not pruned plant will become tall, will show no or only few branching and may loose the leaves from the bottom up because of the dense stand. In contrary, a pruned plant will have an increased number of twigs and leaves sprouting newly after the cut. Therefore, different silvicultural practice will doubtlessly lead to different shoot dry weight of plants having the same shoot height. In the case of this study it is not known, when and how often the plant shoot was pruned. Pruning is generally recommended, in particular for Eucalyptus species (compare FAO, 1979) and it is a common practice also in highland and lowland zones of central Ethiopia (see chapter 4.1.5), but general guidelines for optimal nursery operation are not clearly known for some tree nurseries of highland and lowland zones of central Ethiopia.

A different question is the role of the container fillings (Table 2). Compare the highland nurseries it is obvious, that Garmama and Menagesha use the same proportion of ingredients; local soil, sandy soil and animal manure. Hence, the same shoot size of the stock is expected. But Garmama nursery stock is obviously the tallest and Menagesha nursery stock in most of the cases the smallest stock of the analyzed plant material. In spite of the fact, that more details of the ingredients are not known, the filling seems to be less decisive for the stock quality than the nursery management operations (e.g. pruning). Compare the lowland nurseries, where the nursery with the highest content of animal manure (Modjo, 30% animal manure: Table 2) exhibits best shoot size (Tables 11, 12), provides a hint, that the proportion (and may be quality?) of animal manure is of certain meaning for the stock quality (compare Jaenicke 1999). This finding is supported by the fact, that among the highland nurseries the one with the same animal manure proportion (Bekate, 29% animal manure, Table 2) can be found with a medium stock size at least (Tables 6, 7).

4.4.2 Root Characteristics of the Nursery Stock in Highland and Lowland Zones of Central Ethiopia

Discussing root characteristics it is to be expected, that using the same type of container in all nurseries results in comparable data of root length. But the mean root length of the highland nursery stock differed significantly between Menagesha nursery and the other two nurseries for two species under observation (Table 8) and it differed significantly between all three nurseries in the case of *Hagenia abyssinica* (Table 8). The same pattern of results was obtained from the analysis of the lowland nurseries: Again the mean root length of the fast growing species (genera *Acacia* and *Eucalyptus*) differed significantly between one nursery and the other two nurseries (Table 13), as there was the Godino stock in case of *A. albida* and the Modjo stock in the case of *Eucalyptus camaldulensis* (Table 13). The mean root length differed significantly between all three lowland nurseries in the case of *Grevillea robusta* (Table 13).

The first explanation for these findings may be that the polythene tubes are not filled to the same extent in every nursery. Besides the fact, that this type of soft wall containers can hardly be handled precisely in the same way during filling and all the subsequent nursery operations, it can not be excluded that the amount of container filling depends on nursery usage. Menagesha nursery stock, for instance, shows shortest root values for all species.

A second explanation may be found in the root pruning practice, which is common in highland and lowland zones of central Ethiopia (see chapter 4.1.5). Comparing the mean root length values with the root dry weight indicates some tendencies of intensive root pruning, in spite of the limited sample size for root dry weight measurement (Tables 9, 14) and in spite of detailed information on pruning practice in the studied nurseries. As root pruning stimulates the fibrous root development, it results in a higher dry weight of the root in case of comparison of pruned and not pruned root of same root length. Thus, Garmama from the highland zone and Modjo from the lowland nurseries have obviously a successful pruning concept, as their stock exhibits best dry weight values.

The surprising low dry weight values of the Menagesha nursery stock can not be explained by the amount of container filling, nor by the proportion of ingredients (as they are same like Garmama), nor by the pruning practice. Supposed there is regular pruning, the growth of fibrous roots will definitely depend on a proper irrigation of the nursery batch. Thus, one explanation for the small root size of Menagesha stock may be irregular or missing irrigation.

4.4.3 Root Collar Diameter in Highland and Lowland Nurseries of Central Ethiopia

Compare the mean root collar diameter values from the studied nurseries of highland and lowland zones of central Ethiopia, it is obvious, that two nurseries produce best results for the respective whole set of species: Garmama from the highland nurseries (Table 10) and Modjo from the lowland nurseries (Table 15). Moreover, the Menagesha nursery stock exhibits by far the smallest root collar diameter values, which is one additional hint for irrigation problems in that nursery, as discussed above. The respective nursery practice seems to influence this result, as there is a clear tendency for the best and the "worst" of the nurseries in spite of comparable proportions of filling ingredients, as it was discussed earlier in the case of Garmama and Menageha nurseries and in spite of the missing detailed information on the management practice in the studied nurseries.

The shoot height and root collar diameter growth alone or in combination with other seedling attributes have been used to relate planting stock quality to future field success (Thompson and Schultz 1995; Bayley and Kietzka 1996; Dey and Parker 1997; Jacobs et al. 2005). Root collar diameter prior to planting, however, appears to be a potential predictor of future diameter growth of planted tree species in the field (Chavasse, 1977). Similar results have been reported for red oak seedlings where the best model derived using initial root collar diameter predicted as high as of the variation in field diameter, depending on the planting site (Dey and Parker 1997; Jacobs et al. 2005). In some of the analyzed nurseries (Garmama, Modjo) from the highland and lowland zones of central Ethiopia, the mean root collar diameter values showed promising results in predicting future growth performances of the seedlings after outplanting in the field.

4.4.4 Nursery Stock Quality Parameters

Based on the computed results (Table 17), the shoot to root ratio of *Acacia albida* stock from Bushoftu and Godino nurseries as well as the one of *Grevillea robusta* stock from Bushoftu nursery fit to the general expectations of a balanced shoot to root ratio (e.g. Jaenicke 1999). The remaining values of the lowland nurseries indicate, in spite of the small sample size for dry weight measurements, that Modjo nursery in particular and *E. camaldulensis* nursery stock in general are produced as big plants missing a suitable size of the roots, which is expected to result in a diminished survival ratio after outplanting. The size of the container obviously does not fit to the fast growing shoot of the *Eucalyptus* species and so, a bigger container size as well as an optimized shoot pruning should be discussed for improving the stock quality. All together, the shoot/root values of the lowland nurseries are generally by far better than those of the highland nurseries (Tables 16, 17) of central Ethiopia. This findings can be explained by a more intensive pruning practiced by the lowland nurseries, without knowing the precise operation plans of the nurseries, as a smaller shoot size is obviously the target for different species of the lowland nurseries in spite of comparable production time for the species of the same genus in lowland and highland nurseries (Tables 6, 11) of central Ethiopia.

The results of sturdiness ratios (Tables 18, 19) do not meet the general expectations, which postulate smaller values than 6 (e.g. Jaenicke 1999). This analysis of selected highland and lowland nurseries of central Ethiopia revealed two trends: First, the lowland nursery stock has obviously the "better" results as an outcome of more intensive nursery management. Second, there are species specific effects as the slow growing *Hagenia abyssinica* can be produced in a way which results in nearly acceptable sturdiness values (Table 18). Therefore, the suitability of the container size should be newly discussed for producing *Acacia* and *Eucalyptus* species in the nurseries of highland and lowland zones of central Ethiopia.

The shoot-to-root ratio is an important measure for seedling survival rate. Production of planting seedlings with a large, vigorous root system and a shoot-to-root ratio to match the needs of the out planting site is an important factor in successful seedling establishment. Over the past two decades, a variety of seedling quality assessment methods and their importance in predicting field performance has been tested and developed (Ritchie 1984, 1985; Mattsson 1996; Mohammed 1996; Folk and Grossnickle 1996). Seedling morphological attributes, such as shoot height, root collar diameter, sturdiness (shoot height to root collar diameter ratio), and root to shoot ratio, are widely used to assess seedling quality at planting due to their relative simplicity to measure and their good correlation with field performance in many cases (Dey and parker 1997; Bayley and Kietzka 1996; Jacobs et al. 2005). Jaenicke (1999) reported that a small quotient indicates a sturdy plant with a higher expected chance of survival, especially on windy or dry sites.

5 Conclusions

The tree nurseries of the highland and lowland agro-ecological zones of central Ethiopia have produced the seedlings of different trees and shrub species. The produced trees and shrub seedlings are given to the local communities and other developmental organizations for out planting in various regions of the agro-ecological zones. However, there are problems in relation to survival and growth rates of most of out planted seedlings of tree species. The decisive factors for low survival and growth rates of the out planted seedlings are to some extend the effect of mismanagement in the nursery practices such as pruning, watering, time of sowing seed quality and also the lack of the availability of the guiding manual in relation to tree stock quality requirements. Hence, the research on the evaluation of nursery management practices in the two agro-ecological zones of central Ethiopia was needed to initiate the formal and operational evaluation of planting stock quality production practices in this country.

The nursery stock characteristics of the observed tree species are not similar across the respective agro-ecological zones of central Ethiopia. The computed results showed that the growth of mean shoot height, mean root length, mean root collar diameter and the shoot and root dry weight values of *Hagenia abyssinica* were significant between the tree nurseries of highland agro-ecological zone of central Ethiopia. The shoot height, mean root collar diameter and the shoot and root dry weight values of *Acacia mearnsii,* showed significant differences between tree nurseries of the highland agro-ecological zone of central Ethiopia, however, the mean root length growth of *Acacia mearnsii* achieved non-significant differences between Bekate and Garmama tree nurseries and the difference in mean root length growth showed at Menagesha tree nursery was significant. The mean shoot height, mean root length, and mean root collar diameter growth of *Eucalyptus globulus,* were not significant different at Bekate and Menagesha tree nursery sites and the seedlings mean root length growth of *Eucalyptus globulus* was not significant different at Garmama tree nursery site but the seedlings mean shoot height and root collar diameter growth of *Eucalyptus globulus* showed significance differences at Garmama tree nursery. As the consequences of analysed data, there were differences in shoot and root dry weight values of *Eucalyptus globulus* between tree nurseries of the highland agro-ecological zone of central Ethiopia.

The computed results showed that the mean shoot height, mean root length, mean root collar diameter growth and the shoot and root dry weight values of *Grevillea robusta* were significant different between the tree nurseries of the lowland agro-ecological zone of central Ethiopia. The mean shoot height, mean root collar diameter growth and the shoot and root dry weight values of *Acacia albida,* showed significant differences between tree nurseries of the lowland agro-ecological zone of central Ethiopia but the mean root length growth of *Acacia albida* achieved non-significant differences between Bushoftu and Modjo tree nurseries and the differences in mean root length growth showed at Godino tree nurseries were significant. The mean shoot height, mean root length, and mean root collar diameter growth of *Eucalyptus camaldulensis,* were not significant at Bushoftu and Godino tree nurseries and the mean shoot height, mean root length and mean root collar diameter growth of *Eucalyptus camaldulensis* were significant different at Modjo tree nursery. As the consequences of analysed data, there were differences in shoot and root dry weight values of *Eucalyptus camaldulensis between* tree nurseries of the lowland agro-ecological zone of central Ethiopia.

It was shown that the tree nurseries in the lowland and highland agro-ecological zones of the central Ethiopia apply different management practices. In that context a quantification of the effect of tree nursery management practices on the growth performances of seedlings was hard. The study on the evaluation of nursery management practices was carried out only in tree nurseries of the highland and lowland agro-ecological zones of central Ethiopia. However, the computed results of the mean shoot height, mean root length, mean root collar diameter growths and shoot and root dry weight values showed differences in the growth rates of all tree species between the three nurseries of lowland or highland agro-ecological zones of central Ethiopia. The growth results indicate that the nursery management practices between tree nurseries of lowland and highland zone are different. The growth of planting stock of most tree species obtained at Garmama tree nursery in the highland agro-ecological zone of central Ethiopia is relatively performed better seedling quality parameters than in the other nurseries. Likewise, the planting stock of tree species raised at Modjo tree nursery in the lowland agro-ecological zone of central Ethiopia demonstrated promising seedling quality parameters as compared to the other tree nurseries. In that context the variations in the application of nursery management practices like root and shoot pruning, irrigation practices and the use of fertilizers may have impacts on the growth of tree species in the lowland and highland agro-ecological zones of central Ethiopia. In all selected study tree nurseries of the highland and lowland agro-ecological zones of central Ethiopia, the tree nurseries normally use the same types of filling substrates and of similar filling mixture ratios for the production of planting stocks of different tree species. Based on the author's personal observations during the field study work and the information obtained from all the study tree nurseries of the two agro-ecological zones of central Ethiopia, the author can conclude that all tree nurseries found in similar agro-ecological zones of central Ethiopia used the same filling substrates and similar filling mixture ratios for the production of planting stocks of different tree species.

So, it was possible to evaluate nursery stock quality based on mean shoot height, root length, root collar diameter, shoot and root dry weights of six tree species in the lowland and highland agro-ecological zones of central Ethiopia. However, a formal quantification of relationships between nursery management practices and growth performances was not possible according to missing data and information.

Ethiopia is a country of large area coverage and the areas of the two agro-ecological zones of the central Ethiopia represent only a very small part of the country. According to financial and temporal constraints only a limited sample size for root dry weight measurements and some basic information on nursery management practices could be studied. Moreover, the six experimental tree nursery sites and the six tree species involved are not sufficient to reach overall conclusions on the evaluation of all the tree nursery management practices in Ethiopia. However, the findings of this study provide hints for improvement needs and challenges in Ethiopian forest nurseries. The results may lead to future research designed to explore ways to improve the tree nursery management practices in order to evaluate the tree seedling growth under various conditions in tree nurseries and the plantation success. Therefore, additional research work should be needed and widely implemented to evaluate the nursery management practices of the remaining tree nursery sites of the country and draw the conclusion based on the results and establish databases on tree nursery management practices of the country. Based on the results obtained from this study the future research should be suggested as follows:

1. The soil substrate requirement of different tree species should be investigated as most nurseries currently use blanket recommendations
2. The sowing depth of each tree species should be studied since this has impact on the germination and subsequent growth of the seedlings
3. The sturdiness and shoot to root ratio for various tree species at national level has to be studied as the current study deals only on limited tree species and nursery sites
4. The individual treatment of tree species and the nursery management practices should be observed in detail along with an analysis of quality parameters
5. The establishment of information database (nursery manual) on nursery management practices should be needed based on the results of evaluation of nursery management practices in different agro-ecological zones of Ethiopia.

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Appendices

Appendix 1: Descriptives and ANOVA for shoot height growth of *Acacia mearnsii* at three nurseries of highland zone of central Ethiopia

Shoot height (cm)

	N	Mean	Std. Deviation	Std. Error	Minimum	Maximum
Garmama	100	49.58	12.95	1.29	15.00	82.00
Bekate	100	68.46	13.75	1.37	32.00	108.00
Menagesha	100	23.52	5.45	0.55	14.00	37.00
Total	300	47.19	21.64	1.25	14.00	108.00

ANOVA-Shoot height (cm)

	Sum of squares	Df	Mean Square	F	Sig
Between groups	101819.51	2	50909.76	395.41	0.000
Within groups	38239.42	297	128.75		
Total	140058.93	299			

Shoot height (cm) -Duncan[a]

Nursery sites		Subset for Alpha = 0.05		
	N	1	2	3
Menagesha	100	23.52		
Garmama	100		49.58	
Bekate	100			68.46
Sig		1.000	1.000	1.000

Means for groups in homogeneous subsets are displayed. a Uses Harmonic Mean Sample Size = 100.000.

Appendix 2: Descriptives and ANOVA for root length growth of *Acacia mearnsii* at three nurseries of highland zone of central Ethiopia

Root length (cm)

	N	Mean	Std. Deviation	Std. Error	Minimum	Maximum
Garmama	100	13.08	3.18	0.32	10.00	26.80
Bekate	100	12.63	2.47	0.25	9.00	24.10
Menagesha	100	11.10	1.67	0.17	8.00	17.70
Total	300	12.27	2.65	0.15	8.00	26.80

ANOVA-Root length (cm)

	Sum of squares	Df	Mean Square	F	Sig
Between groups	214.10	2	107.50	16.97	0.000
Within groups	1881.51	297	6.34		
Total	2096.51	299			

Root length (cm) -Duncan[a]

Nursery sites		Subset for Alpha = 0.05	
	N	1	2
Menagesha	100	11.10	
Bekate	100		12.63
Garmama	100		13.08
Sig		1.000	0.201

Means for groups in homogeneous subsets are displayed. a Uses Harmonic Mean Sample Size = 100.000.

Appendix 3: Descriptives and ANOVA for root collar diameter growth of *Acacia mearnsii* at three nurseries of highland zone of central Ethiopia

Root collar diameter (cm)

	N	Mean	Std. Deviation	Std. Error	Minimum	Maximum
Garmama	100	0.31	0.13	0.01	0.10	0.70
Bekate	100	0.39	0.13	0.01	0.20	0.70
Menagesha	100	0.22	0.08	0.01	0.10	0.50
Total	300	0.31	0.13	0.01	0.10	0.70

ANOVA-Root collar diameter (cm)

	Sum of squares	Df	Mean Square	F	Sig
Between groups	1.41	2	0.71	53.48	0.000
Within groups	3.92	297	0.01		
Total	5.34	299			

Root collar diameter (cm) -Duncan[a]

Nursery sites		Subset for Alpha = 0.05		
	N	1	2	3
Menagesha	100	0.22		
Garmama	100		0.31	
Bekate	100			0.39
Sig		1.000	1.000	1.000

Means for groups in homogeneous subsets are displayed. a Uses Harmonic Mean Sample Size = 100.000.

Appendix 4: Descriptives and ANOVA for shoot height growth of *Eucalyptus globulus* at three nurseries of highland zone of central Ethiopia

Shoot height (cm)

	N	Mean	Std. Deviation	Std. Error	Minimum	Maximum
Garmama	100	43.97	13.20	1.32	16.00	72.00
Bekate	100	22.32	11.79	1.18	7.00	76.00
Menagesha	100	19.60	4.23	0.42	11.50	36.00
Total	300	28.63	15.13	0.87	7.00	76.00

ANOVA-Shoot height (cm)

	Sum of Squares	Df	Mean Square	F	Sig.
Between Groups	35671.96	2	17835.98	161.62	.000
Within Groups	32775.99	297	110.36		
Total	68447.95	299			

Shoot height (cm) -Duncan[a]

Nursery sites	N	Subset for alpha = 0.05	
		1	2
Menagesha	100	19.60	
Bekate	100	22.32	
Garmama	100		43.97
Sig.		.067	1.000

Means for groups in homogeneous subsets are displayed. a Uses Harmonic Mean Sample Size = 100.000.

Appendix 5: Descriptives and ANOVA for root length growth of *Eucalyptus globulus* at three nurseries of highland zone of central Ethiopia

Root length (cm)

	N	Mean	Std. Deviation	Std. Error	Minimum	Maximum
Garmama	100	11.3370	1.7973	.1797	8.00	18.00
Bekate	100	11.3250	2.8559	.2856	8.00	21.00
Menagesha	100	10.7907	1.6181	.1618	8.00	18.00
Total	300	11.1509	2.1684	.1252	8.00	21.00

ANOVA-Root length (cm)

	Sum of Squares	Df	Mean Square	F	Sig.
Between Groups	19.47	2	9.73	2.09	0.13
Within Groups	1386.46	297	4.678		
Total	1405.93	299			

Root length (cm) - Duncan[a]

Nursery sites	N	Subset for alpha = 0.05
		1
Menagesha	100	10.79
Bekate	100	11.33
Garmama	100	11.34
Sig.		0.091

Means for groups in homogeneous subsets are displayed. a Uses Harmonic Mean Sample Size = 100.000.

Appendix 6: Descriptives and ANOVA for root collar diameter growth of *Eucalyptus globulus* at three nurseries of highland zone of central Ethiopia

Root collar diameter (cm)

	N	Mean	Std. Deviation	Std. Error	Minimum	Maximum
Garmama	100	0.21	0.20	0.02	0.10	2.00
Bekate	100	0.18	0.09	0.08	0.10	0.50
Menagesha	100	0.17	0.06	0.06	0.10	0.30
Total	300	0.19	0.13	0.01	0.10	2.00

ANOVA-Root collar diameter (cm)

	Sum of Squares	Df	Mean Square	F	Sig.
Between Groups	0.12	2	0.06	3.66	0.03
Within Groups	5.02	297	0.02		
Total	5.14	299			

Root collar diameter (cm) -Duncan[a]

Nursery sites	N	Subset for alpha = 0.05	
		1	2
Menagesha	100	0.17	
Bekate	100	0.18	
Garmama	100		0.21
Sig.		0.61	1.000

Means for groups in homogeneous subsets are displayed. a Uses Harmonic Mean Sample Size = 100.000.

Appendix 7: Descriptives and ANOVA for shoot height growth of *Hagenia abyssinica* at three nurseries of highland zone of central Ethiopia

Shoot height (cm)

	N	Mean	Std. Deviation	Std. Error	Minimum	Maximum
Garmama	100	26.94	7.19	0.72	15.00	79.00
Bekate	100	19.33	4.29	0.43	10.00	30.00
Menagesha	100	17.64	3.11	0.31	9.70	27.00
Total	300	21.30	6.54	0.38	9.70	79.00

ANOVA-Shoot height (cm)

	Sum of Squares	Df	Mean Square	F	Sig.
Between Groups	4908.35	2	2454.18	92.33	.000
Within Groups	7894.09	297	26.58		
Total	12802.44	299			

Shoot height (cm) -Duncan[a]

Nursery sites	N	Subset for alpha = 0.05		
		1	2	3
Menagesha	100	17.64		
Bekate	100		19.33	
Garmama	100			26.94
Sig.		1.000	1.000	1.000

Means for groups in homogeneous subsets are displayed. a Uses Harmonic Mean Sample Size = 100.000.

Appendix 8: Descriptives and ANOVA for root length growth of *Hagenia abyssinica* at three nurseries of highland zone of central Ethiopia

Root length (cm)

	N	Mean	Std. Deviation	Std. Error	Minimum	Maximum
Garmama	100	11.73	1.70	0.17	9.80	17.20
Bekate	100	10.73	1.75	0.17	6.00	16.10
Menagesha	100	10.07	1.58	0.16	8.00	15.30
Total	300	10.84	1.81	0.10	6.00	17.20

ANOVA-Root length (cm)

	Sum of Squares	Df	Mean Square	F	Sig.
Between Groups	140.33	2	70.176	24.87	.000
Within Groups	837.80	297	2.82		
Total	978.13	299			

Root length (cm) -Duncan[a]

Nursery sites	N	Subset for alpha = 0.05		
		1	2	3
Menagesha	100	10.07		
Bekate	100		10.73	
Garmama	100			11.73
Sig.		1.000	1.000	1.000

Means for groups in homogeneous subsets are displayed. a Uses Harmonic Mean Sample Size = 100.000.

Appendix 9: Descriptives and ANOVA for root collar diameter growth of *Hagenia abyssinica* at three nurseries of highland zone of central Ethiopia

Root collar diameter (cm)

	N	Mean	Std. Deviation	Std. Error	Minimum	Maximum
Garmama	100	0.36	0.09	0.01	0.20	0.80
Bekate	100	0.32	0.11	0.01	0.20	0.70
Menagesha	100	0.24	0.07	0.01	0.10	0.40
Total	300	0.31	0.10	0.01	0.10	0.80

ANOVA-Root collar diameter (cm)

	Sum of Squares	Df	Mean Square	F	Sig.
Between Groups	0.70	2	0.35	42.22	.000
Within Groups	2.45	297	.01		
Total	3.15	299			

Root collar diameter (cm) -Duncan[a]

		Subset for alpha = 0.05		
Nursery sites	N	1	2	3
Menagesha	100	10.07		
Bekate	100		10.73	
Garmama	100			11.73
Sig.		1.000	1.000	1.000

Means for groups in homogeneous subsets are displayed. a Uses Harmonic Mean Sample Size = 100.000.

Appendix 10: Descriptives and ANOVA for shoot height growth of *Acacia albida* at three nurseries of lowland zone of central Ethiopia

Shoot height (cm)

	N	Mean	Std. Deviation	Std. Error	Minimum	Maximum
Modjo	100	43.81	7.62	0.76	23.40	61.00
Bushoftu	100	21.46	4.28	0.43	10.40	31.00
Godino	100	19.45	3.51	0.35	11.00	27.80
Total	300	28.24	12.32	0.71	10.40	61.00

ANOVA – Shoot height (cm)

	Sum of Squares	Df	Mean Square	F	Sig.
Between Groups	36578.20	2	18289.10	618.24	.000
Within Groups	8785.95	297	29.58		
Total	45364.15	299			

Shoot height (cm) -Duncan[a]

Nursery sites	N	Subset for alpha = 0.05		
		1	2	3
Godino	100	19.45		
Bushoftu	100		21.46	
Modjo	100			43.81
Sig.		1.000	1.000	1.000

Means for groups in homogeneous subsets are displayed. a Uses Harmonic Mean Sample Size = 100.000.

Appendix 11: Descriptives and ANOVA for root length growth of *Acacia albida* at three nurseries of lowland zone of central Ethiopia

Root length (cm)

	N	Mean	Std. Deviation	Std. Error	Minimum	Maximum
Modjo	100	10.74	1.55	0.16	8.00	18.00
Bushoftu	100	10.31	1.33	0.13	6.00	15.30
Godino	100	13.47	2.58	0.26	8.00	22.00
Total	300	11.51	2.36	0.14	6.00	22.00

ANOVA-Root length (cm)

	Sum of Squares	Df	Mean Square	F	Sig.
Between Groups	586.86	2	293.437	81.295	.000
Within Groups	1072.00	297	3.61		
Total	1658.854	299			

Root length (cm) -Duncan[a]

Nursery sites	N	Subset for alpha =0 .05	
		1	2
Bushoftu	100	10.31	
Modjo	100	10.74	
Godino	100		13.47
Sig.		.108	1.000

Means for groups in homogeneous subsets are displayed. a Uses Harmonic Mean Sample Size = 100.000.

Appendix 12: Descriptives and ANOVA for root collar diameter growth of *Acacia albida* at three nurseries of lowland zone of central Ethiopia

Root collar diameter (cm)

	N	Mean	Std. Deviation	Std. Error	Minimum	Maximum
Modjo	100	0.37	0.08	0.01	0.11	0.60
Bushoftu	100	0.14	0.03	0.00	0.10	0.20
Godino	100	0.20	0.07	0.01	0.11	0.80
Total	300	0.24	0.12	0.01	0.10	0.80

ANOVA-Root collar diameter (cm)

	Sum of Squares	Df	Mean Square	F	Sig.
Between Groups	2.85	2	1.43	323.39	
Within Groups	1.31	297	0.00		
Total	4.16	299			

Root collar diameter (cm) -Duncan[a]

		Subset for alpha = 0.05		
Nursery sites	N	1	2	3
Bushoftu	100	0.15		
Godino	100		0.20	
Modjo	100			0.37
Sig.		1.000	1.000	1.000

Means for groups in homogeneous subsets are displayed. a Uses Harmonic Mean Sample Size = 100.000.

Appendix 13: Descriptives and ANOVA for shoot height growth of *Eucalyptus camaldulensis* at three nurseries of lowland zone of central Ethiopia

Shoot height (cm)

	N	Mean	Std. Deviation	Std. Error	Minimum	Maximum
Modjo	100	50.64	5.97	0.60	33.60	67.00
Bushoftu	100	29.60	5.58	0.56	17.50	42.00
Godino	100	28.62	4.36	0.44	19.00	43.10
Total	300	36.29	11.48	0.66	17.50	67.00

ANOVA-Shoot height (cm)

	Sum of Squares	Df	Mean Square	F	Sig.
Between Groups	30943.67	2	15471.83	541.35	.000
Within Groups	8488.22	297	28.58		
Total	39431.89	299			

Shoot height (cm) -Duncan[a]

Nursery sites	N	Subset for alpha = 0.05	
		1	2
Godino	100	28.62	
Bushoftu	100	29.60	
Modjo	100		50.64
Sig.		0.194	1.000

Means for groups in homogeneous subsets are displayed. a Uses Harmonic Mean Sample Size = 100.000.

Appendix 14: Descriptives and ANOVA for root length growth of *Eucalyptus camaldulensis* at three nurseries of lowland zone of central Ethiopia

Root length (cm)

	N	Mean	Std. Deviation	Std. Error	Minimum	Maximum
Modjo	100	13.50	2.13	0.21	10.00	20.00
Bushoftu	100	11.36	1.42	0.14	8.00	16.60
Godino	100	11.83	2.91	0.29	8.00	31.10
Total	300	12.23	2.41	0.14	8.00	31.10

ANOVA -Root length (gm)

	Sum of Squares	Df	Mean Square	F	Sig.
Between Groups	252.49	2	126.24	25.19	.000
Within Groups	1488.40	297	5.011		
Total	1740.89	299			

Root length (cm) -Duncan[a]

Nursery sites	N	Subset for alpha = 0.05	
		1	2
Bushoftu	100	11.36	
Godino	100	11.83	
Modjo	100		13.50
Sig.		0.135	1.000

Means for groups in homogeneous subsets are displayed. a Uses Harmonic Mean Sample Size = 100.000.

Appendix 15: Descriptives and ANOVA for root collar diameter growth of *Eucalyptus camaldulensis* at three nurseries of lowland zone of central Ethiopia

Root collar diameter (cm)

	N	Mean	Std. Deviation	Std. Error	Minimum	Maximum
Modjo	100	0.31	0.07	0.01	0.14	0.52
Bushoftu	100	0.26	0.09	0.01	0.11	0.60
Godino	100	0.26	0.05	0.00	0.15	0.42
Total	300	0.28	0.07	0.00	0.11	0.60

ANOVA-Root collar diameter (cm)

	Sum of Squares	Df	Mean Square	F	Sig.
Between Groups	0.12	2	0.06	11.45	.000
Within Groups	1.55	297	0.01		
Total	1.67	299			

Root collar diameter (cm) -Duncan[a]

		Subset for alpha = 0.05	
Nursery sites	N	1	2
Godino	100	0.26	
Bushoftu	100	0.26	
Modjo	100		0.31
Sig.		0.961	1.000

Means for groups in homogeneous subsets are displayed. a Uses Harmonic Mean Sample Size = 100.000.

Appendix 16: Descriptives and ANOVA for shoot height growth of *Grevillea robusta* at three nurseries of lowland zone of central Ethiopia

Shoot height (cm)

	N	Mean	Std. Deviation	Std. Error	Minimum	Maximum
Modjo	100	27.52	4.83	0.48	18.00	38.50
Bushoftu	100	11.32	1.58	0.16	8.00	15.20
Godino	100	16.22	2.70	0.27	10.00	24.20
Total	300	18.36	7.560	0.44	8.00	38.50

ANOVA-Shoot height (cm)

	Sum of Squares	Df	Mean Square	F	Sig.
Between Groups	13807.05	2	6903.54	624.95	.000
Within Groups	3280.83	297	11.05		
Total	17087.88	299			

Shoot height (cm) -Duncan[a]

		Subset for alpha = .05		
Nursery sites	N	1	2	3
Bushoftu	100	11.32		
Godino	100		16.22	
Modjo	100			27.52
Sig		1.000	1.000	1.000

Means for groups in homogeneous subsets are displayed. a Uses Harmonic Mean Sample Size = 100.000.

Appendix 17: Descriptives and ANOVA for root length growth of *Grevillea robusta* at three nurseries of lowland zone of central Ethiopia

Root length (cm)

	N	Mean	Std. Deviation	Std. Error	Minimum	Maximum
Modjo	100	11.81	1.8402	0.1840	8.90	17.20
Bushoftu	100	8.76	0.99	0.10	7.00	14.00
Godino	100	10.73	1.76	0.18	7.00	19.30
Total	300	10.43	2.02	0.12	7.00	19.30

ANOVA-Root length (cm)

	Sum of Squares	Df	Mean Square	F	Sig.
Between Groups	479.05	2	239.53	96.49	.000
Within Groups	737.26	297	2.48		
Total	1216.32	299			

Root length (cm) -Duncan[a]

Nursery sites	N	Subset for alpha = .05		
		1	2	3
Bushoftu	100	8.76		
Godino	100		10.73	
Modjo	100			11.81
Sig		1.000	1.000	1.000

Means for groups in homogeneous subsets are displayed. a Uses Harmonic Mean Sample Size = 100.000.

Appendix 18: Descriptives and ANOVA for root collar diameter growth of *Grevillea robusta* at three nurseries of lowland zone of central Ethiopia

Root collar diameter (cm)

	N	Mean	Std. Deviation	Std. Error	Minimum	Maximum
Modjo	100	0.34	0.8	0.01	0.20	0.50
Bushoftu	100	0.12	0.04	0.00	0.10	0.30
Godino	100	0.28	0.05	0.01	0.18	0.40
Total	300	0.25	.1081	0.01	0.10	0.50

ANOVA-Root collar diameter (cm)

	Sum of Squares	Df	Mean Square	F	Sig.
Between Groups	2.51	2	1.25	378.08	.000
Within Groups	0.99	297	0.00		
Total	3.49	299			

Root collar diameter (cm) -Duncan[a]

		Subset for alpha = .05		
Nursery sites	N	1	2	3
Bushoftu	100	0.12		
Godino	100		0.28	
Modjo	100			0.34
Sig		1.000	1.000	1.000

Means for groups in homogeneous subsets are displayed. a Uses Harmonic Mean Sample Size = 100.000.

Appendix 19: Descriptives and ANOVA for sturdiness ratio of *Acacia mearnsii* at three nurseries of highland zone of central Ethiopia

Sturdiness ratio

	N	Mean	Std. Deviation	Std. Error	Minimum	Maximum
Garmama	100	17.91	6.38	0.64	5.00	42.00
Bekate	100	18.98	5.92	0.59	7.00	39.00
Menagesha	100	11.87	5.11	0.51	5.00	33.00
Total	300	16.25.33	6.60	0.38	5.00	42.00

ANOVA Sturdiness ratio

	Sum of Squares	Df	Mean Square	F	Sig.
Between Groups	2939.29	2	1469.64	43.30	0.00
Within Groups	10079.46	297	33.94		
Total	13018.75	299			

Sturdiness ratio-Duncan[a]

Nursery sites	N	Subset for alpha = .05	
		1	2
Menagesha	100	11.87	
Garmama	100		17.91
Bekate	100		18.98
Sig		1.000	0.194

Means for groups in homogeneous subsets are displayed. a Uses Harmonic Mean Sample Size = 100.000.

Appendix 20: Descriptives and ANOVA for sturdiness ratio of *Eucalyptus globulus* at three nurseries of highland zone of central Ethiopia

Sturdiness ratio

	N	Mean	Std. Deviation	Std. Error	Minimum	Maximum
Garmama	100	24.47	7.81	0.78	2.00	50.00
Bekate	100	13.21	4.77	0.48	5.00	38.00
Menagesha	100	13.02	4.43	0.44	7.00	28.00
Total	300	16.90	7.94	0.46	2.00	50.00

ANOVA Sturdiness ratio

	Sum of Squares	Df	Mean Square	F	Sig.
Between Groups	8597.54	2	4298.77	124.66	0.000
Within Groups	10241.46	297	34.48		
Total	18839.00	299			

Sturdiness ratio-Duncan[a]

		Subset for alpha = .05	
Nursery sites	N	1	2
Menagesha	100	13.02	
Bekate	100	13.21	
Garmama	100		24.47
Sig		0.819	1.00

Means for groups in homogeneous subsets are displayed. a Uses Harmonic Mean Sample Size = 100.000.

Appendix 21: Descriptives and ANOVA for sturdiness ratio of *Hagenia abyssinica* at three nurseries of highland zone of central Ethiopia

Sturdiness ratio

	N	Mean	Std. Deviation	Std. Error	Minimum	Maximum
Garmama	100	8.04	2.53	0.25	3.00	20.00
Bekate	100	6.69	2.22	0.22	3.00	13.00
Menagesha	100	7.94	2.84	0.28	2.00	19.00
Total	300	7.557	2.61	0.15	2.00	20.00

ANOVA Sturdiness ratio

	Sum of Squares	Df	Mean Square	F	Sig.
Between Groups	113.17	2	56.58	8.77	0.000
Within Groups	1916.87	297	6.45		
Total	2030.04	299			

Sturdiness ratio-Duncan[a]

Nursery sites	N	Subset for alpha = .05	
		1	2
Bekate	100	6.69	
Menagesha	100		7.94
Garmama	100		8.04
Sig		1.000	0.781

Means for groups in homogeneous subsets are displayed. a Uses Harmonic Mean Sample Size = 100.000.

Appendix 22: Descriptives and ANOVA for sturdiness ratio of *Acacia albida* at three nurseries of lowland zone of central Ethiopia

Sturdiness ratio

	N	Mean	Std. Deviation	Std. Error	Minimum	Maximum
Modjo	100	12.22	3.57	0.36	7.00	39.00
Bushoftu	100	15.51	3.96	0.40	8.00	26.00
Godino	100	10.51	2.83	0.28	3.00	20.00
Total	300	12.75	4.057	0.23	3.00	39.00

ANOVA Sturdiness ratio

	Sum of Squares	Df	Mean Square	F	Sig.
Between Groups	1291.61	2	645.80	53.17	0.000
Within Groups	3607.14	297	12.14		
Total	4898.75	299			

Sturdiness ratio-Duncan[a]

Nursery sites	N	Subset for alpha = .05		
		1	2	3
Godino	100	10.51		
Modjo	100		12.22	
Bushoftu	100			15.51
Sig		1.000	1.000	1.000

Means for groups in homogeneous subsets are displayed. a Uses Harmonic Mean Sample Size = 100.000.

Appendix 23: Descriptives and ANOVA for sturdiness ratio of *Eucalyptus camaldulensis* at three nurseries of lowland zone of central Ethiopia

Sturdiness ratio

	N	Mean	Std. Deviation	Std. Error	Minimum	Maximum
Modjo	100	17.33	4.17	0.42	10.00	41.00
Bushoftu	100	12.06	3.16	0.32	6.00	19.00
Godino	100	11.29	2.50	0.25	7.00	18.00
Total	300	13.56	4.29	0.25	6.00	41.00

ANOVA Sturdiness ratio

	Sum of Squares	Df	Mean Square	F	Sig.
Between Groups	2161.58	2	1080.79	96.39	0.000
Within Groups	3330.34	297	11.23		
Total	5491.92	299			

Sturdiness ratio-Duncan[a]

		Subset for alpha = .05	
Nursery sites	N	1	2
Godino	100	11.29	
Bushoftu	100	12.06	
Modjo	100		17.33
Sig		0.10	1.000

Means for groups in homogeneous subsets are displayed. a Uses Harmonic Mean Sample Size = 100.000.

Appendix 24: Descriptives and ANOVA for sturdiness ratio of *Grevillea robusta* at three nurseries of lowland zone of central Ethiopia

Sturdiness ratio

	N	Mean	Std. Deviation	Std. Error	Minimum	Maximum
Modjo	100	8.39	1.69	0.17	4.00	17.00
Bushoftu	100	9.76	2.4417	0.24	3.00	15.00
Godino	100	5.84	1.17	0.12	4.00	12.00
Total	300	8.00	2.45	0.14	3.00	17.00

ANOVA Sturdiness ratio

	Sum of Squares	Df	Mean Square	F	Sig.
Between Groups	791.53	2	395.76	116.67	0.000
Within Groups	1007.47	297	3.39		
Total	1799.00	299			

Sturdiness ratio-Duncan[a]

Nursery sites	N	Subset for alpha = .05		
		1	2	3
Godino	100	5.84		
Modjo	100		8.39	
Bushoftu	100			9.76
Sig		1.000	1.000	1.000

Means for groups in homogeneous subsets are displayed. a Uses Harmonic Mean Sample Size = 100.000.

Appendix 25: Descriptives and ANOVA for shoot height to root length ratio of *Acacia mearnsii* at three nurseries of highland zone of central Ethiopia

Shoot height to root length ratio

	N	Mean	Std. Deviation	Std. Error	Minimum	Maximum
Garmama	100	3.92	1.11	0.1112	1.50	6.60
Bekate	100	5.48	0.89	0.09	2.56	7.57
Menagesha	100	2.15	0.57	0.06	1.13	4.00
Total	300	3.85	1.62	0.09	1.13	7.57

ANOVA _Shoot height to root length ratio

	Sum of Squares	Df	Mean Square	F	Sig.
Between Groups	554.11	2	277.06	353.377	.000
Within Groups	232.86	297	0.78		
Total	786.97	299			

Shoot height to root length ratio-Duncan[a]

		Subset for alpha = .05		
Nursery sites	N	1	2	3
Menagesha	100	2.15		
Garmama	100		3.92	
Bekate	100			5.48
Sig		1.000	1.000	1.000

Means for groups in homogeneous subsets are displayed. a Uses Harmonic Mean Sample Size = 100.000.

Appendix 26: Descriptives and ANOVA for shoot height to root length ratio of *Eucalyptus globulus* at three nurseries of highland zone of central Ethiopia

Shoot height to root length ratio

	N	Mean	Std. Deviation	Std. Error	Minimum	Maximum
Garmama	100	3.85	0.95	0.09	1.70	6.50
Bekate	100	1.9032	0.65	0.06	0.81	5.43
Menagesha	100	1.82	0.31	0.03	1.20	2.75
Total	300	2.53	1.16	0.06	0.81	6.07

ANOVA _Shoot height to root length ratio

	Sum of Squares	Df	Mean Square	F	Sig.
Between Groups	263.93	2	131.97	277.59	.000
Within Groups	141.19	297	0.48		
Total	405.13	299			

Shoot height to root length ratio-Duncan[a]

		Subset for alpha = .05	
Nursery sites	N	1	2
Menagesha	100	1.82	
Bekate	100	1.90	
Garmama	100		3.85
Sig		0.408	1.000

Means for groups in homogeneous subsets are displayed. a Uses Harmonic Mean Sample Size = 100.000.

Appendix 27: Descriptives and ANOVA for shoot height to root length ratio of *Hagenia abyssinica* at three nurseries of highland zone of central Ethiopia

Shoot height to root length ratio

	N	Mean	Std. Deviation	Std. Error	Minimum	Maximum
Garmama	100	2.32	0.60	0.06	1.05	6.53
Bekate	100	1.81	0.31	0.03	0.85	2.44
Menagesha	100	1.77	0.30	0.02	1.06	2.70
Total	300	1.97	0.49	0.03	0.85	6.53

ANOVA _Shoot height to root length ratio

	Sum of Squares	Df	Mean Square	F	Sig.
Between Groups	18.67	2	9.34	51.03	.000
Within Groups	54.34	297	0.18		
Total	73.01	299			

Shoot height to root length ratio-Duncan[a]

		Subset for alpha = .05	
Nursery sites	N	1	2
Menagesha	100	1.77	
Bekate	100	1.81	
Garmama	100		2.32
Sig		0.545	1.000

Means for groups in homogeneous subsets are displayed. a Uses Harmonic Mean Sample Size = 100.000.

Appendix 28: Descriptives and ANOVA for shoot height to root length ratio of *Acacia albida* at three nurseries of lowland zone of central Ethiopia

Shoot height to root length ratio

	N	Mean	Std. Deviation	Std. Error	Minimum	Maximum
Modjo	100	4.14	0.84	0.08	2.34	6.10
Bushoftu	100	2.11	0.49	0.04	1.06	4.42
Godino	100	1.48	0.33	0.03	0.75	2.50
Total	300	2.58	1.28	0.07	0.75	6.10

ANOVA Shoot height to root length ratio

	Sum of Squares	Df	Mean Square	F	Sig.
Between Groups	384.88	2	192.44	545.36	.000
Within Groups	104.80	297	0.35		
Total	489.68	299			

Shoot height to root length ratio-Duncan[a]

		Subset for alpha = .05		
Nursery sites	N	1	2	3
Godino	100	1.48		
Bushoftu	100		2.11	
Modjo	100			4.14
Sig		1.000	1.000	1.000

Means for groups in homogeneous subsets are displayed. a Uses Harmonic Mean Sample Size = 100.000.

Appendix 29: Descriptives and ANOVA for shoot height to root length ratio of *Eucalyptus camaldulensis* at three nurseries of lowland zone of central Ethiopia

Shoot height to root length ratio

	N	Mean	Std. Deviation	Std. Error	Minimum	Maximum
Modjo	100	3.83	0.66	0.06	2.35	5.42
Bushoftu	100	2.63	0.52	0.06	1.68	3.88
Godino	100	2.53	0.63	0.06	0.71	4.31
Total	300	3.00	0.85	0.04	0.71	5.42

ANOVA Shoot height to root length ratio

	Sum of Squares	Df	Mean Square	F	Sig.
Between Groups	104.46	2	52.23	141.42	.000
Within Groups	109.70	297	0.37		
Total	214.16	299			

Shoot height to root length ratio-Duncan[a]

		Subset for alpha = .05	
Nursery sites	N	1	2
Godino	100	2.53	
Bushoftu	100	2.63	
Modjo	100		3.83
Sig		0.250	1.000

Means for groups in homogeneous subsets are displayed. a Uses Harmonic Mean Sample Size = 100.000.

Appendix 30: Descriptives and ANOVA for shoot height to root length ratio of *Grevillea robusta* at three nurseries of lowland zone of central Ethiopia

Shoot height to root length ratio

	N	Mean	Std. Deviation	Std. Error	Minimum	Maximum
Modjo	100	2.36	0.45	0.04	1.22	3.50
Bushoftu	100	1.30	0.19	0.02	0.86	1.77
Godino	100	1.54	0.31	0.03	0.93	2.50
Total	300	1.74	0.56	0.03	0.86	3.50

ANOVA Shoot height to root length ratio

	Sum of Squares	Df	Mean Square	F	Sig.
Between Groups	61.95	2	30.98	277.24	0.000
Within Groups	33.18	297	0.11		
Total	95.13	299			

Shoot height to root length ratio-Duncan[a]

		Subset for alpha = .05		
Nursery sites	N	1	2	3
Bushoftu	100	1.30		
Godino	100		1.54	
Modjo	100			2.373
Sig		1.000	1.000	1.000

Means for groups in homogeneous subsets are displayed. a Uses Harmonic Mean Sample Size = 100.000.

Appendix 31: Questionnaires for the Assessment of Information on the Tree Nursery Management Practices of Nurseries of Highland and Lowland Zones of Central Ethiopia

I. Location ____________ Name of nursery ____________

AEZ ____________

Altitude ____________ Annual mean rain fall ____________

II. Personal information about the interviewee

1. Name: ____________
2. Educational level: ____________
3. Knowledge about tree nursery: (Degree, Diploma, Certificate, Experience)

____

III. Questions regarding the nursery

1. Capacity of production per year (No. of seedlings): ____________
2. How many types of tree species: ____________
3. Seedlings of major tree species produced in the nurse ____________
4. Are there fruit trees that the nursery produces? (Yes/No). if Yes, which ones

____

5. Number of employees in the nursery
   i. Male ____________
   ii. Female

   ____

   iii. What is the ratio of female to male? ____________
6. Type of soils used in the nursery: ____________
7. Soil mixture ratio: ____________
8. Does the nursery have documented information on sowing date, germination rate, and survival rate, substrate (soil mix) for different tree species, watering schedule and silvicultural treatments? ____________

IV. Questions on seedling quality and quantity

1. Is the nursery site free of frost? ____________
2. What is the method of tree propagation used in the nursery (Is it Vegetative propagation? or is it Propagation via Seed? If both, which is the most convenient method? ____________

3. What methods of sowing can be applied in the nursery? Direct sowing or transplanting)____
4. What type of fertilizer can be applied in the nursery? (Manure, DAP or Urea) and also did you apply pesticides to seedlings in the nursery

   ____

5. Where do you get tree seeds? (through collection, purchasing)

   ____

6. What types of tree seedlings are produced at this nursery?(Bare rooted or potted / containerized
   seedlings)____
7. Which method is convenient

   ____

8. How do you understand the necessity of producing quality seedlings?

   ____

9. What measures do you take to increase the quality of seedlings?

   ____

10. What are the major tending operations that can carried out in the nursery?(root pruning, shoot pruning,, weeding or cultivation and its frequency) __________________________
11. In what criteria do you rate the quality of seedlings?

    ____

12. Can you apply culling of seedlings in the nursery? ______________________________
13. Can you apply shading of seedlings in the nursery? If yes, for what purpose?

    ____

V. Customer service of the tree nursery

1. Who are the customers of this nursery?

   ____

2. What is the demand of customers regarding the type of tree seedlings?

   ____