



**ADDIS ABABA UNIVERSITY
SCHOOL OF GRADUATE STUDIES**

**GROWTH PERFORMANCE OF TWO EVERGREEN AND THREE
DECIDUOUS INDIGENOUS TREES OF ETHIOPIA ON DEGRADED LAND
AT TULU KORMA**

**BY
TAMENE BELUDE**

**A THESIS SUBMITTED TO THE SCHOOL OF GRADUATE STUDIES ADDIS
ABABA UNIVERSITY, IN PARTIAL FULFILLMENT FOR THE
REQUIREMENTS OF MASTER OF SCIENCE DEGREE IN BIOLOGY**

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**JUNE 2007
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“Ebenezer” 1 Sam. 7: 12.

Dedication

To my family!

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Abstract

A study was conducted on young trees of *Prunus africana* (Hook. f.) Kalkman, *Podocarpus falcatus* (Thunb.) Mirb., *Millettia ferruginea* (Hochst.) Baker, *Cordia africana* Lam., and *Croton macrostachyus* Del., planted and maintained within the land holdings of the Center for Indigenous Trees Propagation and Biodiversity Development. The Center is located at 47 Km west of Addis Ababa, along the highway to Ambo. From a mixed stand of young trees planted 5 months before the start of this study, 200 seedlings of *P. africana*, 185 seedlings of each of *P. falcatus*, *C. africana*, and *M. ferruginea*, and 110 plants of *C. macrostachyus* were randomly selected and tagged with labeled metal tags. These were followed up for 8 months from October 2005 to May 2006 by assessing parameters such as height, diameter growth, survival, relative growth rate, tip dieback and damage by browsers. During the study period, care and management activities such as watering at intervals of 3 days during the dry months, weeding, hoeing the seedlings, mulching, dung application, fencing and guarding were carried out. Guarding was done regularly, but other activities were done when necessary. Data on plant height were collected every 45 days; root collar diameter measurements were done at the end of the experiment; extent of survival and mortality and damage by browsers were inspected every month. Relative growth rates were calculated for the plant height taking the period of time between two successive measurements. Data were subjected to One Way Analysis of Variance (ANOVA) and Tukey's Honest Significant Difference Test at $P = 0.05$. Growth performances of all species varied significantly regardless of the similar treatments administered. Consequently, for variables such as height, survival, relative growth rate in plant height, and tip dieback *M. ferruginea* performed better compared to all the other species; *C. africana* was good in root collar diameter increase, but ca 31.4% experienced dieback at the tip. *Prunus africana* was good in height increment, but ca 14.5% of the seedlings was damaged by browsing animals. *C. macrostachyus* was good in relative growth rate of seedling height, but 6.4% of the stock was damaged by tip dieback. *Podocarpus falcatus* was lowest in all the parameters measured, but was very good in terms of percentage survival. Overall, seedlings survival of the studied species was

significantly higher during the period of rainfall and months of well-watering than during the dry and months less-watering. Soil analysis of the study site yielded a value of 1.3 ppm for available P, 0.071% of total N, and 1.6% of organic C. The values for available P and total N were below the standard minimum values, while that for organic C was somewhat marginal, thus warranting the classification of the site as degraded.

1. INTRODUCTION

The causes of forest destruction in the tropics are complex, but agricultural expansion and forest clearings for various purposes are believed to be the main drivers (Khurana and Singh, 2001). For instance, the chief reasons for deforestation in Africa are conversion of forests to agricultural land, demand for fuel and construction wood, inappropriate land use policy, traditional way of farming, and population growth (EFAP, 1993; Legesse Negash, 1995; Girma Balcha, 1999). The destruction of tropical forests is leading to unmatched loss of biological diversity (Whitemore and Sayer, 1992). However, in developed regions, the area of forest remained unchanged over the decade, 1980-1990, whereas in developing countries deforestation was five times that of planting rate during the same period (Frankel and Soule, 1991). This challenge can be met only if efforts are made, on the one hand, to maintain the remaining forests and on the other hand to restore deforested and degraded areas (Gerhardt, 1994).

Forests have received the most intensive studies of ecosystem function (Silvertown, 1982; Smith, 1992). Forests are home for much of the known terrestrial biodiversity, but about 45% of the natural forests have gone, mostly during the past century (FAO, 1995).

Among African countries, Ethiopia is often quoted as one of the six countries of the world where about 60% of the plants are said to be indigenous (Belachew Demissie, 1984). These plants vary in their distribution over the country because of variation in topography and climate (Amare Getahun, 1976). Currently, Ethiopia is one of the worst hit countries in the world when it comes to poverty and food insecurity due to natural resources degradation in an unmatched scale (Legesse Negash, 1995, 2002). For instance, it has been reported that 129 plant species, which are endemic to Ethiopia and Eritrea, were threatened due to forest destruction (Ensermu Kelbessa *et al.*, 1992). Consequently, this severe deforestation has resulted in recurrent drought, reduction in soil productivity, shortage of water, flooding, loss of wildlife, irregular rainfalls, and development of xeric conditions that have seriously

threatened livelihoods of the rural community (Legesse Negash, 1995). Other factors, such as land use conflicts between settlers and indigenous people, land and tree ownership, wild fire, unconsolidated forest policy statement, and clearing forests for coffee and tea plantations, exacerbated forest destruction in Ethiopia (Legesse Negash, 1994; Melese Damtie, 2001).

Moreover, the production capacity of the remaining forest is small while the demand for forest products is tremendous and is growing day-to-day (Yonas Yemishaw, 2001). In contrast, planting of indigenous trees is impeded by lack of adequate knowledge with regard to collection, handling, and treatments of seeds (Demel Teketay, 1996). As a result, the indigenous forest resources of Ethiopia have undergone substantial changes over the years. It has often been quoted that the closed natural high forests, which once covered more than 40% of the highland area of the country, have now been decreased to less than 3% (TeweldeBirhan G/Egizabher, 1990). Likewise, the poor soil management practice among the rural population, renting the fragile and relatively pristine ecosystems to investors for agroindustry projects, alongwith the increasing population, is converting agricultural land into degraded, barren land (Legesse Negash, 1995; Demel Teketay, 1996).

On the other hand, there is no sign of meaningful legislative efforts to halt the alarming deforestation and the continued threats on forest resources (Legesse Negash, 1990). People of North Showa described the shortage of fuel wood as follows: “... since there was no forest in Northern Showa, we cooked our food by burning cow dung and crop residues” (GebreMarkos W/Selassie and Deribe Gurm, 2001). This is to say that forest resources for fuel wood and other purposes have been seriously lacking in central highlands of Ethiopia.

Unless strong measures are taken to develop the already declining forest resources of Ethiopia, it will diminish further and its vital role as life support system will be seriously disrupted (Legesse Negash, 1995). This situation calls for an immediate action of developing forest resources together with devising an effective method of conserving indigenous tree species through regeneration by various means (Melesse

Damtie, 2001). One way of enhancing natural regeneration is by planting various types of indigenous tree species through establishing mixed plantation (Legesse Negash, 1990; Evans, 1992). Such plantations help to divert the negative effects of monocultures, low stability, low level of biodiversity, low resource use efficiency, the tendency to use exotics that displaced indigenous species, water and soil erosion (Evans, 1992).

In combating these problems, and in order to bring about sustainable production of forest goods and services, we need to look at alternative forms of land restoring with indigenous natural forests because, a quick move towards conservation of the remaining forests is of paramount importance, at least as a seed source for a reforestation program (Legesse Negash, 1995).

2. SCOPE OF THE PROBLEM

In Ethiopia, the traditional sources of commercial indigenous tree species were the natural forests (TeweldeBirhan G/Egizaber, 1991). However, these indigenous forests have been declining at an alarming rate leaving behind a damaged ecology (Addis Tsehaye, 1992). Trials of reforestation programmes had been underway in specific parts of Ethiopia for economic reasons and to prevent denudation by deforestation, overcultivation and overgrazing (EFAP, 1994). However, the planted trees are mainly monoculture and exotic such as *Eucalyptus*, *Cupressus*, *Pinus*, etc, which are susceptible to various types of pests and diseases, climatic changes, and fire hazards compared to indigenous tree plantation. For any given exotic tree species, the chance of failure is much greater than the chance of success because it requires many years to determine its success of establishment. A minor disease in its native habitat may turn out to be extremely severe under the new conditions, and it may encounter a disease in its new habitat to which it has no resistance (Mengistu Huluka, 1992). For instance, *Cupressus lusitanica* Mill. is prone to stem cracking and *Pinus radiata* D. Don. is vulnerable to fungal attack (Abdurrahman Abdullahi, 1992). *Eucalyptus* is known for its water and nutrient depletion, allelopathic effects, poor erosion control, and aggressive competition with other plants (Legesse Negash, 1990).

According to Legesse Negash (1995, 2002), much of Ethiopia's highlands, watersheds, and woodlands were once covered with a variety of indigenous trees such as *Prunus africana* (Hook. f.) Kalkaman, *Millettia ferruginea* (Hochst.) Baker, *Cordia africana* Lam., *Croton macrostachyus* (Hochst.) Del., *Podocarpus falcatus* (Thunb.) Mirb., and various *Acacia* species. Today, however, a large proportion of Ethiopia's landscape is deforested, thus exacerbating desertification throughout its huge expanses of dryland. Since indigenous forests are wombs for a range of above and below ground organisms; it is believed that there should be an urgent need to reverse the loss and degradation of trees by restoring degraded landscapes with plantation and/ or regeneration of native trees (Legesse Negash, 1990; Jiregna Gindaba, 2006).

Landscape restoration with indigenous trees is important for re-establishing lost vital connection that indigenous trees used to provide for both people and other forms of life (Legesse Negash, 1990, 1995, 2002). It also connects forest fragments, establishes a network of vegetation bridges among protected areas, and creates corridors for wild life (Legesse Negash, 2002).

However, in the past sufficient attention was not given to the indigenous flora of Ethiopia, particularly to use them in plantations (Legesse Negash, 1990; Jiregna Gindaba, 2006), because their growth have been regarded as slow compared to introduced exotics such as eucalyptus (Pohjonen, 1989). But, thorough studies are scanty to prove this assertion except from casual observations on eucalyptus plantations (Jiregna Gindaba, 2006).

Since the success of natural regeneration is limited in many places owing to various anthropogenic pressures, the alternative method used to rehabilitate cutover forest is planting using indigenous tree species (Evans, 1982). It is only by planting that the genetic structure of the original forest can be maintained, restored, or improved (Wood, 1976; Andrew and Burley, 1976). Hence, seedling establishment techniques for indigenous trees restoration should be studied (Evans, 1992).

However, mechanisms of seedling establishment vary from species to species, and from location to location. Consequently, studies on temporal and/or spatial factors preventing or promoting seedling establishment of woody tree species may help in the restoration of degraded forestlands (Fenner, 1987; Bullock *et al.*, 1995). The factors hindering seedling establishment and survival are drought, diseases, damage from insects, lack of a suitable place to sprout, and browsing mammals, as well as nutrient status of the soil (Silvertown, 1982; Gerhardt, 1994).

The present study on five indigenous trees was initiated with a view to making contributions towards establishing these trees on degraded sites.

3. OBJECTIVES OF THE STUDY

General objective

The general objective of the present study is to:

- * Assess growth performance of the five economically and ecologically important, multipurpose indigenous tree species of Ethiopia: *Prunus africana*, *Cordia africana*, *Croton macrostachyus*, *Millettia ferruginea*, and *Podocarpus falcatus*, on a degraded site at Tulu Korma.

Specific objectives

The specific objectives of the study are to:

- ⇒ Assess the extent of growth performance of the seedlings of *P. africana*, *C. africana*, *C. macrostachyus*, *M. ferruginea*, and *P. falcatus*;
- ⇒ Generate preliminary data on growth performance of the five indigenous trees and contribute towards the establishment of long-term field studies;
- ⇒ Apply some seedling establishment techniques that would help the seedlings to overcome environmental stresses during dry seasons.

4. LITERATURE REVIEW

4.1 Location and physical features of the study area

Ejere Wereda is found within the Oromia Regional Government, West Showa Zone, at 44 km west of Addis Ababa. The district is located between $9^{\circ} 14'$ N and $38^{\circ} 28'$ E of astronomical grids (BPEDORS, 1998). The specific location of the study site is 3 km past Addis Alem, at Tulu Korma, within the land holdings of the Center for Indigenous Trees Propagation and Biodiversity Development, at an altitude of 2,180 m a.s.l., and $09^{\circ} 01'$ N, $38^{\circ} 21'$ E .

4.1.1 Climate and soil of the area

Two agro-climatic zones are recognized: Highland (45%) and “Weyina-Dega” (55%). The altitudinal range of highland is above 2,300 m with temperatures in the range of $10-15^{\circ}$ C whereas that of “Weyina-Dega” is between 1,500-2,300 m with temperatures range $15-20^{\circ}$ C. The average maximum and minimum temperatures are 28 and 9° C, respectively, while average annual rainfall is between 700 to 1,200 mm (BPEDORS, 1998).

Two types of soils are found in the Wereda (BPEDORS, 1998). These are chromic and orthic luvisols (characterized by reddish color, having argillic B horizons, with high base status cracking clay soil) and chromic and pellic vertisols (characterized by reddish and dark colored, often poorly drained, dominant in the soil matrix throughout in the upper 30 cm, cracking clay soil). Vertisols form wide and deep cracks when shrinking during the dry season and surface soil materials may then crumble down into the bottom of the cracks (Mesfin Abebe, 1998). In addition to their high swell-shrink capacity, the soils are sticky when wet and very hard when dry (Tan, 1994). The peasants in the district practice various traditional methods such as using chemical fertilizers, animal dung, crop rotation, and fallowing to maintain soil fertility (BPEDORS, 1998).

4. 1.2 Vegetation and wildlife

In the past, natural vegetation cover of the area was substantial. But now all types of vegetation are nearly completely removed leaving behind bare lands. This is because of increased human interferences. As a result, forest cover of the Wereda at present is less than one percent (BPEDORS, 1998) and the great majority of the trees are eucalyptus. For instance, remnant tree species such as *Podocarpus falcatus*, *Cordia africana*, *Croton macrostachyus*, *Ekbergia capensis* Sparm., *Acacia abyssinica* Hochst. ex Benth., *Olea europea* L. sub-species *cuspidata* (Wall. ex G. Don.) Cif., *Albizia gummifera* (J. F.Gmel.) C. A. Sm., and shrubs such as *Carissa edulis* (Forsk.) Vahl., (syn. *Carissa spinarum* L.), *Maytinus arbutifolia* (Hochost. ex A. Rich.) Wilczek., etc as well as some herbs and grasses. Generally, availability of forest resources is low. Hence, environmental problems such as deforestation, soil erosion, and flooding, dry and hot climate are prevelant.

Advanced deforestation and increasing expansion of farmlands with unabated hunting and indiscriminate killing have gradually decreased the number of wild animals in the Wereda. Since wildlife concentration is inversely related to human population density, the densely populated Shewa plateaus have only few wild animals (RAO, 1997). The main types of animals in the Werada includes aardvark, spotted-hyena, black-backed jackal, bush-back, bush pig, colobus monkey, unguis baboon, hedgehog, rabbit, civet and other small wild animals and birds. There is no reserved area for wildlife (BPEDORS, 1998).

4.2 Status of Ethiopia's indigenous trees

The total number of woody plant species in Ethiopia is estimated to be 1,000 out of which about 300 are tree species (Legesse Negash, 1990). According to EFAP (1994), information on the extent, distribution, species diversity, and rate of depletion of the forest resources of Ethiopia is very limited, and there is no accurate information on stand dynamics. However, it is known that indigenous forests of Ethiopia have rapidly been destroyed over the last several decades, with a sharp decline from the estimated 40% at the turn of the 20th century below 3% (Legesse Negash, 1995; Reusing, 1998). Such massive habitat degradation is accompanied with huge erosion of genetic resources at unmatched rate, including the gene pool

of wild populations (Tadesse W/Mariam and Demel Teketay, 2001). Consequently, contemporary Ethiopia is under silent environmental crisis that includes rapid biodiversity loss, massive soil erosion, and falls in land productivity, as well as complicated changes in temperature and diminished underground water (Taye Bekele *et al.*, 1999). Clearly, urgent actions are needed for the sustainable management of the remnant natural forests and for immediate ecological restoration (Legesse Negash, 1995, 2002).

4.2.1 Germination and growth problems associated with indigenous trees

Many tree growing organizations and individuals have been complaining about the poor germination and growth of indigenous trees of Ethiopia (Legesse Negash, 1995; Jiregna Gindaba, 2006). However, these complaints are not warranted as there are plenty of indigenous trees that can germinate easily and grow quite fast, provided that the propagation biology and ecological requirements of those trees are understood. Examples include *M. ferruginea*, the various *Acacia* and *Ficus* spp., *C. africana*, and *P. africana* (Legesse Negash, 2007).

4.2.2 Restoration of indigenous trees

Discussion about the alarming forest destruction in the highlands of Ethiopia has been in progress for some decades (Kumilachew Yeshitela, 2001). However, detailed analyses of the biodiversity crisis associated with the destruction and practical solutions on how to effectively reverse the course of destruction in the country are generally scarce (EFAP, 1994). Global climate change and the increasing genetic manipulations of the limited number of presently used trees suggest that maintenance of forest diversity is probably the only insurance for humankind, particularly for countries such as Ethiopia, which are characterized by under-development, poverty, fragile ecosystems, and recurrent drought (Anonymous, 1992; Zerihun Woldu, 1999; Legesse Negash, 2007).

Since ecological restoration is viewed as second to the preservation of the original habitats, its potential as a means to prevent the continual loss of biodiversity has been widely valued (Muutka and Laasonen, 2002). This is especially relevant in

situations like Ethiopia where the original habitats are already at risk (Yalden, 1983; Eshetu Yirdaw, 2001). Ecological vegetation restoration deals with nature management practices aimed at reconstruction of a natural tree on degraded or modified lands (Bakker *et al.*, 1996). The recovery of plant species, their composition, structure, and function on restoration sites depend on three main factors. These are the presence of the seed bank in the soil, transporting seeds to the restoration sites if disappeared from seed bank, and proving safety of the sites before inducing restoration (Harper, 1977).

Generally, rehabilitation processes at a site may be fast or slow depending on the degrees of previous land use effects and on the above mentioned three factors. Most degraded lands are poor in self regenerating potentials as a result it is difficult to achieve the desired degree of rehabilitation within a fixed time frame (Bakker *et al.*, 1996). But, by active rehabilitation through planting tree seedlings, successful restoration of native forest flora is possible on degraded lands (Eshetu Yirdaw, 2001; Mulugeta Limeneh, 2006). For this purpose, species selection for reforestation would be based on the following criteria: good survival rates, rapid early growth, and ease to cultivate, ability to coppice, and preference by indigenous people (Smith, 1992).

4.3 Purpose of tree plantation

Plantation is reforestation of land, which has carried forest within the last 50 years by renewal of essentially the same tree as before or regenerating an existing forest by enrichment through planting tree seedlings (Evans, 1982). Obtaining satisfactory natural regeneration of forest has proved difficult. This problem was overcome by planting desired types of species through mixed plantation (Evans, 1992). Tree planting is not only for industrial purposes but also for agroforestry development, fire wood, and fodder and food security. It is also essential for rehabilitating degraded land, reversing the consequences of desertification, and creating an opportunity to introduce a new and better species (Evans, 1992; Legesse Negash, 1995).

Plantations are established on much kind of sites such as degraded land, grassland, savanna and recently cleared woodland or forest (Evans, 1982). The important objectives of establishment are good survival and rapid early growth of seedlings. For this purpose, correct choice of species, adequate ground preparation, control of weeds, addition of fertilizers, mulching, protection against browsing animals, watering are all required, in which omission of any one of these may prolong establishment (Evans, 1992).

4.4 Seedling growth

Growth is one of the most fundamental and conspicuous characteristics of living organisms, being the consequences of increase in the amount of living protoplasm (Street and Opik, 1976). It may be expressed in terms of dry weight, length, height or diameter (Evans, 1972; Tisdale *et al.*, 1985). Difficulty occurs in measuring the amount of protoplasm in growing plants, but a variety of ways such as fresh weight, dry weight, height and area measuring is used as alternative methods (Evans, 1972; Tisdale *et al.*, 1985). Height or length is a suitable measure in the case of an organ growing in one direction with uniform diameter, such as a young shoot tip or root tip (Evans, 1972). The units in which growth is expressed are as diverse as the methods of measurement; and growth rates can be expressed in absolute or relative terms (Evans, 1972).

Under favorable conditions, seedlings have indeterminate growth habit, but varieties of stresses impose limitations on the progress of growth. Stresses present at the planting site vary widely with climate and vegetation type (Iverson and Newton, 1980). For instance, drought was the main mortality factor (72.6%) during first growing season of the seedlings (Castro *et al.*, 2004). Generally, environmental and physiological factors interact to shape growth and survival of seedlings in nursery and after outplanting (Lavender, 1984). Hence, cultivation according to the chemical, physical, and physiological requirements is essential to produce plants with maximum survival and growth rate (Lavender, 1984).

4.4.1 Non-destructive and destructive growth analyses

For scientific investigation of plants, it is essential to study the natural plant in the field in that a chance to observe how any particular plant would behave as a functioning whole is created (Evans, 1972). Hence, growth analysis is at best a useful method for obtaining preliminary descriptions of plant growth as a framework for more detailed studies of the underlying biological processes (Evans, 1982). Plant growth analysis forms only a part of the activity of studying plant growth in relation to time (Hunt, 1982). In plant growth analysis destructive measurement has difficulties to deal with because, it is expensive to collect data in terms of time taken, a large sample is required for precise estimate of biomass, and impossible to follow the same plant through the season or from time to time. Non-destructive methods for determining shoot height, root collar diameter, and leaf area of individual trees throughout their growing time are an essential tool in agroforestry research because, researchers of an area need periodic measurements of tree productivity to establish the value and potential of the system under examination (Black, *et al.*, 2000)

4.4.2 Seedling root collar diameter (RCD)

Root collar diameter is a measure of the seedling's survivability potential and also the parameter on which seedling price is based (Evans, 1982). Nurseries measure the root collar diameter of thousands of seedlings each year to obtain a statistical measure of the crop value in the field (Evans, 1992). In contrast to height growth, diameter growth depends primarily on current photosynthesis, although some reserve carbohydrates may be used for diameter growth very early in the season (Kozlowski *et al.*, 1991). During the long period of diameter growth, seedlings are subjected to a variety of environmental stresses which reduce diameter increment. Therefore, diameter growth responds readily to fluctuations in environmental factors, especially soil moisture, light intensity, and temperature (Evans, 1992).

4.4.3 Seedling relative growth rate (RGR)

Plant growth analysis is an essential step in the understanding of plant performance and productivity and may reveal various strategies of plants to survive under

limiting conditions (Hunt, 1982). One method used to analyze seedling is the comparison of relative growth rates (Evans, 1972; Hunt, 1982). The relative growth rate of a plant is the increase of plant material per unit of material present per unit of time (South, 1992). Relative growth rates are comprehensive traits of plants, which characterize plant performance and are also important components of fitness (South, 1995). RGR is also useful in comparing the growth of seedlings of various sizes and determines how much water or ions are taken on any given time. Therefore, the differences in relative growth rate between species are caused by morphological parameters, while the temporal changes in relative growth rate are caused by physiological parameters such as net assimilation rate (Hunt and Cornelissen, 1997).

Generally, it integrates morphological and physiological traits of plants. Relative growth rate is also an inherent quantitative trait that may vary among plant species, occurring in a wide range of habitats. Plants in suitable environments have an inherently high RGR, whereas those from unfavorable habitats have an inherently low RGR (Grime and Hunt, 1975; South, 1995). For seedlings, a high level of nutrition was essential to maintain a high mean RGR (Van den Driessche, 1992).

RGR is measured at a number of isolated times and then calculated over the period between two measurements (South, 1992). In some comparative studies, deciduous plants grow faster than evergreens, but it was impossible to generalize that deciduous species always grow faster than evergreens (Antunez *et al.*, 2001). Deciduous woody species show higher potential growth rates, higher specific leaf areas, and higher photosynthetic rates than evergreen species (Reich and Walters, 1992; Reich, 1998). The greater relative growth rate of deciduous species has been considered an important determinant of their distribution in productive habitats through greater competitive ability (Cornelissen *et al.*, 1998).

4.5 Factors affecting growth

4.5.1 Physiological factors

Carbohydrates

Carbohydrates provide the principal substrates for producing energy necessary for plant metabolism. Therefore, plants require carbohydrates to balance the availability and demand to sustain their metabolism and support their growth and development (Smeekens, 2000). Plants produce carbohydrates they require in mature leaves and transport via phloem where they support growth of developing tissues or to be stored in anticipation of less favorable environmental conditions (Rook and Bevan, 2003). Carbohydrates levels have been related to, development of cold hardiness, based on the hypothesis that relatively high levels of substrate are necessary if a plant is to cold harden fully (Weiser, 1970; Ritche and Dunlap, 1980). Sugars also play a role as a signaling molecule that regulates a variety of genes, in which it may affect various aspects of development in higher plants (Ohto *et al.*, 2001).

Hormones

Plant growth hormones, in the form of an appropriate concentration, can stimulate the activity of chemical substances and physiological processes, which are reflected by growth (Trewaves, 1981; Awan *et al.*, 1999). The major accepted hormones and functions of each are, auxins: stimulate cell enlargement, rooting of cuttings, apical dominance, inhibit abscission of leaves, fruits and root elongation; gibberellins: stimulate cell division, seed germination, and reproductive growth; cytokinins: retard senescence, promote bud growth and cell division, expansion and differentiation; ethylene: stimulates fruit ripening, break of dormancy and epinasty, inhibits elongation of shoots and roots (Thimann, 1972).

Frost hardiness

Frost hardiness is the ability of a plant cell to withstand temperatures below freezing, without suffering irreversible physical damage (Lavender, 1984). The cause of changes in plant cells during the hardening processes is not fully

understood, but it clearly involves changes in cell membranes, to allow movement of water to extra-cellular ice crystals and in the protoplasm to resist the effects of desiccation (Weiser, 1970). Significant frost hardiness is developed in seedlings only if the plants have an adequate carbohydrate reserve and if active growth has ceased (Hermann, 1974).

4.5.2 Exogenous factors

Light

Light affects the growth of plants in two ways: as energy source that drives photosynthesis; and regulates seedling development through photoperiodism, in which daily darkness of less than ten hours stimulate active shoot elongation, whereas longer than 14 hrs of dark periods stimulate dormancy (Lavender, 1984).

Moisture

Soil Moisture deficit influences seedlings growth and development by sharply reducing the rate of photosynthesis (Zahner, 1968). Seedlings should be moistened thoroughly during dry days to prevent moisture stress and subsequently reduce seedling growth (Daniels, 1979). However, watering seedlings at wrong times can cause physiological damage (Lavender and Cleary, 1974). Every process occurring in trees is more or less affected by water deficits (Kozlowski *et al.*, 1991). Generally, seedling growth is reduced by water deficits indirectly through interference with physiological processes such as photosynthesis, nitrogen metabolism, salt absorption, and translocation, and directly by affecting cell turgor, enlargement, division and differentiation (Taiz and Zeiger, 1998).

Nutrients

To be healthy, seedlings must be well supplied with all nutrients in proper proportions (Ingestad, 1979). Any environmental factor that affects growth will affect seedling nutrient requirements. If a given nutrient is deficient, seedlings may compensate by increasing their capacity to take up the deficient ion (Ingestad, 1979). Such deficiency is reflected by reducing growth and by distinct changes in the plants habit, such as nitrogen deficiency causing chlorosis; low levels of

phosphorus resulting in reddish-purple foliage; boron deficiency causing terminal dieback and necrotic buds. Physiological malfunctioning of seedlings is exhibited by deficiency in other nutrients (Lavender and Walker, 1979).

Generally, a range of carefully controlled, designed studies, wherein all environmental factors including nutrients are fully controlled is needed to answer questions about species, quantities and timing of seedling nutrient applications (Weiser, 1970; Smith, 1975; Lavender, 1984).

Temperature

Temperature extremes may damage seedlings. However, proper seedling spacing may minimize effects of high temperatures supplemented by occasional light or cooling irrigation on hot days (Lavender, 1981). Frost damage may be avoided by initiating dormancy and by seedling spacing which permits maximum photosynthesis and production of carbohydrate reserves (Lavender, 1984). Under high temperature, leaves of *C. macrostachyus* and *C. africana* transpire more water and have low water use efficiencies compared to *M. ferruginea* (Jiregna Gindaba, 2006).

4.6 Some post-planting care and protection

Watering

Water is a critical resource, limiting distribution, survival, and growth of plants (Grace, 1997). The amount of moisture in the air affects the extent of water stress to plants, which sharply reduces the rate of photosynthesis. This reduction in rate of photosynthesis also reduces total seedling growth (Hartmann and Kestler, 1997). The capacity to store water in the soil is improved by incorporation of organic matter that alters the physical and chemical properties of soil, which may further improve seedling growth (Jacobs *et al.*, 2003).

Soil moisture exerts a powerful impact on seedling establishment because the seedling stage is highly vulnerable to drought stress (Brady and Weil, 1996). Water supplementation during the earliest phases of the plant life cycle increases natural seedling establishment of woody species (Lonsdale and Abrecht, 1989). Daniels (1979) reported that watering should be done during the dry season for seedlings survival and growth. One of the two major factors often acknowledged as establishing the upper limit of the potential yield of plants is the amount of moisture available during the growing season (Tisdale *et al.*, 1985). The growth of many plants is proportional to the amounts of water present because too little or too much level of soil moisture restricts growth (Evans, 1982).

Impact of browsing animals on seedlings

One of the serious problems that make the regeneration of some indigenous tree species in the natural forest is, the damage done by browsing animals to their seedlings (Crawly, 1983). According to Swaine (1996), tree seedlings are more vulnerable to browser damages not only due to their size but also because of the meal available to animals is richer in younger plants than older plants. The accumulated pieces of evidence have shown that browsing animals hinder reproductive success of the individual plant, as well as structure and composition of forests (Silvertown, 1982; Hendrix, 1988). The effect of browsing animals is highly variable among species depending on seasons and conditions (Adams, 1975). However, despite large populations of livestock grazing in forest seedlings, little attempts have been made on the role of browsing animals on tree seedling population in Ethiopia (Demel Teketay, 1997).

Mulching

Mulching is widely used for conserving soil water, reducing soil erosion and evaporation, increasing activity of soil fauna, and for further improvement of soil structure and temperature (Huxely and Ong, 1996). Mulch also reduces the impact of raindrops on the soil; and minimizes splash and sheet erosion on slopes, reduces the wind speed and radiation at the soil surface, and control weeds (Young, 1989; Rose and Smith, 2001). The physical structure of mulch may also impede vapor transfer from the soil surface, and further reducing evaporation. Generally,

vegetation cover increases infiltration and reduces run off (Kiepe and Rao, 1994). The specific time for mulching is in spring after the soil has warmed and in the autumn (Singh *et al.*, 1996).

Dung application

Fertilizers are used in plantation for three purposes; to correct a specific deficiency; to establish a crop on until now impoverished and implantable land; and to stimulate growth (Evans, 1992). The application of 150 g of NPK per seedling generally doubles first year height growth (WRI, 1978). Since chemical fertilizers are expensive, alternative methods of maintaining soil fertility are important. These are using inherently fertile soil, local manures such as cow dung, organic wastes, blood and bone meal, weeds and mulch (Romney *et al.*, 1994). Impact of fertilization was less on leguminous species compared to non-leguminous species (Lugo, 1997). Inter-planting of leguminous tree seedlings increased shoot growth of non-leguminous species, indicating the impact of nitrogen input through symbiotic nitrogen fixation (Singh *et al.*, 1996).

Fencing and weeding

Newly planted tree seedlings must be protected until they are well established, because they are susceptible to grazing and browsing animals, insect attack, and various assaults of wild herbivores (Evans, 1992). For this purpose, fencing with protecting tree species, as well as using guarding person, is required to protect from large browsing animals. Species suitable for fencing need to be resistant to browsing and so are often very spiny (Evans, 1982).

In addition, weeding is required to avoid competition from weeds for moisture, nutrients, and light. For this purpose, mechanical weeding and hoeing the seedlings were the cheapest to be used (Evans, 1992).

4.7 Botanical description, ecology and uses of the study plants

4.7.1 Prunus africana (Hook.f.) Kalkman

Botanical description

Prunus africana (*Pygeum africanum*) belongs to Rosaceae family, genus *Prunus*, and the only species of *Prunus* native to Africa (Kalkman, 1965). It is commonly known by various names such as African cherry, bitter almond, ironwood, red stinkwood, and African prune (Legesse Negash, 2002, 2004). Its vernacular name in Ethiopia is Tikur enchet (Amharic), Homi, Burayyu, Muka gurraacha (Oromic) (Legesse Negash, 2002). It is a large evergreen tree that can grow to more than 40 m in height and a diameter of 1 m (Dawson, 1997). It is also an important multipurpose and fast growing indigenous tree in the natural forests of Ethiopia and other African countries (Friis, 1992). Its bark is dark brown to gray, longitudinally fissured or scaly; leaves simple, alternate, leathery, deep pink petiole and midrib, glabrous, dark green glossy above; petals creamy-white and fragrant; filaments green on underside; ovary ovoid; fruit transversely ellipsoid brown to purple; seeds germinate easily but recalcitrant (Mulugeta Limeneh and Demel Tekatay, 2004); seedlings reach plantable size in 9-12 months (Hedberg, 1989). *P. africana* takes 15 to 20 years to produce seed and between 12 to 15 years to produce bark that contains the prostate remedy's active ingredient (Legesse Negash, 2004).

Ecological distribution and importance

Prunus africana is a geographically widespread tree, growing in the highland forest of mainland Africa and outlying islands (Hedberg, 1989; Cunningham and Mbenkum, 1993). In Ethiopia, it occurs in dry evergreen montane forest vegetation where the altitude ranges are between 1,550-3,100 m a.s.l. with annual rainfall exceeding 1,000 mm (Hedberg, 1989; Dawson, 1997; Legesse Negash, 2002). In Ethiopia, it is distributed in all the administration regions, except in Tigray and Wello (Hedberg, 1989; Dawit Abebe and Ahadu Ayehu, 1993). It is often found in riverine vegetation, on forest margin, and forest gaps (Legesse Negash, 2002).

Prunus africana provides various goods and services, including timber, fuel wood, soil fertility improvement, erosion control, wind break, shade and shelter, as bee

forage, for heavy construction work, maintaining forest integrity, food for many bird and mammal species, making household furniture and farming tools (Legesse Negash, 2002). It is also used as traditional medicine to treat various ailments among some indigenous African peoples (Cunningham and Mbenkum, 1993). It is the only plant used by pharmaceutical companies as a raw drug for the synthesis of a drug used in treating prostate problems in men, and the bark is sold up to 60 dollar per kilogram (Cunningham *et al*, 1997; Dawson and Powell, 1999; Dawit Abebe *et al.*, 2003).

Currently, the bark extracts of *P. africana* are traded on a larger scale than any other wild collected African tree (Acworth, 1999). In Ethiopia, international trade of this species is not yet known (Legesse Negash, 2002), but the demand for bark is expected to double or triple in the coming decades as populations in industrialized countries age and as these populations seek natural cures from *P. africana* (Stewart, 2003).

Threats to conservation of *P. africana*

Prunus africana is threatened due to unsustainable extraction methods that involve excessive debarking and the felling of entire trees (Schippmann, 2001). The skyrocketing demand for commercial exploitation, habitat loss, and unsustainable harvesting have led to a rapid decline in the population of *P. africana* and is threatening conservation of its genetic diversity (Cunningham and Mbenkum, 1993). The species is listed as vulnerable in the world list of threatened species because of its rapid population declines (Schippmann, 2001). The FAO Panel of Experts on Forest Genetic Resources lists *P. africana* as one of the 18 top priority species in Africa (FAO, 1997).

In Ethiopia, commercial exploitation of *P. africana* bark is not practiced yet, but it is an important timber tree and has local medicinal uses (Ensermu Kelbessa and Edward, 1999; Legesse Negash, 2002). Serious efforts to conserve good stands of this species in Ethiopia should be made before it gets destroyed through overexploitation (Legesse Negash, 2002, 2004). The success of conservation

through planting program depends on effective plant distribution and post-planting monitoring (Legesse Negash, 1995).

4.7.2 *Podocarpus falcatus* (Thumb.) Mirb.

Botanical description

Podocarpus falcatus (*Podocarpus gracilior* Pilg.) is one of the two indigenous conifers of Ethiopia and the only representative of the family Podocarpaceae in Ethiopia (Breitenbach, 1963; Lgesse Negash, 1992a, 1995, 2001). The tree's crown is pyramidal, evergreen, and dense; tree is dioecious and its growth rate is moderate to slow; bole cylindrical, a source of excellent timber; bark pale gray to pale brown, fissured both horizontally and longitudinally; texture fine; leaf, simple, opposite, entire, linear, evergreen, blue-green or green; venation parallel; wood undifferentiated and soft, creamy to pale brown; fruit fleshy, green, edible by wild animals; in nature seeds germinate slowly, but can be rapid when *in vitro* germination methods are employed (Lgesse Negash, 1992a). Planting size seedlings obtained within 12-14 months; trunk branches droop; male cones borne singly or in bunches; female cone spherical, borne, singly, in pairs or in bunch (Legesse Negash, 1995, 2001). At maturity, the tree reaches a height of 30-45 m (Friis, 1992).

Currently, *P. falcatus* in Ethiopia is not only degrading, but is also seriously threatened mainly due to continuous logging for timber, lack of easy and reliable seed based method for propagation, lack of suffice knowledge about the physiology of its hard coated seeds, deforestation of natural vegetation, and lack of scientific knowledge for the successful establishment of the seedlings in the field (Lgesse Negash, 1992a, 1995; Kassa Simagn and Legesse Negash, 1996; Legesse Negash, 2001).

Distribution and importance

Podocarpus falcatus is found in undifferentiated Afromontane forest between altitudinal ranges of approximately 1,500-2,800 m. In this forest type, it is one of

the dominant species forming *Podocarpus* forest or the co-dominant species with *Juniperus-Podocarpus* forest (Friis, 1992). It also grows along roadside, in riverine areas, open graveyards, and in farmlands (Legesse Negash, 2001).

Ecologically, its massive evergreen plant body and dense crown helps to protect the soil from strong stormy and erosive rainfall, thus contributing to the formation of cool and clear springs. On top of this, its fruits are eaten by many wild animals; and the massive dense and evergreen branches are used as a habitat for different organisms (Legesse Negash, 1995). Economically, the tree yields excellent timber, and is used to manufacture various furniture (Legesse Negash, 1995).

4.7.3 *Cordia africana* Lam.

Botanical description

Cordia africana Lam. (syn. *Cordia abyssinica* R. Br.) belongs to the family Boraginaceae, Sub-family Cordioideae, and genus *Cordia* (Jansen, 1981; Legesse Negash, 1995). It is one of the most popular and fast growing indigenous tree species of Ethiopia and the whole of East Africa. Its plantation should be laid out in a dense manner and should be mixed in order to stimulate fast growth and obtain straight stems (Breitenbach, 1963; Mebrate Mihretu, 1999). Germination is epigeal, regenerates from stumps, and its main adaptation to drought is by shedding its leaves (Legesse Negash, 1992b).

Cordia africana is a much-branched deciduous tree that varies in size from a shrub to a large tree up to a height of 25 m (Dawit Abebe and Ahadu Ayehu, 1993). Leaves alternate, simple, large, broadly oval, base rounded, tubular-campanulate; crown rounded; trunk crooked; bark pale brown or gray, finely grooved but rough with age; seeds germinate within 21 days and planting size seedlings obtainable within 6-8 months; fruits, smooth and ovoid, yellowish, sticky flesh, edible; wood somewhat soft, medium textured, pinkish brown (Legesse Negash, 1995). During dry months, *C. africana* seedlings close their stomata, shed their leaves, and allocate more biomass to roots. In nutrient depleted soils, the tree produces

extensive lateral roots that help to absorb surface nutrients (Jiregna Gindaba *et al.*, 2005).

Ecological distribution and importance

Cordia africana is distributed over wide geographic areas and in diverse climates, suggesting that there are differences within species (Feyisa Abate and Mebrate Mihertu, 1994). It is a common tree in highlands and is reported in all provinces in Ethiopia (Jansen, 1981). It is also distributed in tropical Africa. It grows well in dry, moist and wet "Weyina Dega" agroclimatic zones at altitude between 1,600-2,200 m (Dawit Abebe and Ahadu Ayehu, 1993). *C. africana* prefers regions with a fairly high amount of rainfall, a sufficiently warm climate with fertile and drained soil (Legesse Negash, 1995).

Cordia africana is an economically important indigenous tree species, that is, important in agro-forestry, timber production, and ecological well-being. The tree helps ensure nutrient recycling, improves soil fertility and water conservation, fruits edible, leaves serve as fodder for livestock, a shade for shade loving plants like coffee, and used as medicine (Dawit Abebe and Ahadu Ayehu, 1993; Legesse Negash, 1995). Due to land clearing for farming, settlement, fuel wood and commercial logging, rapid depletion of *C. africana* has occurred during the last decades. Consequently, this species has been proclaimed as endangered (Negaritt Gazetta, 1994 E.C.; Taye Bekele *et al.*, 1999).

4.7.4 Croton macrostachyus Del.

Botanical description

Croton macrostachyus Del. belongs to the family Euphorbiaceae and genus *Croton*, and is one of the top three abundant indigenous tree species of Ethiopia, along with *Acacia seyal* Del. and *Combretum molle* R. Br. ex D. Don.. The estimated total number of individual trees is 54, 133, and 531 million individuals (Taye Bekele *et al.*, 1999). *C. macrostachyus* is a deciduous, fast growing, economically and biologically important tree that grows to 25 m high (Hedberg, 1986). It is a well-known tree, inter-cropped with agricultural crops under small subsistence farming (Yeshanew Ashagrie *et al.*, 1998). *C. macrostachyus* is also one of the 400 tree species listed on a master list for future fuel wood potential tree screening

(Dachassa Jiru, 1999). Its leaves release nutrients more rapidly compared to *M. ferruginea* (Jiregna Gindaba *et al.*, 2004).

In open area, it is often shrub or small tree, which is 3-8 m tall, whereas in a closed forest it becomes a tree reaching a height of 25 m or more (Friis, 1992). It grows between 500-2,350 m where rainfall range is 750-2,000 mm per year. Trunk is light, open and slender; branches spreading; crown hemispherical; wood cream-colored, soft, light, strong and tough, perishable in the ground; leaves simple, alternate, ovate, with densely stellate hairs on both sides; leaf base rounded to cordate; leaf tip acuminate; leaf margin sub-entire to crenulate; bark pale gray and smooth when young and longitudinally fissured when old; petioles 1.5-11 cm; stipules 5-14cm; flowers creamy, yellow, in clusters, sweet scented and spike turning down as fruits mature; seeds germinate easily and seedlings grow fast; fruits capsular, loculicidal, evenly grayish; seeds gray, light brown (Breitenbach, 1963; Jansen, 1981; Hedberg, 1989).

Leaves of *C. macrostachyus* transpire more water in dry days and have lower water use efficiency compared to *M. ferruginea* and have a mechanism to cope with water stress by leaf shedding, stomata closure and biomass allocation to roots (Jiregna Gindaba *et al.*, 2005). It also copes with nutrient stress by producing extensive lateral roots to collect nutrients from soil surface. *C. macrostachyus* and *C. africana* have positive impacts on soil nutrients due to their short leaf life span, high leaf nutrient content and rapid decomposition to release nutrients (Jiregna Gindaba *et al.*, 2005).

Ecological distribution and importance

Croton macrostachyus has a wide range of ecological distributions (Jansen, 1981; Dachasa Jiru, 1999). In Ethiopia, it is found in all provinces and widely distributed in northwestern and southeastern highlands (Friis, 1992). *C. macrostachyus* is dominant in semi-humid lowland, woodland and co-dominant in intermediate and low stories of humid lowland and also found in forest margins and secondary woodlands, extending into disturbed areas and along edges of roads, mostly in soils of volcanic origin (Dachasa Jiru, 1999). *C. macrostachyus* is able to grow on

mountain slopes, waste grounds and eroded places that are poor in nutrients, due to efficient intersystem cycle of nutrient, with relatively higher foliar nutrient restoration (Jiregna Gindaba *et al.*, 2004).

Economically, it is important for sustainable honey production and also used for medicinal purposes, shade for farm animals, and as fuel wood (Jansen, 1981; Dawit Abebe and Ahadu Ayehu, 1993; Dachasa Jiru, 1999). It is, also one of the few species that increase phosphorous level in the soil (Dachasa Jiru, 1999).

4.7.5 *Millettia ferruginea* Hochst.) Baker

Botanical description

Millettia ferruginea belongs to the family Fabaceae, sub-family Papilionoidae and genus *Millettia* (Hedberg, 1989; Legesse Negash, 1995). It is a fast growing, endemic, indigenous, deciduous and multipurpose tree. Its leaves are up to 40 cm long; leaflets up to 27, oblong-acuminate up to 5-9 x 1-2.5 cm; pubescent present or absent on both sides or sub- glabrous above; lobes ca 1 mm; pod flat up to 27 cm and brown upon maturity; pubescent first and then glabrescent; seeds 5-10; corolla 17-30 mm, violet, standard sticky outside, disc tubular 1-10 (Hedberg, 1989). *M. ferruginea* has higher water use efficiency compared with *C. macrostachyus* and *C. africana* and its mechanism to cope with water stress is by closing stomata, biomass allocation to roots, and leaf re-orientation (Jiregna Gindaba *et al.*, 2005).

Importance and distribution

M. ferruginea fixes nitrogen, protects shade-loving trees such as coffee and barley from strong sunlight, and is used as a source of fuel wood both for domestic consumption and income generation. It's crushed and pulverized product of the seeds is used for fish poisoning, as insecticides, and also as a remedy to treat infection caused by chigger flea; stem used to make small household utensils; flowers used as a source of bee forage (Legesse Negash, 1995; Tadesse Hailu *et al.*, 2000). *M. ferruginea* is a useful agroforestry species that acts as nutrient pump by adding its leaves and flowers to the soil (Tadesse Hailu *et al.*, 2000). It fixes

nitrogen, thus successfully surviving in N-deficient soils and improving soil fertility (Legesse Negash, 1995).

The natural habitat of *M. ferruginea* is commonly between altitudinal ranges of 1,000-2,500 m (Tadesse Hailu *et al.*, 2000).

5. MATERIALS AND METHODS

5.1 The study site

The study is within the Center for Indigenous Trees Propagation and Biodiversity Development (Oromia Regional Government, West Showa Zone and Ejere Wereda). The specific location of the Center is $09^{\circ} 01' N$, and $0 38^{\circ} 21' E$. The Center's average elevation is 2,180 m a.s.l. The mean annual rainfall of the area is 1,100 mm, and is bimodal. The short rains occur from February to May while the long rains fall between mid-Junes to September. The mean maximum and minimum temperatures are $22.5^{\circ} C$ and $6.5^{\circ} C$, respectively, and average temperatures ranges from $11.6^{\circ} C$ to $15.3^{\circ} C$ (BPEDORS, 1998).

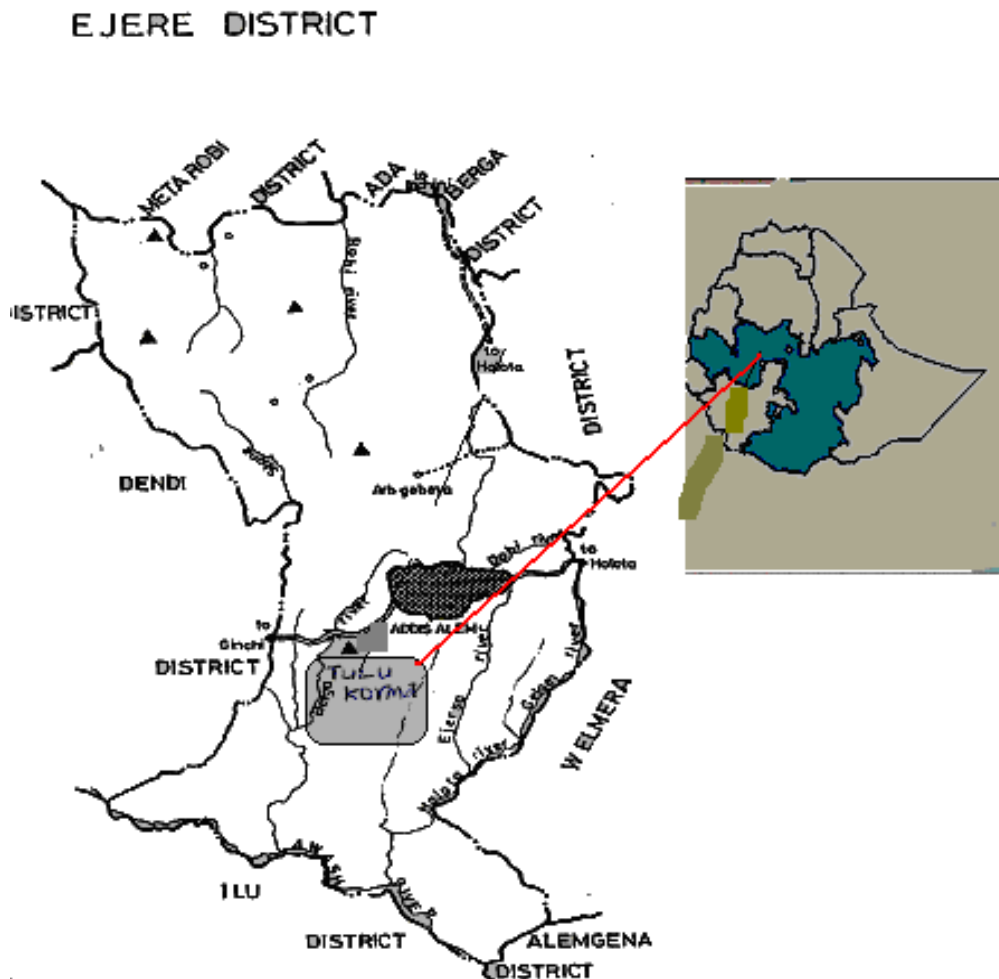


Figure 1. Map of the study area, Tulu Korma

5.2 Experimental design

The research work was conducted on five indigenous tree seedlings: *P. africana*, *C. africana*, *C. macrostachyus*, *M. ferruginea*, and *P. falcatus*, which were raised in the nursery site of the "Center for Indigenous Trees Propagation and Biodiversity Development". The seedlings were transplanted from polyethylene bag to the plots in June 2005. Activities related to the raising of seedlings, and their subsequent planting was accomplished by the Center prior to the start of the research work. This was done on 1.5 hectare of land. The seedlings were planted one meter apart from one another.

The experiments were conducted following randomized complete block design with five treatments (species) and six replications (plots). Each plot consisted of 5 species, except 2 plots that consisted of 3 species only. For the determination of parameters such as height growth, root collar diameter, relative growth rate, tip dieback, and percentage survival, the area was divided into six plots, each plot having an area of 20 x 30 m = 600 m². For the purpose of data collection, the following schedule was followed:

- 1) Of the 1,000 individual seedlings of *P. africana*, every 5th were selected and tagged with labeled metal tag, giving a total of 200 tagged seedlings;
- 2) From 370 seedlings of *M. ferruginea*, those with odd numbers were selected;
- 3) All of the 185 seedlings of *P. falcatus* and 185 seedlings of *C. africana* were tagged;
- 4) *Croton macrostachyus* were represented by 110 individual seedlings;
- 5) Mulching was done in spring and autumn by using mowed grass and uprooted weeds. Hoeing the seedlings and weeding was done whenever needed;
- 6) About 300 gm of crushed cow dung was applied to each seedling in December 2005;
- 7) Ditches for storing water to be used during the dry months of the year were dug in October 2005;
- 8) Watering of the young plants was done at intervals of 3 days during dry months.



Figure 2. Mulched *Podocarpus falcatus*



Figure 3. Applying crushed cow dung to seedling.



Figure 4. A large temporary dam from where water had been pumped to each of the three ditches dug in the study site.

Temporary dam construction

A temporary dam was built by using locally available materials such as wood pole, hoe, big basalt stone, gravel, teff straw, mud, and a large plastic sheet. From this large temporary dam, water was pumped to 3 ditches dug in the site. From each of these ditches, water was scooped with watering cans of 15 litre volume to be supplied to each of the seedlings (Figure 5). Watering was done every three days during the dry months of the year.



Figure 5. Watering each seedling during the dry months was done by scooping water from a circular ditch prepared for storing water by pumping from a temporary dam built for the purpose of this study.

Seedlings survival

Survival counts of seedlings were monitored every 45 days, alongwith height measurements, identification and recording of browsed seedlings, tip dieback, and dried seedlings.

Damage by browsing animals to seedlings

Browsed seedlings were counted and recorded every 45 days. To protect damage caused by browsing animals, mechanical barrier was done by fencing around the site, with indigenous spiny shrubs such as *Carissa edulis* (Forsk.) Vahl. and *Maytenus arbutifolia* (Hochost. ex A. Rich.) Wilczek.. For *P. africana*, fencing was done around each seedling, and also watchman was hired for guarding. As seedlings increased in height, new fences were maintained.



Figure 6. Fencing around seedlings of *P. africana* using spiny indigenous shrubs such as *Carissa edulis*.

5. 3 Soil sample collection and analyses.

Composite soil samples taken from six randomly selected plots of the study site at soil depth of 0-15 cm were analyzed for pH, total nitrogen, available phosphorus, organic carbon, texture, bulk density, and electrical conductivity at the National Soils Laboratory, Addis Ababa. Five different spots, each having an area of 15 x 15 cm² were dug and ca 200 g of soil was taken from a depth of 15 cm. A total of 1 kg of soil from each plot was taken and sent to the National Soils Laboratory for analyses. For bulk density, soil samples were taken from each plot using auger. Auger was inserted into moistened soil and taken out by mechanical digging around the inserted auger. The protruded soils from auger end were cut by knife and collected soil samples were taken to the National Soils Laboratory for analyses.

5. 4 Seedling data collection and analyses

Growth performances of the seedlings were assessed every 45 days using morphological parameters in non-destructive ways. The variables assessed were height, root collar diameter, survival percentage and tip dieback. Height growth assessments were carried out from October 2005 to May 2006 for eight months. Root collar diameter was determined using Vernier caliper in May 2006, towards the end of the experiment. All the collected data were subjected to One Way Analysis of Variance (ANOVA) (SAS, 2005) statistical package version-12) to seek evidence whether there is significant difference in height and other assessed parameters between the species at $p = 0.05$. In addition, the relative growth rate in height (RGR_{HT}) was calculated using a standard formula (Evans, 1972; Hunt, 1982; Amanuel Mehari, 2005):

$$RGR_{HT} = \frac{\ln HT_f - \ln HT_i}{t_f - t_i}$$

Where:

RGR_{HT} = relative growth rate of height

ln = natural logarithm

HT_f = Total shoot height at final measurement

HT_i = Total shoot height at initial measurement.

t_f, t_i = final time minus initial time(days)

6. RESULTS

6.1 Height growth performances

Data on growth patterns of the five studied tree species are provided in Figure 7. In all the species studied, growth was somewhat gradual up to 135 days since the start of the measurement. Thereafter, plants grew relatively fast. In particular, *M. ferruginea* grew much faster between days 135 and 225 compared to its growth between 0 and 135 days. Although the initial height of *M. ferruginea* was 50% less than that of *C. africana*, *P. falcatus* or *P. africana*, the seedling grew remarkably fast and attained and even surpassed heights of the above three species. Figure 7 further shows that *C. macrostachyus* grew ca 60% less than *M. ferruginea*.

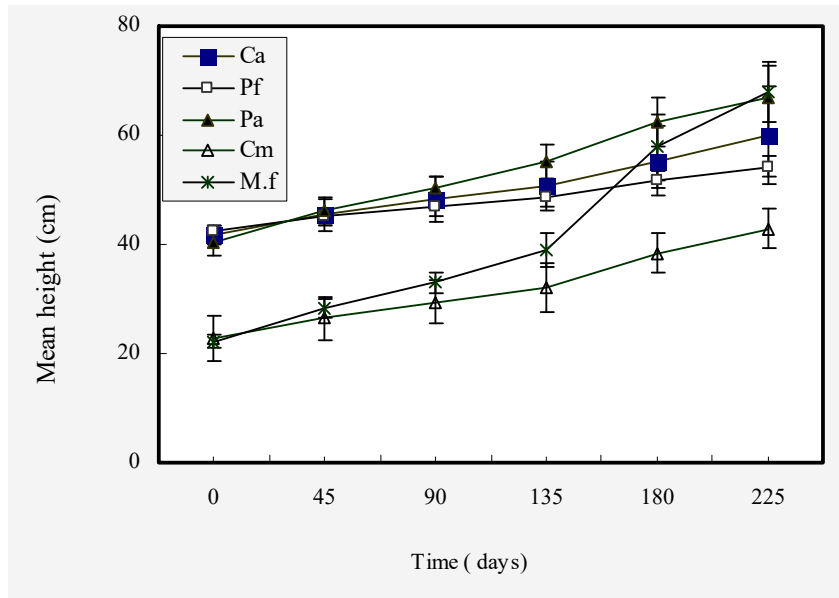


Figure 7. Growth patterns (mean height \pm SD) of the five indigenous tree species across months. Ca = *C. africana*, Pf = *P. falcatus*, Pa = *P. africana*, Cm = *C. macrostachyus*, Mf = *M. ferruginea*

Mean height increments of the five indigenous trees studied (obtained by calculating the differences between the initial and final heights) are provided in Fig. 8. Of all the species studied, *M. ferruginea* performed best (45.7 cm), followed by *P. africana* (26.7 cm), *C. macrostachyus* (20.3 cm), *C. africana* (18.2 cm), and *P. falcatus* (11.9 cm) in descending order (Fig. 8).

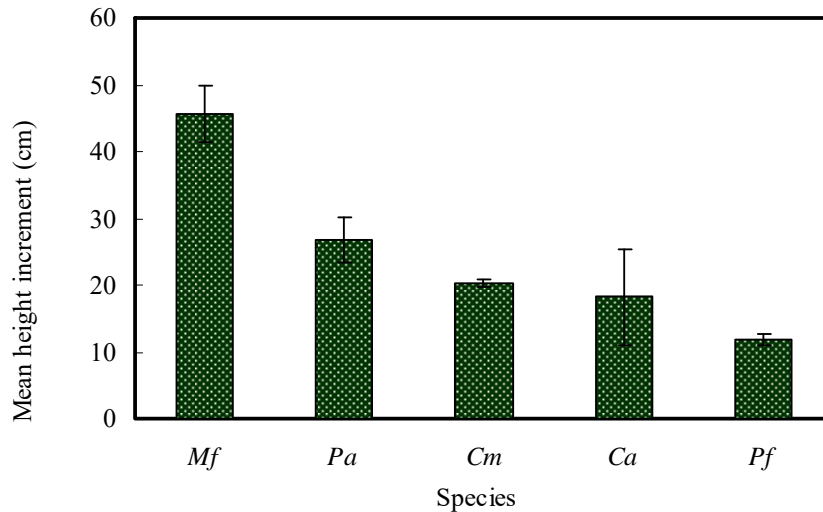


Figure 8. Mean height increments (\pm SD) of the five indigenous tree species after eight months. *Mf* = *M. ferruginea*, *Pa* = *P. africana*, *Cm* = *C. macrostachyus*, *Ca* = *C. africana*, *Pf* = *P. falcatus*

6. 2 Seedlings survival

Survival counts indicated that *M. ferruginea* had the highest survival percentage (100%), followed by *C. macrostachyus* (98.2%), *P. falcatus* (97.3%), *C. africana* (96.8%), and *P. africana* (96%) (Fig. 9). Overall, survival of the studied trees was good for the period of the first one and a half years.

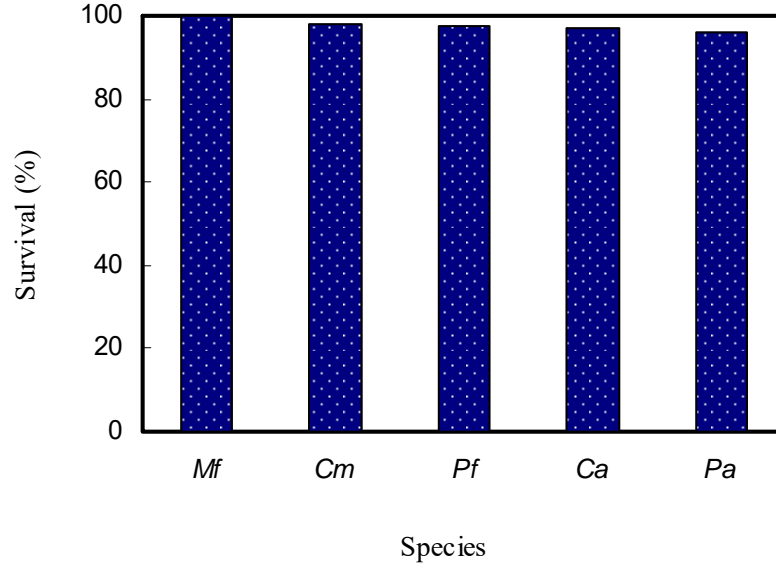


Figure 9. Survival percentages of the five indigenous tree species. Mf = *M. ferruginea*, Cm = *C. macrostachyus*, Pf = *P. falcatus*, Ca = *C. africana*, Pa = *P. africana* survivability

6.3 Damage by browsing animals to seedlings

Of the five tree species studied, *P. africana* and *M. ferruginea* were highly damaged by gazelle and cattle, respectively. Hence, 14.5% and 12.4% of both species browsed during the study (Fig. 10). Damage by browsers to *P. falcatus* (0.5%) and *C. macrostachyus* (0.9%) was insignificant, compared to the other three tree species. About 3.2% *C. africana* was browsed by cattle during the entire study period. It was less damaged than both *P. africana* and *M. ferruginea*, but was more browsed than *P. falcatus* and *C. macrostachyus* (Fig. 10). Browsing was common when grasses are not available for browsers during the dry months of the year, namely from January to April.

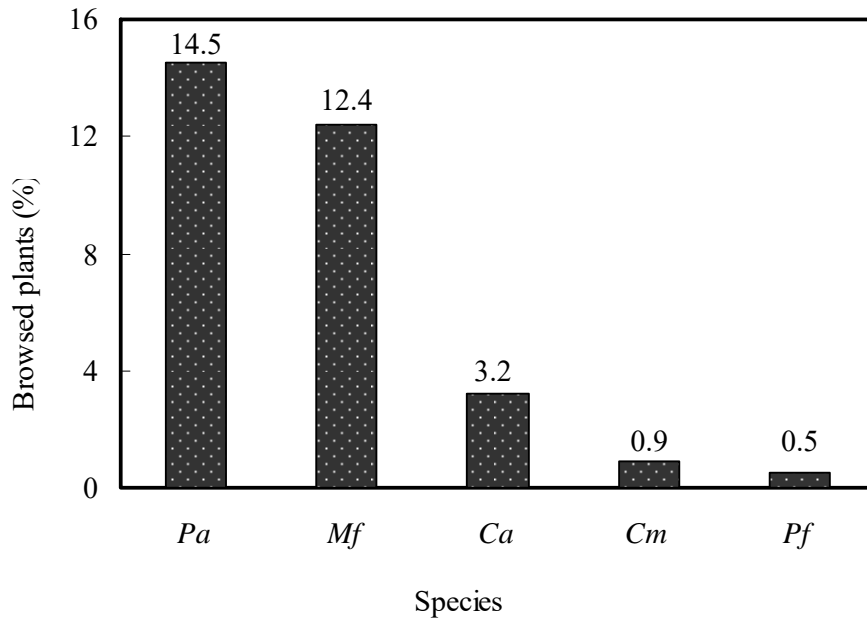


Figure 10. Browsed percentages of the five indigenous tree species studied. Pa = *P. africana*, Mf = *M. ferruginea*, Ca = *C. africana*, Cm = *C. macrostachyus*, Pf = *P. falcatus*

6.4 Tip dieback of seedlings

Of all the tree species studied, *C. africana* experienced severe tip dieback (31.4%) followed by *C. macrostachyus* (6.4%) and *P. africana* (1.5%) (Fig.11). In February alone, 21.7% seedlings of *C. africana* experienced tip dieback. In our study site, February was a month in which most deciduous seedlings experienced death, leaf shedding, as well as tip dieback. Interestingly, no mortality of *C. africana* was observed since seedlings that experienced severe tip dieback developed multi-leader shoots at their root collars (Fig. 12). *P. falcatus* and *M. ferruginea* were two of the five studied species that did not experience any tip dieback.

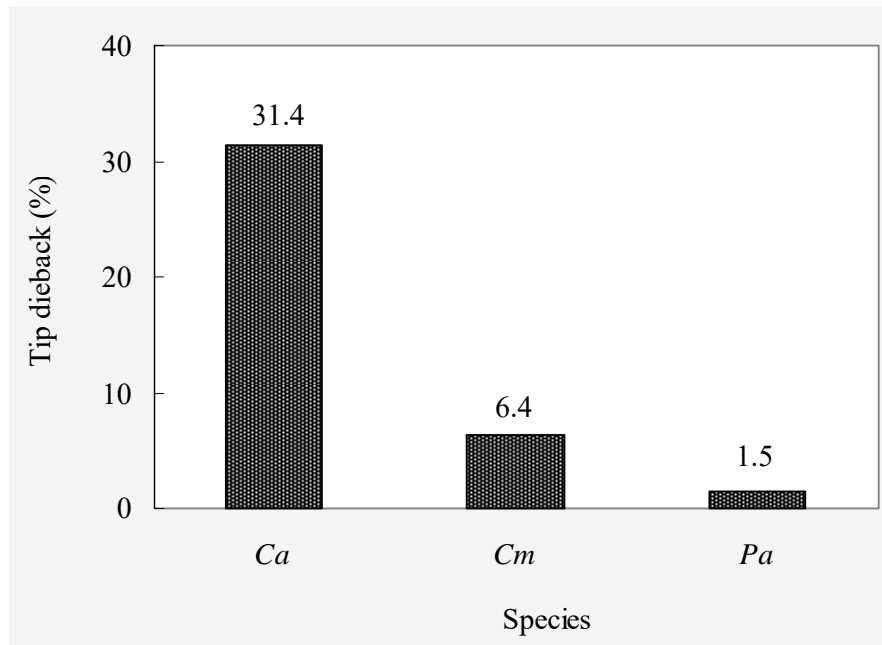


Figure 11. Tip dieback percentages of the three species during the study. *Ca* = *C. africana*, *Cm* = *C. macrostachyus*, and *Pa* = *P. africana*



Figure 12. A photograph of *C. africana* that developed multi-leader shoots after tip dieback.

6.5 Mean relative growth rates (RGR) of plant heights

As shown in Figure 13, the RGR of all the studied species slowly declined from the start of the measurement up to 135 days, except for *M. ferruginea* in which the decrease was up to 90 days only. Thereafter, the RGR of *M. ferruginea* started to increase slowly up to 135 days, and then sharply increased up to days' 180, followed by another sharp declined up to the end of the study period. Relative growth rate (RGR) of *C. macrostachyus*, *P. africana*, *C. africana*, and *P. falcatus*, gradually increased from days 135 up to day 180, but declined slowly at the end of the study period (Fig. 13). Generally, *M. ferruginea* was better in RGR compared to the other four species, followed by *C. macrostachyus*, *P. africana*, *C. africana*, and *P. falcatus*. In general, RGR of all the studied tree species declined with declining moisture (between days 45 and 135), and increased with increasing moisture (between days 135 and 180), again declined with declining moisture (between days 180 and 225).

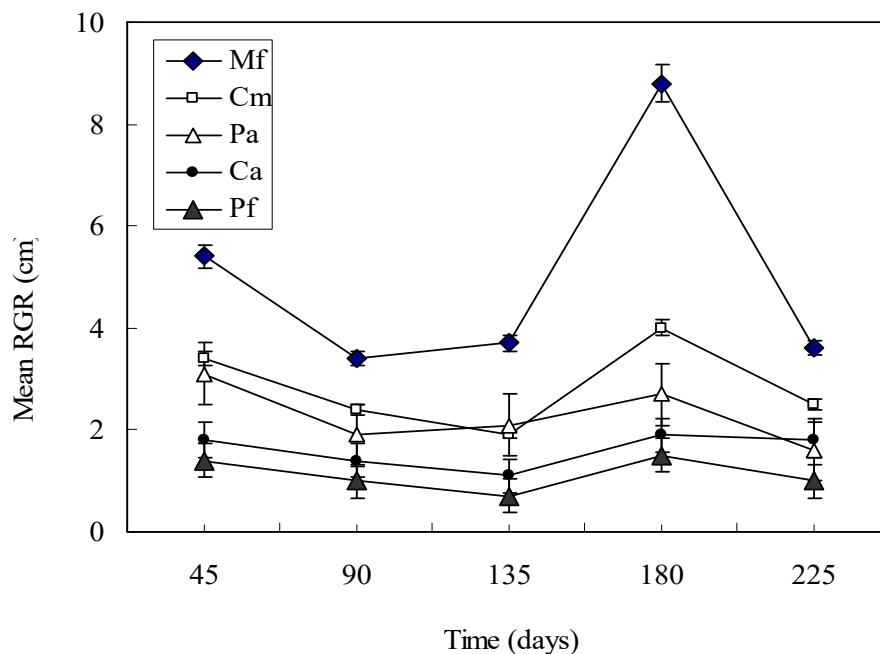


Figure 13. Comparison of mean relative growth rates (\pm SD) of the five indigenous tree species studied across months. Relative growth rate declined at the beginning of the dry season and slowly increased at the end of the dry period. Ca = *C. africana*, Pf = *P. falcatus*, Pa = *P. africana*, Cm = *C. macrostachyus*, Mf = *M. ferruginea*

6. 6 Root collar diameter

Root collar diameter assessments across plots showed, overlapping values for *C. macrostachyus* and *M. ferruginea* at two points, 1.2 and 1.3 mm in fifth and sixth plots (Fig. 14a). In addition, in sixth plots three species, *C. macrostachyus*, *M. ferruginea*, and *P. africana* attained similar mean root collar diameter value, 1.3 mm (Fig. 14a). Overall, root collar diameter assessments showed that *C. africana* had the highest root collar diameter (1.5 mm) compared to the other four species studied (Fig. 14b). It is followed by *M. ferruginea* (1.3 mm), *C. macrostachyus* (1 mm), *P. africana* (0.8 mm), and *P. falcatus* (0.7 mm) (Fig. 14b).

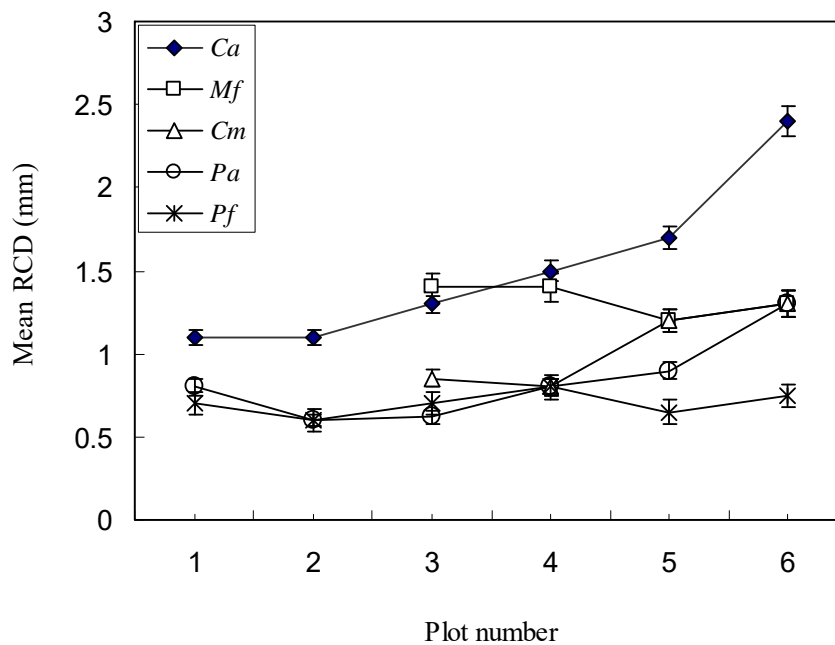


Figure 14a. Mean root collar diameter (MRCD \pm SD) assessments across plots. Pa = *P. africana*, Ca = *C. africana*, Pf = *P. falcatus*, Cm = *C. macrostachyus*, Mf = *M. ferruginea*

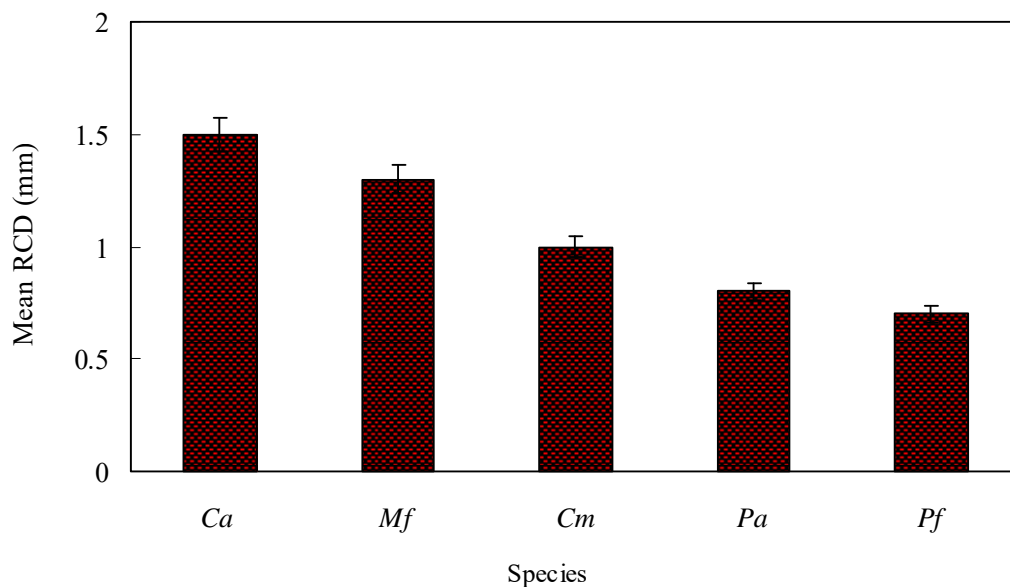


Figure 14b. Mean root collar diameter (\pm SD) of the five indigenous trees studied. Ca = *C. africana*, Mf = *M. ferruginea*, Cm = *C. macrostachyus*, Pa = *P. africana*, and Pf = *P. falcatus*.

6.7 Soil analyses results

Results from soil analyses showed that the average pH was 6.1 and slightly acidic; texture was clay-vertisol because 51% of the particles were clay; available P and total N were below required standard minimum; organic C was marginal; bulk density was incompact; and electrical conductivity was non-saline. These results are shown in Table 1, along with the standard reference quoted from London (1984).

Table 1. Results of physical and chemical analyses of soils collected from the study site at Tulu Korma.

No.	Parameters	Unit	Range*	Rating*	Soil analyses results of the study site
1.	pH (1: 2.5)		5.6-6.0 6.1-6.5 6.5-7.0	medium slightly acid neutral	6.1
2.	EC (Electrical Conductivity)	ds/m	<4 4-8 8-15 >15	non-saline slightly saline medium highly saline	0.038
3.	Total N	%	< 0.075 0.075 >0.075	low medium high	0.071
4.	Av. P	ppm	0-5 6-13 14-19 20-28	very low low medium high	1.3
5.	Organic C	%	<1.5 1.5-3.0 3.0-5.0 >5	very low medium high very high	1.6
6.	Bulk density	g/cm ³	0.9-1.2 1.2-1.4 > 1.46	recently cultivated incompact compact	1.2
7.	Texture	%		clay	51

Source: London (1984)*

7. DISCUSSION

7.1 Seedlings growth in height

Of the five tree species studied, *Millettia ferruginea* was the best in terms of height growth performance. This is very important for Ethiopia, as the tree is N-fixing endemic indigenous species useful for restoring nutrient depleted areas. Highest height increment in *M. ferruginea* could probably be attributed to its stress avoiding strategies such as leaf re-orientations, immediate stomata closing, and allocation of biomass to roots during severe water shortage, and its nitrogen fixing ability (Jiregna Gindaba *et al.*, 2005). Similarly, *P. africana* was also good in its height growth performance. Several workers have noted that *P. africana* is a fast growing indigenous tree species (Dawson, 1997; Legesse Negash, 2004). However, growth of *P. africana* is limited by browsing pressure, absence of favourable soil moisture and soil nutrients, as well as prevalence of supra-and suboptimal temperatures.

P. falcatus attained least height growth during the study period, compared to the other four species. This could probably be due to photo-inhibition at juvenile stage in open field, and environmental stresses such as drought and nutrient or both (Legesse Negash, 1995). Also, Masresha Fetene and Yonas Feleke, (2001) noted that field grown *P. falcatus* experienced moderate photo-inhibition and hence, it is non-pioneer shade tolerant species. This result was in line with Gilman and Watson (2003) that confirmed the relatively slow growth of *P. falcatus*.

Height growth in *C. macrostachyus* and *C. africana* were highly affected during the prolonged dry months. Consequently, complete leaf shedding, sensitivity to frost, decreases in relative growth rates, and tip dieback were some of the observed problems during the dry months of the study year. Worse still, some individual plants of these two species, stopped height growth for over six weeks. Hence, ca 20.9% of *C. macrostachyus* plants and ca 14.6% of *C. africana* plants had the same measured values in height for two consecutive measurements (App. 1, highlighted values). However, due to management activities such as watering, applying cow

dung, mulching, and hoeing the trees, the species average heights of 20.3 cm and 18.2 cm were attained for *C. macrostachyus* and *C. africana*, respectively during the 225 days of the studied period. Consequently, *C. macrostachyus* was third while *C. africana* stood fourth in terms of height increment, compared to the other three species. Also, there were variations in height growth among individuals of *C. macrostachyus* and *C. africana* during the study period. These variations could be due to provenance differences during seed collection and environmental stresses. Preliminary studies have shown that this is indeed the case for *C. africana* (Mebrate Mihretu, 1999). Also, Abraham Loha *et al.* (2006) reported that genetic variation in *C. africana* caused 57-58% seedling height differences. We conclude that variations in growth among individual plants of the same species are interactive results of genetic, moisture, and temperature factors. *C. africana* plants of the same age, displayed height variations that ranged from 44 cm up to 217 cm, and root collar diameter variations of 0.5 mm to 6.9 mm in the same site and growing periods (Appendix 1). As dry months proceeded from November to February, *C. africana* and *C. macrostachyus* shed their leaves, with distinct tissue death at growing tips. This is in line with Gordon *et al.*, (1989) who reported that height increment in woody seedlings is limited due to competition for soil water during dry season and young seedling stage.

In our case, *C. africana* displayed an average of 10-30 cm increase in height during the study (App. 2). This result also agrees with Legesse Negash (1992a) and Mebrate Mihretu and Belachew Gizachew (2004) that confirmed variation in seed source caused variation in height that detected at all seasons and ages.

In general, highest mean height increments observed among the studied species occurred in April just after Ethiopia's little rains. The rain improved soil and plant moisture status, thereby facilitating nutrient absorption and cell division. In contrast, height increments were hampered during the dry months, particularly in *C. africana* and *C. macrostachyus*, but with fewer pronouncements in *M. ferruginea*.

Differences in height growth among the five studied species are statistically significant at the 5-percent probability level, with *M. ferruginea* showing the fastest growth. Better growth performance of *M. ferruginea* could be attributed to its ability to fix nitrogen, for conserving water and better water use efficiency than the other four tree species. Jiregna Gindaba (2006) explained better performance of *M. ferruginea* in terms of its water use efficiency, leaf re-orientation, stomata closing, and nitrogen fixing capacity. In general, height growth across plots and months showed significant variation from species to species and from month to month. To sum up, height growth patterns were highly affected by water deficit in the dry deciduous species of *C. africana* and *C. macrostachyus*. However, height increments in both the dry deciduous and evergreen tree species sharply declined at the start of the dry months, followed by relatively sharp increases after the little rainfall.

7.2 Seedlings survival

Our results showed that long dry months significantly ($p < 0.01$) affected survival percentages in the five studied species. For instance, 4% *P. africana*, 3.2% *C. africana*, 2.7% *P. falcatus*, and 1.8% *C. macrostachyus*, died during the dry months. The survival percentages for *M. ferruginea*, *C. macrostachyus*, *P. falcatus*, *C. africana*, and *P. africana* were 100%, 98.2%, 97.3%, 96.8%, and 96%, respectively. However, the fact that seedlings exhibited more than 96% survival during the first year of outplanting indicated that the seedlings did not experience a high degree of transplant and water stresses effects. Hence, survival percentages of the five studied species in the first year of outplanting were significant. This is attributed to intermittent watering during the dry months, applied cow dung, mulching and fencing, as well as other care provided during the study period. Davis *et al.* (1999) remarked that a more than 80% seedling survival shows less transplant stresses during or after outplanting. Cadenasso and Pickett (2000) stressed on the essentiality of care and control, to avoid partial or complete loss of planted seedlings. Lugo *et al.* (1978), Neil (1990), Merwin *et al.* (1995) indicated watering as a key factor in influencing the growth and survival of plants. However, no experimental studies are available on indigenous trees of Ethiopia to address the

quantitative impacts of water stress in relation to survival, mortality, and relative growth rates of seedlings planted in degraded sites. This study concludes that the main causes of the reported seedlings mortality are water stress, mammalian browsers, poor soil fertility status, intense radiation, and high dry season temperatures.

7.3 Damage by browsing animals to seedlings

Damaged percentages by browsers were high in *P. africana* and *M. ferruginea* compared to other studied species. This is due to night and day browsing pressure by gazelle and cattle, respectively of *P. africana*, and due to its palatable green-leaves for cattle during the dry months, of *M. ferruginea*. In our findings, 14.5% *P. africana*, 12.4% *M. ferruginea*, 3.2% *C. africana*, 0.9% *C. macrostachyus*, and 0.5% *P. falacatus* were browsed during the entire study period. This indicates that the extent to which seedlings are damaged by browsing animals varies from species to species. Gazelle and livestock were the principal cause of damage to seedlings during dry months in this site. This finding is in line with Crawley (1983), Swaine (1996), and Hendrix (1988) who reported that browsing and mortality in seedlings were common during the dry months, when grasses are not available for grazers and browsers.

In general, browsing animals not only caused damage to the seedling parts, but also increased susceptibility to other biotic and abiotic stresses such as diseases, water stress, intense radiation, elevated temperatures, and frost.

7.4 Relative growth rates (RGR)

The mean relative growth rates of the studied trees differed from species to species and from plots to plots, even within the same species and on the same sites. These variations depended largely on soil moisture, elevated temperatures and nutrient status of the site. Thus, relative growth rate of each of the species studied declined sharply during the dry months and increased during the more moist months. In all

the studied species, highest RGR was observed after 180 days (in April) since the start of the measurement. This is certainly because of available soil water and release of nutrients from the applied cow dung after the rainfall has taken place. As expected, there were positive relationships between height increments and relative growth rates in all the studied species. For instance, *M. ferruginea* fast growth is reflected in its high relative growth rate. *C. macrostachyus* ranked second in relative growth rate, and *P. africana* was third. The study showed that the deciduous species had more RGR than the evergreens. Antunez *et al.* (2001), Reich and Walters (1992), and Reich (1998) reported that deciduous species grew faster than evergreens. Other studies also found that deciduous woody species show higher potential growth rates, higher specific leaf areas, and higher photosynthetic rates than evergreen species (South, 1995; Cornelissen *et al.*, 1998).

Except for *M. ferruginea*, there were similarities in relative growth rates across months between *C. africana* and *C. macrostachyus*, as well as between *P. africana* and *P. falcatus* during the entire study period. During severe water shortage, some *C. africana* and *C. macrostachyus* plants stopped growth completely for over six weeks. But, this problem was not observed in *M. ferruginnea*, which continued to grow despite the prevalence of water stress. This could probably be due to its efficient water use strategy and nitrogen fixing capacity, compared to *C. africana* and *C. macrostachyus*. Jiregna Gindaba *et al.* (2005) made similar observations and concluded that leaf re-orientation, stomatal closure, biomass allocation to roots, and nitrogen fixation capacity of *M. ferruginea* contributed significantly to the tree's fast growth.

In general, RGR may vary among plant species, and is high when plants grow on favorable sites, and is low in unfavorable sites, being negatively affected by water deficit (Grime and Hunt, 1975). In general, soil water deficit caused by prolonged dry months, was the main observed factor that caused the decline in relative growth rates in the five studied species across the studied site.

7.5 Seedlings tip dieback

From the five studied species, two of them, *M. ferruginea* and *P. falcatus*, did not experience tip dieback. This could probably be attributed to their efficient water conserving strategies and ability to avoid and tolerate moisture stress during dry periods. Legesse Negash (1992a) studied stomatal physiology of five indigenous tree species and concluded that of all the tree species investigated, *P. falcatus* was good at conserving water through its tight stomatal control. In contrast, *C. africana*, *C. macrostachyus* and *P. africana* experienced tip dieback, with 31.4% of *Cordia africana* trees having been affected by tip dieback. This might be due to its stress avoiding strategies during dry months. Similarly, 6.4% of *C. macrostachyus* experienced dieback at the tip during the study period. It was observed that during water shortage, both *C. africana* and *C. macrostachyus* shed their leaves, as a strategy to avoid water stress. This finding is in line with Legesse Negash (1992a) and Jiregna Gindaba *et al.* (2005) who reported stomatal closure and leaf shedding as strategies in *C. africana* and other deciduous species to avoid water stress. In addition, *C. macrostachyus* was highly sensitive to frost. Since carbohydrate reserve during water shortage is low due to low photosynthetic activity, damage due to frost may result in tip dieback (Weiser, 1970; Ritche and Dunlap, 1980). For *P. africana*, the mechanism to cope with moisture stress was tolerance; so that only 1.5% of the seedling was dieback at the tip. Generally, deciduous species were sensitive to tip dieback than the evergreen species. This might be due to differences in their strategies to avoid stresses. It has been reported that evergreen species use stress tolerating strategies than avoiding (Jiregna Gindaba *et al.*, 2005).

7.6 Seedlings root collar diameter (RCD)

Root collar diameter assessment of the five studied species showed 1.5 mm for *C. africana*, 1.3 mm for *M. ferruginea*, 1 mm for *C. macrostachyus*, 0.8 mm for *P. africana*, and 0.7 mm for *P. falcatus*. Root collar diameter was measured at the junction where the stem joined the root. In the deciduous species more biomass was allocated in their root during stresses (Jiregna Gindaba, 2006). Hence, this might have contributed higher mean root collar diameter in deciduous than evergreen species.

Root collar diameter differed from species to species and from plots to plots under similar treatment conditions (Fig. 14a and b). Also, there was a relationship between height and root collar diameter growth in the three studied species namely, *M. ferruginea* (first in height and second in RCD), *C. macrostachyus* (third in height and 3rd in RCD) and *P. falcatus* (the least in both height and mean RCD). The relationship between height and RCD was loose in *C. africana*, which was first in mean RCD and fourth in mean height growth. This relationship was also true for *P. africana*, which was fourth in mean RCD and second in mean height growth. This could probably be due to provenance variation, evergreen and deciduous nature of the species, water and temperature stresses. Evans (1992) reported that light, water, and temperature stresses were the main factors that reduced diameter increases in seedlings.

7.7 Soil analyses

The objective of soil analyses was to know the fertility status of the site by identifying the deficiency or sufficiency of the principal elements that are critical for plant growth. Therefore, seven parameters were checked (Table 1). These were pH, electrical conductivity, total N, available P, organic C, bulk density, and texture. Of these, the pH was found to be 6.1, which was in the range of slightly acidic (London, 1984). This pH is suitable for proper growth of most plants. Hence, the site has no problem with soil acidity. The texture was clay (51%), sand (26.7%), and silts (22.3%). Therefore, the soil can be classified as clay-vertisol. Electrical conductivity was 0.038 ds/m, which was non-saline. Since bulk density of clay soil is low, and decreases from sand to clay, the soil can be considered as low in bulk density. Its organic C content was 1.6%, a critical value that is very close to the minimum standard, which is 1.5% (London, 1984). Available P was 1.3 ppm and total nitrogen was 0.071%; both elements were below the minimum standard reference value. This warrants the classification of the soil as degraded. It must be remembered that nitrogen and phosphorus are two of the essential nutrient elements that are critical for plant growth and development (London, 1984; Mesfin Abebe, 1998).

8. CONCLUSIONS AND RECOMMENDATIONS

Conclusions

In the light of the present study, the following conclusion can be drawn:

Since the most natural forests of the country have already gone, our focus now is to rehabilitate deforested and degraded areas with mixtures of indigenous tree species such as *M. ferruginea*, *P. africana*, *C. macrostachyus*, *C. africana*, *P. falcatus* and others that were better adapted to the climate of the country than exotic species.

Better growth performance of the studied indigenous tree seedling species was achieved through periodic watering during the dry months, weeding, mulching, applying cow dung, hoeing seedlings, fencing by spiny shrubs and guarding by watchman to protect damage caused by browsing animals.

All the studied species possess good survival percentages that were equal to 96% or greater than 96%. Therefore, these indigenous species could be good candidate for successful planting programs on degraded sites.

In increasing water stress during dry season *C. africana*, and *C. macrostachyus* shed their older leaves due to high transpiration rate that caused by strong radiation. As the dry months progressed, both species stopped increase in height for more than six weeks and lastly dieback at leader shoots. However, most tips dieback seedlings in *C. africana* re-sprout lateral shoot at their root collar. Therefore, this condition had negative impact on bole form which has economic value in this particular species.

In the studied deciduous species leaves shedding and subsequent tip dieback caused accumulation of assimilate in stem and root. As a result, the three deciduous species *C. africana*, *M. ferruginea*, and *C. macrostachyus* were high in rank of root collar diameter increase.

The two evergreen species *P. africana* and *P. falcatus* grew throughout dry months due to high water use efficiency, low foliar shedding, and high leaves life span. But, *P. africana* was least in survival rate due to browsing animals, while *P. falcatus* was least in all investigated parameters except in survival percentage (97.3%).

All the studied species were more prone to damage by browsers during dry months when grasses are not available for browsing from January to May, particularly *P. africana* and *M. ferruginea*, but the other studied species were less browsed by browsing animals. Hence, effective protection of seedlings through fencing and guarding can reduce browsers-induced mortality as well as the time during which browsing is a problem.

Recommendations

Since the natural forest cover in Tulu Korma has been depleted and sparsely distributed there should be a massive plantation programs using fast growing indigenous tree species such as *M. ferruginea*, *P. africana*, *P. falcatus*, *C. africana*, and *C. macrostachyus* that have been proved a suitable tree species for degraded sites due to their high degree of adaptability.

In order to establish planted indigenous tree seedlings on degraded land, all points' access to plantation including gates, individual seedlings, and water crossing were properly covered by fences, and fences were maintained by regular inspection with watchman.

The height and diameter growth, survival percentages, relative growth rate, tip dieback and browsers damage to seedlings were significantly decreased with increasing of dry months, which was due to the corresponding decrease in the level of soil moisture. Therefore, to successfully establish these tree seedlings on degraded sites, watering during the dry months, mulching, weeding, hoeing seedlings, cow dung applying, fencing and guarding were extremely important. Thus, further studies regarding ecologically and economically vital indigenous tree species was recommended.

Planting indigenous tree species helps to reverse the accelerated loss of natural forests than leaving the land bare. For this purpose, mixtures of indigenous tree species are better than monocultures, local experience being exchanged and blended with scientific knowledge. Governments, local authorities, and non governmental agencies should initiate the people to propagate, cultivate, domesticate and care for indigenous tree seedlings.

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10. APPENDICES

Appendix 1. Data collected on the five indigenous tree seedling species: SC= Seedlings code, Pa = *Prunus africana*, Ca = *Cordia africana*, Pf = *Podocarpus falcatus*, Mf = *Millettia ferruginea*, Cm = *Croton macrostachyus*, B = browsed, D (CD) = dried, Td = tip dried, RCD = Root collar diameter.

Date	Months and Date of measurements						RCD
	2/2/1998	17/3/98	2/5/1998	17/6/98	2/8/1998	17/9/98	
SC	Tikimti	Hidar	Tir	Yekatit	Miyazia	Ginbot	RCD
Pa1	28	32	34.5	39.5	45.2	49	0.3
Pa2	30	37.4	42	B	B	B	0.3
Pa3	48	52.5	56.3	59.1	65	68	0.4
Pa4	72	82.1	89	95.6	107.2	114	1.5
Pa5	37.5	42.5	45	50.8	55	58	0.4
Pa6	32.5	40	44.5	46	68.7	72	1
Pa7	44	48.5	52.2	54	64.1	66	0.8
Pa8	47	49.5	52	54.3	58	60	0.9
Pa9	50.5	60	63.2	65	67	67.6	1.2
Pa10	25	30.6	34	36.4	48	50	0.3
Pa11	30	35	38.5	B	B	B	B
Pa12	24.2	28.8	32	35.7	38	40.3	0.3
Pa13	31	38.4	48.6	55	63.5	66	0.6
Pa14	46.5	52	66	76	77	88	1
Pa15	52	58.5	61	71.8	100.3	128	1.9
Pa16	38	45.6	49.4	60	62.5	65.5	0.8
Pa17	36.5	38	40	42	46	B	
Pa18	33.5	40.2	42	44.6	46	48	0.8
Pa19	32	41	44	52	59.5	62	0.4
Pa20	22.4	27.5	33.2	38	62	66.5	0.6
Pa21	24	28	34.4	42	58.8	61.6	0.9
Pa22	36	41	43.7	48.4	63	64	1.1
Pa23	50	55.7	59	64.2	80	83.5	0.3
Pa24	37	42.9	48	52.6	59	62	0.9
Pa25	27	32.4	37	B	B	B	B
Pa26	26	33.5	38	41.8	56	70	0.8
Pa27	46.5	51	57.2	59.3	62	65.1	1.8
Pa28	45.5	54.5	58.2	61	64.3	67	0.8
Pa29	42.1	47.9	54	55.5	59.2	61	0.7
Pa30	43	47	51.4	53.2	54	56	0.6
Pa31	40.5	44.5	49.3	56	60.7	64	0.9
Pa32	52	60.4	68.6	77	81.3	84	0.7
Pa33	42	49	53.7	59.6	63	67	0.9
Pa34	28.2	34	38.3	41	44	46	0.5
Pa35	27	32	38	D	D	D	D

Pa36	26	33	37.8	43	48.2	B	B	
Pa37	62	67.4	70	74.2	82	86.5	1	
Pa38	28.5	31.5	34	36.5	38	40	0.4	
Pa39	28	34	37.6	41	42.6	44	0.7	
Pa40	34	37.3	42	47.1	49.2	52	0.6	
Pa41	48.5	56.1	58.2	B	B	B	B	
Pa42	29	34	38.5	45	50	51	0.5	
Pa43	35	41.4	46	48	51.1	54	0.7	
Pa44	22	25	28	33	40	43	0.5	
Pa45	39	44	47.3	55.1	62	69	0.6	
Pa46	41	49	52.9	55	55.3	57	0.8	
Pa47	38	40	45.5	49.5	50.5	52	0.7	
Pa48	47	53.5	60	60	62	63	1.8	
Pa49	35	38.2	41	B	B	B	B	
Pa50	32	38	47	63.5	69.5	72.5	0.7	
Pa51	30	33.4	40	D	D	D	D	
Pa52	38	42	45.8	54	63.6	70.3	0.8	
Pa53	28	31.5	39.5	45	55	57	0.5	
Pa54	33.5	38	43	55.2	60.9	68	0.9	
Pa55	37	42.5	48	50.5	54	57.3	0.9	
Pa56	26	29	33.2	36	46.1	51	0.9	
Pa57	23	29	36	36	48.5	50	0.5	
Pa58	52	62.3	69.1	72	76.4	80	0.8	
Pa59	34	40	46.4	td	td	td		
Pa60	36.5	39	42.2	47	49	53	0.8	
Pa61	45.5	54	60	66	66	73	0.9	
Pa62	31	36	40	B	B	B		
Pa63	25.5	30	35	45.4	50	56	0.5	
Pa64	29	36	38.6	B	B	B		
Pa65	29	36	38.6	42	45.4	47	0.6	
Pa66	39.5	42	50.3	60	69.2	80	1	
Pa67	35	47	51	B	B	B		
Pa68	38.5	49	54.5	65.4	82.6	88	1	
Pa69	39	44.2	52	61.5	66	69.1	0.6	
Pa70	40	47.3	49.1	55	59	69	0.7	
Pa71	47	56	62.5	64	69	73	0.9	
Pa72	38	50	56	62.5	67	70.5	1	
Pa73	37	42.2	47	B	B	B		
Pa74	51	62.1	70.2	75	82	85.3	1	
Pa75	25	34	41	B	B	B		
Pa76	39	43.5	50.1	52	58	61.6	0.5	
Pa77	44	58.3	62.7	73	83	88	1	
Pa78	38.5	45	50.2	52.4	56	59.3	0.6	
Pa79	37.5	42	48.5	50	51	54	1	
Pa80	46.5	51	55	57.5	59	59.5	0.8	
Pa81	34.5	42.4	48.6	B	B	B		

Pa82	43.8	54.8	64	D	D	D	
Pa83	40	52.1	62	72.3	85	88.5	1
Pa84	42	45.6	47.9	B	B	B	
Pa85	29	35.4	36	td	td	td	
Pa86	58.5	64.1	74	76.5	87	89	0.6
Pa87	42.5	45.5	48.5	51	54	55.1	0.5
Pa88	35	39.5	41	44.5	54	57.8	0.7
Pa89	36	40.5	43	45.5	57	59	0.4
Pa90	44	49	52.5	53.1	59	63.4	0.9
Pa91	43	50.2	56	57	B	B	
Pa92	40	46	49.2	50	56	58	0.6
Pa93	42	47	49.4	51	B	B	
Pa94	36	40.7	45	47.3	59	64	1.1
Pa95	37.5	42	46	49	54	56	0.4
Pa96	27	30	33	D	D	D	
Pa97	39	46	50	52	57	59	0.4
Pa98	37	40.4	41.6	B	B	B	
Pa99	41	47	50.2	51.1	58	61	0.6
Pa100	37.5	50	56.5	61	65	68	0.6
Pa101	45.5	51.5	54	55.5	58.5	60	0.6
Pa102	46	51.5	52	57.1	59	63	1.1
Pa103	49.5	64.5	68	76	81	85.5	0.9
Pa104	38	49.2	51	51.7	56.3	B	
Pa105	48	63	65.5	66	72	75.7	0.6
Pa106	47.5	55.5	61	67.1	74	80	1.1
Pa107	34.5	38	41.5	43	46	48.6	0.4
Pa108	48	62.5	70	72	76	78	0.8
Pa109	33	38	41	44.3	48	57	0.3
Pa110	50	55.5	56.5	60	62	65.2	0.9
Pa111	49	58	66	69	B	B	
Pa112	39.5	48.1	54	56.2	61	63	0.6
Pa113	39	43	45.1	47	50	51.2	0.6
Pa114	32	35.5	39.5	47	58	61.3	0.7
Pa115	40.5	46.5	50	51.8	52	55	0.7
Pa116	39	42.6	46	48	B	B	
Pa117	30.5	35	36	38.6	43	46.7	0.5
Pa118	38	43.2	48	48	56	58	0.7
Pa119	36.5	44.5	48.1	52.3	66	70.2	0.6
Pa120	45	48.1	50.3	54	55	59.6	0.8
Pa121	51	58	60.2	65	71.7	89	1
Pa122	33	43.5	48	50.5	54	56	0.6
Pa123	43	50.5	51.5	52	54	56	0.9
Pa124	39	43	44	47.4	52	55	0.5
Pa125	40	47	51	55.5	B	B	
Pa126	45	50	52	54	56.5	B	
Pa127	32	37.5	40	43	42	46.8	0.5

Pa128	35	40.6	42	45	B	B	
Pa129	34	39	44.2	51	51	64.6	0.7
Pa130	38	46.2	51	51	66.3	73	0.9
Pa131	46	51	57	63	69	70.4	0.9
Pa132	43	46.5	46.5	48.5	46.5	48	0.6
Pa133	21	24	33	39	51.5	54.3	0.8
Pa134	33.5	40.5	45	53.5	70	90	0.6
Pa135	43	46	48	D	D	D	
Pa136	48	53.5	56	56.5	60	62	0.9
Pa137	55	61.1	64.3	65	72.2	83	0.9
Pa138	49	56.5	59	65.6	77	81.8	1.1
Pa139	39.2	46	50	57.5	74	79	0.8
Pa140	25	29	29	33	38	44	0.7
Pa141	39.1	42	44.6	54	69	72	1.1
Pa142	34	38	42.7	50.2	57	66.6	0.9
Pa143	37.5	43	48	51	B	B	
Pa144	38.5	44.5	47	47.5	48	50	0.8
Pa145	44.5	51	51	54.5	76	89	1
Pa146	41	46	52.5	54.6	58	59	1.1
Pa147	40	46	54	56.8	96	111.5	1.1
Pa148	40	42.5	45	47.5	59	63	1.1
Pa149	47.3	53	60	66.5	67.5	70.6	0.7
Pa150	46	56.5	59	60.2	61	63.4	0.8
Pa151	34.5	37.5	47	51.3	62	63.8	0.6
Pa152	41	44	46	47	50	B	
Pa153	40	44	51	53.1	55	56	0.6
Pa154	40.5	46.5	48	50	54	55	0.5
Pa155	31.6	34	36	D	D	D	
Pa156	37	39	42	45	B	B	
Pa157	52	57	58	61	62.5	65	1
Pa158	46	48	td	td	td	td	
Pa159	34	39.5	41.5	45	60	72.2	0.9
Pa160	40	47	50	54.1	72	82.2	0.9
Pa161	55	60	65	74.5	88	97.3	0.9
Pa162	47.1	53	56	60.2	68	79	0.9
Pa163	54	61	62.5	65.7	75	85.6	0.6
Pa164	33	36	38	43	78	82	0.7
Pa165	38.5	42	47.5	50	59	62.1	0.5
Pa166	29	36.2	40.3	45	50	52.6	0.4
Pa167	51	57.5	60	63.5	74	76	0.8
Pa168	58	67	71.8	84	89	91	0.9
Pa169	38.2	41	45	54	55	58.4	0.8
Pa170	59	64	70	75	81	85	1.1
Pa171	39.1	44	48	60.2	68	71.3	0.8
Pa172	3 9	43.5	46	48	50	54.6	0.7
Pa173	44	47.5	47.5	48.5	61	B	

Pa174	42	47	50	55	B	B	
Pa175	56.5	60	67	71.6	90.3	104	1.1
Pa176	44	47.5	54	61	64	66	1
Pa177	26	29	31	38	48	51.6	0.5
Pa178	41.5	45.5	47.5	55.5	61	64.2	1.1
Pa179	36.5	39	42.5	52.7	59	66	0.6
Pa180	34.5	36	38	41	B	B	
Pa181	35	38	38	43.5	48.5	50.7	0.5
Pa182	56	63	66	75	84.5	87.4	1
Pa183	47	57	60	67.4	72.6	82	0.7
Pa184	26	30	33	38.4	49.5	58	0.5
Pa185	18	21	21	23	25	32.8	0.3
Pa186	36	44.5	54	58.2	66.4	69	1
Pa187	20	24	25	D	D	D	
Pa188	42	46.5	49	58.6	61	66.9	0.9
Pa189	21	27.5	31	32.5	38	44	0.8
Pa190	30	35.5	38	42	42	42	0.9
Pa191	51	63	68	78	82	83	1.1
Pa192	50	56.5	60	64	70	76	1.5
Pa193	42	48	51	D	D	D	
Pa194	63	69	77.4	87.3	93	114	1.5
Pa195	49.5	61	68.5	81	94	115	1
Pa196	60	64	71	76.2	91.5	98	1
Pa197	49.3	58	63.5	69	76.8	80.4	1.5
Pa198	56	60.5	63.5	74.5	94	102	1.6
Pa199	58	78.5	90	101	109	120	1.2
Pa200	60	64	71	73.5	79	83.8	1

	months and date of measurement						
Date	2/2/1998	17/3/98	2/5/1998	17/6/98	2/8/1998	17/9/98	17/9/98
SC	Tikimti	Hidar	Tir	Yekatit	Miyazia	Ginbot	RCD
Ca1	46.2	49	49.5	52.6	56	57	1.4
Ca2	36	36.5	37.5	38.5	43.5	45	1.3
Ca3	41	42.3	43.5	45	46.2	48	1.2
Ca4	40	42	44	46	50	52	0.5
Ca5	41.8	43	44.5	Td	Td	td	1.5
Ca6	32	34	36	37	42	44	0.5
Ca7	36.5	42.5	47.5	D	D	D	D
Ca8	32.5	38.5	43.5	45.5	46	48	1.3
Ca9	44.5	48	50	50	55.5	td	1.6
Ca10	41	43.8	45	Td	Td	td	1
Ca11	22	24	26	Td	Td	td	0.9
Ca12	52.8	56	57.7	60.4	62	62.6	1.1
Ca13	34	37.6	41	Td	Td	td	0.5
Ca14	46	49.5	52.5	54	54	td	1
Ca15	39	Td	Td	Td	Td	Td	Td
Ca16	38	40.5	42	43.6	43.5	45	0.7
Ca17	42	44.5	46	48	Td	td	0.6
Ca18	45	46	49.5	Td	Td	td	1.4
Ca19	36	38	39	Td	Td	td	1
Ca20	39	40	43	48	48.5	50	1.2
Ca21	50.5	53	56.1	59.5	Td	td	1
Ca22	36	38.3	41	43.5	44	46.4	1
Ca23	37	39	D	D	D	D	1
Ca24	47.6	49	50	53.2	56.5	58	0.5
Ca25	54	56	57	Td	Td	td	1.2
Ca26	39	40	41.5	43.5	46	48.2	0.7
Ca27	46	48.1	49	Td	Td	td	0.5
Ca28	45	47.4	49	50.3	52	54	1.4
Ca29	36	37.5	40	40	47	B	0.5
Ca30	44.5	46.5	49	50	53.5	55	1.6
Ca31	50.5	52.5	55.5	56	59.5	td	1.9
Ca32	52	56	59	59	62	64	2
Ca33	35	37.5	40	41.5	42	44	0.9
Ca34	37	40.2	41.5	43.6	46	td	1.4
Ca35	44	45	46	Td	Td	td	1.1
Ca36	26	28.3	30.2	33	34	td	2.1
Ca37	34	37	40	40	41	43	0.8
Ca38	33.5	35.2	37	38.5	40.1	42	0.8
Ca39	46	48	49	50	Td	td	1.8
Ca40	41	43	44	45.5	45	47.5	1.9

Ca41	38	39.5	44.2	45	47.6	50.4	1.6
Ca42	40	43.2	45.8	49.3	52	53	1
Ca43	36	38	41	42.5	45	47	2.2
Ca44	34	36.5	40.5	43	44	46	2.3
Ca45	37	40	41	43	Td	td	0.9
Ca46	34	36.5	37	39.3	42	td	0.9
Ca47	40	42.5	43	44.5	47	49	1.2
Ca48	39	42	45	45	Td	td	0.5
Ca49	49	52.5	54.6	Td	Td	td	0.6
Ca50	43.5	45.5	47	49.2	50	B	1.4
Ca51	36	39	40	40	D	D	1.1
Ca52	41.5	44.5	46	46	51	td	1.4
Ca53	41	45	47	48	Td	td	0.8
Ca54	31	34	38.5	40.2	43.5	45	0.6
Ca55	40	43.5	47	47.5	Td	td	0.9
Ca56	33.5	37.5	40	Td	Td	td	0.9
Ca57	39	41	44	53	55.5	68	3.3
Ca58	45	48	54.5	56	57	62	2.5
Ca59	39	41	46	46	56.5	71	2.7
Ca60	27	30.5	35	35	39	43	2.7
Ca61	42	45.5	47.8	49	50	52	0.6
Ca62	38	40	40	Td	Td	td	1.2
Ca63	36	39	39	42	46.5	47	1.2
Ca64	37	38	38.5	39	45.4	50	2.4
Ca65	43	46	49.5	50	51	54	0.9
Ca66	38	40.5	45	D	D	D	0.7
Ca67	39	40	43	45	49	51	0.6
Ca68	43	46	48	49	Td	td	1.4
Ca69	43	46	46	Td	Td	td	0.4
Ca70	41	44.5	46	47.1	49	50	0.8
Ca71	42	46	48	48.5	Td	td	0.9
Ca72	43	46	48	50	52.5	54	0.8
Ca73	47.5	52	54.6	57	60.5	62	1.8
Ca74	42	43	44	45	48.5	49	0.5
Ca75	37	39	40	41	44.5	46	1.4
Ca76	41.5	46	47	47	50	52	1.4
Ca77	53.5	56	57.5	60	63	65	1.5
Ca78	42.5	44	46	47.5	48	52	2.1
Ca79	49.5	50	52	56	60	61.2	1.9
Ca80	43.5	46	48.5	Td	Td	td	1.3
Ca81	50.5	52	54.1	56	58.5	60.2	1.7
Ca82	41	44.5	49	49.5	53.5	56	0.9
Ca83	53	55.5	57.2	61	62.3	64	1.5
Ca84	46.5	48	50	51	56	59	1
Ca85	46	48.5	51	52.6	56	57.3	0.9
Ca86	34	36.5	39	40.8	45	47	1.5

Ca87	45	47	49.5	50.9	57	60	1.7
Ca88	38	41.3	45	td	Td	td	0.7
Ca89	45	47	48	50	51	53	1.2
Ca90	47	48.5	52	53.1	55	57.2	1.6
Ca91	48.5	53	55	56.4	60	62	2.5
Ca92	51	54	57.8	59.1	60	61.2	2.2
Ca93	48.5	50	52	Td	Td	td	0.9
Ca94	38	40.5	43.5	47	B	B	2.4
Ca95	44.5	47.2	51	53.8	80	100	4
Ca96	45	46.5	49.1	49.5	51	68	1.8
Ca97	50.5	52	52	Td	Td	td	1.6
Ca98	30	35	39	42.5	44	46	1.3
Ca99	41.3	44	46	D	D	D	D
Ca100	39	41.5	43.2	44	45.5	B	0.9
Ca101	48	50.5	54	55.2	58.1	60	2.1
Ca102	40	42.5	43.5	45.7	50	51.3	1.1
Ca103	27	28	30	32.5	33	B	1.2
Ca104	41.5	43.5	47	49	52	54	1.6
Ca105	45	47	47	48	52.5	55.3	2.2
Ca106	31.5	32.5	35	37	37	39	0.9
Ca107	44	44.5	46	Td	Td	td	1
Ca108	37	39.5	44.5	46	Td	td	1.7
Ca109	38.5	40	43.5	43.5	D	D	1.7
Ca110	42	44	45	Td	Td	td	1.6
Ca111	42	45	47	48	49	51	0.4
Ca112	16	19	21	Td	Td	td	1
Ca113	23	25	27.5	Td	Td	td	0.7
Ca114	43.5	47	48.5	50	53	55	0.9
Ca115	38.5	40	41.5	42	46.5	48.6	2.2
Ca116	47.5	50	53	57.5	60	62.3	2.4
Ca117	44	49	54.5	55.5	55.5	58	2.4
Ca118	50	52.5	56	Td	Td	td	1.1
Ca119	40	43	46	52	Td	td	1.5
Ca120	38	40	43.5	45	B	B	0.9
Ca121	42.5	45	50.9	54	54	58	1.8
Ca122	44.5	47	50	51	56.5	td	1
Ca123	45	46	47	50	50	56.4	2.8
Ca124	53	55	60	62	64	75	3.2
Ca125	43	46	49	50	56	58	1.2
Ca126	28	32	34	41.7	47	47.3	0.7
Ca127	45.5	46	49	Td	Td	td	1.2
Ca128	62	63	64.2	66.8	69	72.1	2.9
Ca129	5.5	8	9.5	Td	Td	td	1
Ca130	50	53	54	55	55	58	1.7
Ca131	46	48	50	Td	Td	td	1.5
Ca132	41	43	44	Td	Td	td	1

Ca133	51.5	56	60.4	66	66.5	84	2.9
Ca134	54.5	57	57	58.6	64	65	1.9
Ca135	40.5	41.5	42	Td	Td	td	1.2
Ca136	37.5	38	41	44.2	46.3	50	1.9
Ca137	44	50	52.5	57	57	58	2.2
Ca138	44.5	49	49.5	51.5	54	56	1.4
Ca139	37	39.5	40	Td	Td	td	0.6
Ca140	30	32	34	36	41	47.4	2.2
Ca141	43	46	48	49	51	td	1.3
Ca142	29	32	36	37	52.7	70	2.3
Ca143	37.5	41.5	42	43.1	46.5	48.4	1.4
Ca144	42	45	50	50.5	51.5	54	1.8
Ca145	44.5	47.5	48	49	52	55.7	1.6
Ca146	36	39.5	43.5	45.5	B	B	1.8
Ca147	37.5	40	44	Td	Td	td	1.1
Ca148	45.5	47	51.5	52.5	57.5	59	2.9
Ca149	46	50.5	53.5	Td	Td	td	0.9
Ca150	42	47	51	53	57.5	59	2.4
Ca151	52.5	57	60	63	64	85.4	2.4
Ca152	41	44	47.5	53	54	73.2	3
Ca153	44	47.5	52.5	53.5	52	td	1.1
Ca154	44	46.2	51	Td	Td	td	1.4
Ca155	47.5	50	52	Td	Td	td	1.5
Ca156	34	38.3	42	44.5	47.2	49.1	2.5
Ca157	33.5	36	38.5	Td	Td	td	1.9
Ca158	42.5	46	48.5	52	54.2	56.1	3
Ca159	26	28	30	33	43.6	59.2	3
Ca160	35	39	41	43	43	47	1.1
Ca161	33.4	36	40	Td	Td	td	1.2
Ca162	35	38.4	42.5	44	44.5	47.2	0.7
Ca163	40	43	46	47.5	47.5	50.4	2.2
Ca164	26.5	32	36.6	48.3	61.6	82	3
Ca165	55	60	63	65	69	71	2.9
Ca166	43.5	48	49	49.6	50.8	51.4	2
Ca167	45	47.5	49	51	57.5	59	1.8
Ca168	56	61.4	67	68	70	73	2.9
Ca169	47	50	53	53.5	55	56	1.9
Ca170	37	41	44.5	45.7	46.6	48.2	1.2
Ca171	46	48.6	51.2	52.4	55.8	56.5	1.4
Ca172	40	42.8	59.3	108.2	167	217	6.9
Ca173	32	36.5	39	td	Td	td	1.8
Ca174	42	45.5	50	52	56	61	2.9
Ca175	50	55	57.5	61	64	66	1.5
Ca176	44.5	50	56	61.5	63.5	73	2.6
Ca177	43.5	49.5	52	54	75	79.6	3.4
Ca178	45	53	53	54.5	57	59	2.5

Ca179	46.5	52	53.5	54.5	56	58	2.5
Ca180	33.5	40	49	50	62	77.6	3.9
Ca181	37.5	45	54	55.5	60	62	2
Ca182	55.5	64	66	67.5	74	80	3.2
Ca183	55	65	65.5	69	79	84	2.2
Ca184	31.5	42.5	54	56	60	66	2.9
Ca185	35	40	42	44.5	60	80	3.4

Date	Months and Date of measurements						RCD
	2/2/1998	17/3/98	2/5/1998	17/6/98	2/8/1998	17/9/98	
SC	Tikimti	Hidar	Tir	Yekatit	Miyazia	Ginbot	RCD
Pf1	39	41.5	47	48.5	cd	cd	cd
Pf2	47.5	52.2	55	57.1	60	61.5	1
Pf3	39	41	43.3	45	48.5	50.5	0.7
Pf4	47.5	53.4	56	57.5	61	63	1.1
Pf5	46	47.5	48	49	51	53	0.6
Pf6	37	40	43	43.5	44.5	46	0.9
Pf7	40	43	45	46.2	50	52.3	0.9
Pf8	38	41.5	43	45	46	48.2	0.6
Pf9	38	40	41.6	44.2	46.8	49	0.5
Pf10	35	37	38	39.5	44	49	0.6
Pf11	40	44	44	45.6	50	50	0.9
Pf12	34.5	36.5	38	40	41	43	0.4
Pf13	45.5	47	48.2	51.4	55	56	0.8
Pf14	45	46.5	47	48	54	55	0.6
Pf15	49.5	51.5	54	55	56.7	59.3	0.6
Pf16	50.5	52	54	54.6	57	58	0.4
Pf17	45.5	47	48	48	50	51	0.6
Pf18	37.5	40	41	44.1	47.5	48	0.7
Pf19	47.5	48.5	50.5	51	51.5	52	0.5
Pf20	42.5	45.8	51	52	53.2	54	0.7
Pf21	37	39.5	44	46.5	52	54.5	0.6
Pf22	41	44.5	48.5	50.5	53	54	0.6
Pf23	42	44	45.5	46.5	47	58	0.7
Pf24	32.5	34.5	36	37	39	41.5	0.5
Pf25	41	43	44	44.5	49	51	0.6
Pf26	43	44.5	46	48	51	52	0.9
Pf27	47.5	48.5	51	52	57	58	0.9
Pf28	46	48	50	51.9	57	58	1.1
Pf29	28.5	31.5	34	37.6	42.4	43.8	0.5
Pf30	57	59	60	64	65	66	1
Pf31	46.5	48.5	51	53	55	56	1
Pf32	40	43	45	48	53	55.6	1.4
Pf33	40	42	44	45.5	cd	cd	
Pf34	42.5	44	47	48.5	54.6	57.4	0.9
Pf35	31	33.5	36	36.5	43	45	0.7
Pf36	56	58.5	60.5	62.5	63	64	0.6
Pf37	50	52.5	55	58	cd	cd	
Pf38	40	41.5	42	43.5	48	50	1.2
Pf39	46	48	50	50	53.8	55.3	0.9
Pf40	47	49	50	52	53	55	0.5
Pf41	55.5	56	58	58	59	60	0.7
Pf42	32.5	36.5	38	39	42	46.5	0.5

Pf43	40	42	43	43.5	46	47.6	0.6
Pf44	36	38	39.5	43	46.5	47.5	0.6
Pf45	41	42.5	44.5	45	49	52	0.5
Pf46	41.5	44	47	47.5	50	51	0.5
Pf47	36	38	40	41.5	44	46.5	0.6
Pf48	46	47	49	50	52.5	54	0.6
Pf49	42	44	46	46.5	53	54.5	0.5
Pf50	31	32.5	33	34	38.5	41.6	0.5
Pf51	41	41.5	43.5	43.5	47	49.3	0.9
Pf52	42	44	46	48	54	56	0.8
Pf53	39	41	42	44	48	49.8	0.8
Pf54	40.5	42.5	44	48	51	55.2	0.7
Pf55	37.5	38	39	42.4	45.6	49	0.7
Pf56	40	42	43	43.5	46	48.3	0.5
Pf57	49.5	50	51.5	53.5	56	58	0.5
Pf58	44	46	46.5	47	48.5	49.5	0.5
Pf59	42.5	45	48	48.5	53	57.2	0.5
Pf60	39	41	41.5	43.7	46	48	0.4
Pf61	45	47	49.5	52	55	58	0.6
Pf62	36	38	40	40	44	46	0.6
Pf63	38.5	40	43	45.5	47.2	50.4	0.9
Pf64	39.5	41.5	43	43	45	47	0.4
Pf65	39	41.5	41.5	42.5	45.5	47	0.5
Pf66	51	54	56	57	57	59.4	0.6
Pf67	42	43.5	45.6	47	49.4	51	0.8
Pf68	31.5	32	33	33.5	37.5	40.6	0.5
Pf69	45.5	47.5	49	49.5	54	56.7	0.9
Pf70	46.5	48	49	53	cd	cd	
Pf71	40	43.5	45	47.5	48	48	0.6
Pf72	38	40	42.5	43.2	45.3	48	0.5
Pf73	35	38	39.5	41	43.2	45	0.5
Pf74	44.5	46.5	47	49	51	51	0.6
Pf75	42	43.5	45.5	50	53.5	55	0.5
Pf76	43	45	47.5	48	52.5	56.5	0.7
Pf77	42	44	45.1	46.3	51	53.2	0.5
Pf78	44	46	48	51	52	56	0.9
Pf79	50.5	52.5	54	56.7	60	60.3	0.5
Pf80	40	43	44	45.5	46.5	47.8	0.7
Pf81	46.5	51.3	54	54	55.2	59	0.6
Pf82	41	43	45	48	53	55	0.8
Pf83	37	39.2	42.4	48	53	55.5	0.9
Pf84	30	32	33	34.8	39	41	0.5
Pf85	31.5	33	33	34.6	38	40	0.7
Pf86	30	31.5	33.5	35.5	39	41.5	0.6
Pf87	54	57	57	58.1	60	62	1.1
Pf88	43.5	48	49	50	56	58.5	0.7

Pf89	39	42.4	46	47.5	54.5	56.5	0.7
Pf90	40	46	47	47	49.5	53	0.6
Pf91	41.5	43	43.5	44.5	cd	cd	
Pf92	39	40	41	41.5	43	45.2	0.6
Pf93	54.5	57	59	60.2	64	65	0.9
Pf94	40	43	46	49.8	57	61.7	0.9
Pf95	37	39	42	44.5	50	56.2	0.8
Pf96	46	50.3	55.1	58.5	60	61	0.6
Pf97	36	39	39	41	51.5	53	0.9
Pf98	45	48.1	51	52	58	60.2	0.9
Pf99	37	40	41.5	42	44.5	46	0.7
Pf100	40.5	41.5	42	43.7	50	56.2	0.6
Pf101	42.5	43.5	46	46	49.2	51	0.6
Pf102	38.5	40	42	43	48.5	50	0.5
Pf103	40	43	43	44.5	46	48.5	0.8
Pf104	44	45	45.5	46.2	50	53.7	0.9
Pf105	44.5	48.5	51.5	51.5	54	56	0.6
Pf106	50	51.5	53	53	56	58	0.8
Pf107	52	56.2	59	61.3	64.5	66	0.8
Pf108	46	48.4	50	50	55	55.6	0.6
Pf109	50	53	54	56	56.5	58	0.6
Pf110	31.5	33.5	35	36	40	41	0.8
Pf111	44.5	48	52	53.1	56	60.4	0.8
Pf112	48	52	54.2	57	59.9	68	1
Pf113	33	37	38.5	38.5	43	47.5	0.8
Pf114	42.5	46.3	49	51.4	55	57	0.9
Pf115	52	53	55.5	57	59	60.4	0.7
Pf116	43	45.5	48.5	49	50	52	0.8
Pf117	46.5	48.5	50	51.3	55	58.6	0.9
Pf118	42.5	46	49	53	55	57.3	0.5
Pf119	34.5	38.5	40	40	42.5	45	0.8
Pf120	44	45	46	46.5	49.5	53.6	0.5
Pf121	50	52	56	56.5	60.5	67.8	1
Pf122	32	34	35.5	36	37	38	0.4
Pf123	48.5	54	56	59	60	62	1
Pf124	45	50	54.5	56	59.5	61	0.9
Pf125	55	58	60	61	62	63	0.9
Pf126	45	48	48	50	53.5	59.4	0.9
Pf127	46	49	53.6	58.4	68	70	1.1
Pf128	40	42.5	44	45.5	50	52.3	0.9
Pf129	40	44	44	44.5	46.5	49.7	0.7
Pf130	39	43	44	44	46.5	48.6	0.8
Pf131	51.3	55	57	60	61.5	68	1.1
Pf132	44.2	47.3	50	50.5	51.5	53	0.7
Pf133	46	52	56.5	58	59.5	60	0.6
Pf134	41	44.5	47.5	48	53	60	0.7

Pf135	41	45	46	47	49.5	50.1	0.9
Pf136	51	53	55.5	58	62.5	64	0.9
Pf137	55.2	59.1	62	63	65.5	71	0.8
Pf138	35.5	38.5	40.2	43	49.5	50	0.8
Pf139	43.5	46.5	48.5	50	52	54	0.6
Pf140	43.5	44	44.5	44.5	45	47	0.6
Pf141	47	50	52.5	53	58.5	62	0.8
Pf142	43	45	46.5	47	50.5	51	0.5
Pf143	47	49	51	52	52.5	57	0.6
Pf144	43.2	46	48	49	53.5	55	0.6
Pf145	46	52.5	53	54.5	54.5	55.5	0.7
Pf146	43	52	54	54.5	55	56	0.9
Pf147	36	39	42.5	43.5	48	48.6	0.7
Pf148	50	55	57	58.5	63.5	64	0.9
Pf149	40	42	43.3	46	49	53	0.6
Pf150	44.5	47	50	50	52	52.3	0.7
Pf151	40	42.5	43.5	44.8	53	55	0.9
Pf152	39.5	43	46	46.5	53	56.2	0.8
Pf153	37	40	40	40.5	44	46.6	0.7
Pf154	44	50.5	56.5	60	63.5	66	1
Pf155	41.2	43	44.5	45	48	52.5	0.5
Pf156	47	52.5	56.5	57	58	60	0.9
Pf157	44	47	49.5	53.8	61.4	66	1
Pf158	42	43	43.5	44.5	48.5	50	0.7
Pf159	40	42.5	42.5	47.5	50	53	0.5
Pf160	41.5	46	50	51	55	56	0.8
Pf161	44.5	46	48	51	52.5	53	0.8
Pf162	39.5	41	43.5	45	48	50.4	0.7
Pf163	47	48	49	49.5	53	55.3	0.7
Pf164	47	47.5	49	51	54.5	60	0.8
Pf165	46	49	52	52.5	61	63	0.6
Pf166	32	35	36.5	40	43	45.7	0.5
Pf167	44	47	49	50.5	54.5	56	1
Pf168	43.5	46	47	48.5	52	54.7	0.7
Pf169	38.5	41	43	44	45	46.6	0.7
Pf170	43.5	46	46	47	48.5	50.2	0.6
Pf171	45.5	50	50	51	55	57.3	0.7
Pf172	28	31.5	33.5	36.5	39	41.1	0.9
Pf173	42	46	48	49	53	55	0.7
Pf174	36.5	42	44	45	51	52	0.8
Pf175	39	44	46	47.5	49	51.2	0.6
Pf176	32.5	36	39	39	41	43	0.5
Pf177	25.5	30	32.5	34	B	B	1
Pf178	39	44	45	45	51.5	53	0.5
Pf179	54.5	58.5	61.5	61.5	62.5	64	1
Pf180	44	47	49	49	53	54.5	0.7

Pf181	50	53	56	57.5	62.5	65	1
Pf182	37	39.5	40	41	44	45.2	0.7
Pf183	38	45	48	48.5	50	53.3	0.8
Pf184	41.5	45.5	48	49	55.5	60	1.1
Pf185	41	44.5	46.5	50	52.5	55	0.4

	month and date of measurement							
Date	2/2/1998	17/3/98	2/5/1998	17/6/98	2/8/1998	17/9/98	17/9/98	
SC	Tikimti	Hidar	Tir	Yekatit	Miyazia	Ginbot	RCD	
Mf1	23	33.1	36.3	38	42	66	1	
Mf2	22	33	35.5	37.2	60	66	1.4	
Mf3	19.5	32	43	48.5	88	97.5	1.4	
Mf4	24	28	34.5	38.5	74.1	94.7	1.5	
Mf5	17	28	30	33.5	53.2	60	1	
Mf6	30	37.8	46.5	50.2	56	73.4	1.3	
Mf7	16.5	20	23.5	31	37.6	46.2	0.9	
Mf8	23.5	31	37	44	66.5	74	1.2	
Mf9	25.5	30.5	35.5	37	58	69.2	1.1	
Mf10	16	21	25	27.5	39.5	42	1.1	
Mf11	22	26	31.3	42	70	73	1.1	
Mf12	19	30	32.5	36.3	48	66	1	
Mf13	32	38	45.5	52	87.5	96	1.1	
Mf14	13.5	17	22.5	26.5	38	44	1.4	
Mf15	21.5	25.5	27	32.5	55	60	1.4	
Mf16	30.2	36	44.1	75	101	113.3	2.7	
Mf17	22	25	27	B	B	B	B	
Mf18	16.5	23.5	25.5	27.5	44.5	50	1.2	
Mf19	14	20.5	28	37.3	45.5	55	1.3	
Mf20	21.5	25.5	29.4	38	62.5	69.5	1.7	
Mf21	24.5	28.5	37.5	70	115	148.6	2	
Mf22	21.5	27	28.2	40.6	54	58.5	1.8	
Mf23	17.5	23	23	28.5	47.5	50	0.9	
Mf24	18	29.5	37.2	54.1	85	101	2.4	
Mf25	22.5	34.5	41	43	64.3	69.5	1.5	
Mf26	27	33	37	46	76.4	92.2	1.9	
Mf27	21	25	27	29	50	54.5	0.9	
Mf28	19	23	24	40.5	51	65	1.2	
Mf29	19	24	27	30.6	50	59.4	0.9	
Mf30	28	35	41.6	56	60	83	1.9	
Mf31	17	23	23	25	36	44	1.1	
Mf32	16	24	27	38	53.5	64.1	1.1	
Mf33	26	35.5	38	46	76	88	1.6	
Mf34	23.5	34	36	44.5	57.5	65	1.2	
Mf35	26	32	39	40	55	58	1.8	
Mf36	21.5	31.5	43.5	55	90	113	2.3	
Mf37	16	20	25.5	31.5	46.5	50.2	1.2	
Mf38	14	20	26	29	53	62	1.2	
Mf39	20	25	33.2	37.6	55	58	1.7	
Mf40	28	41.8	53	66.7	84.2	98	1.8	
Mf41	23	27.5	31	38.5	52	98	1.3	
Mf42	14	18.5	24	32.9	73.2	86	1.6	

Mf43	19	26	30	32	32	55	1
Mf44	22	28	32	38.2	63.8	76	1.4
Mf45	28	40.5	42	51	55	61	1.3
Mf46	32	39.5	41	44.5	74	78	1.1
Mf47	20	27	34	36	46.5	55.3	0.8
Mf48	28	37	40	43	83.5	90.3	1.9
Mf49	22.3	28	33	35.5	44	56.7	1.2
Mf50	26	32.6	37.5	42.5	46.4	54.6	1.3
Mf51	22	32.5	39.5	51	82	83	1.8
Mf52	25.5	32	38	47.2	86	90	1.8
Mf53	24	33	43	44.5	74	76	1.5
Mf54	16	20	21	24	46	50.4	1.5
Mf55	22	25.5	27.5	29.6	56	58.5	1.5
Mf56	23	28.5	30	33	B	B	B
Mf57	21	24	26	28	44	45	1
Mf58	23.5	30.5	32	36.5	50.5	60.8	0.9
Mf59	29	35	38	43	76	83	1.2
Mf60	28	34.5	37	40	B	B	B
Mf61	29	34	37.2	39.5	57.5	60.1	1.2
Mf62	26	30	34	34	55.8	66.5	1.5
Mf63	22	27.5	28	32.5	50	59	1
Mf64	19.5	25	28	34	42.5	49	0.9
Mf65	27.5	38.5	45	48.5	73	75	1.3
Mf66	33	40	45	59.5	94.5	100	1.8
Mf67	33	38	45	52	85	97	1.2
Mf68	31	37.6	41	42.5	68.5	78.3	1
Mf69	28.5	36	38	41	B	B	B
Mf70	10.5	14.5	18	19	24	30.2	0.4
Mf71	20.4	25.5	30	56	B	B	0.9
Mf72	29	35	41.6	52.2	89.5	97.2	1.1
Mf73	26.5	30	32	34	45.5	56.3	1.1
Mf74	16.5	20	23	42.5	B	B	1.1
Mf75	17	20.5	21.5	42	68	77	1.5
Mf76	15	18	22	25	44.5	45	1
Mf77	20.5	23	25	27	B	B	0.8
Mf78	26.5	34.5	36.5	37	52.3	55.7	1
Mf79	24.5	27	29	31.5	46	49.1	1
Mf80	27	30	32	32	51	67	1.5
Mf81	30	35	37.5	38.5	57.5	70	1.3
Mf82	30	37	42.5	58.5	70	81	1.7
Mf83	25.5	32.5	33.5	51	66.1	75	1.3
Mf84	27.5	38	41.5	44	69.5	76.4	1.9
Mf85	26	33	37	42	72	76.6	1.8
Mf86	22	27.5	33	34	43	59.6	0.9
Mf87	25	34	37	45	68	74	1.4
Mf88	23	28.5	36	39.1	70.5	73.7	1.3

Mf89	26	32.5	37	39.5	64.5	72	1.5
Mf90	29	38.5	48	74.5	86.5	116	2.7
Mf91	14	19	25	40.8	77	84	1.9
Mf92	16	20	27.2	35.5	49.5	64	1.2
Mf93	28.5	35.5	41.5	56	81	88.4	1.9
Mf94	16.5	25	30	40	61.5	81	1.4
Mf95	14	18	18	18.5	22.5	24	0.6
Mf96	16	23.5	28.5	30	52.5	67	1.2
Mf97	26	46	56.5	92	120	148.5	2.9
Mf98	37	45.5	52	55	84.5	95.7	2
Mf99	24.5	31	41.6	47.4	75	82.6	1.5
Mf100	26	31.5	35	50	86	107	1.6
Mf101	20	25	28	28.5	53	58.2	1.3
Mf102	15	20	26	40	63.5	79.2	1
Mf103	20	25.5	27.5	36	B	B	1
Mf104	25	29.2	32	35.1	56	58.6	1.1
Mf105	29	33	42.5	45	57.6	81	1.7
Mf106	32	40.5	45	49.5	67.5	73	1.5
Mf107	27.5	32.5	34	36.2	56.5	60	1.5
Mf108	26.5	31.5	35	38	61	64	1.2
Mf109	20	23	24	24.5	B	B	0.6
Mf110	14	18	23	27.4	35	47.7	0.8
Mf111	10.5	11.5	15	18	21.5	24	0.7
Mf112	22	27.5	29.5	31	42.5	50	1.2
Mf113	23	31	34	34.5	65	74	1.5
Mf114	23	26.5	29	30.6	48	76	0.8
Mf115	16	25.5	34	43	45	73.2	1.6
Mf116	32	42	49.5	51.5	56	90	1.8
Mf117	14.5	20.5	26	31.2	36	46	1
Mf118	17.5	22.5	28.5	32	47.1	50	1.1
Mf119	28.5	31	37	40	63.5	65.5	1.3
Mf120	10	13	21	32	50.5	52	1
Mf121	28	36.5	40.5	44	74.5	92	1.5
Mf122	9.5	11	16	19.5	28	35	0.6
Mf123	19.5	25.5	28	30.4	46.5	52	1.2
Mf124	10	13.5	17.5	23	56.5	72.4	1.2
Mf125	16.5	20.5	24.5	30	B	B	0.8
Mf126	16	20	23	31	B	B	0.9
Mf127	24.5	26.5	29	31	37	44	1.9
Mf128	16.5	21	23	26	30.5	37.3	0.9
Mf129	34	40	42.5	45	B	B	1.8
Mf130	28.5	33	40.3	45	51	63	1.3
Mf131	23.5	31	33	34	47.5	59.4	1.1
Mf132	21	25.5	30	35.6	57	60	1.6
Mf133	19.5	22	26	28	36	43.6	0.8
Mf134	19.5	23.5	26	45	B	B	1

Mf135	21	25.5	28.5	41	50	71.4	1.8
Mf136	20.5	27.5	29	33.5	44.2	48.3	1
Mf137	18.5	23	30	34.5	68	81	1.6
Mf138	27.5	31	34	37.8	87	94.3	1.6
Mf139	28.5	33.5	35	37	59	72.6	1.8
Mf140	19.5	23	28	31	42	53	0.6
Mf141	23	28.5	33	38	B	B	1.3
Mf142	26	31	39.5	47	B	B	1.4
Mf143	22.5	26.5	29.5	31	43	47	1.1
Mf144	18	21	24	27.5	29.5	32.1	1.1
Mf145	26	29	30	34.6	43	50.8	1
Mf146	9	17.2	20	21.5	27	29.5	0.7
Mf147	18	23	30	30	40	51.3	1.2
Mf148	30	35	44.1	51.5	56.8	61	1.4
Mf149	35	40.5	46	48	77	85	1.5
Mf150	9.5	14.5	20	26.5	45	70.3	1.3
Mf151	14	18.5	23	26	40	46.7	1
Mf152	24.5	27.5	36	40.9	68	82	1.5
Mf153	22	27	30	34	B	B	1.1
Mf154	34.5	43.5	50	53	B	B	1.5
Mf155	26	34.5	42	44	60	63.4	1.4
Mf156	22.5	27	37.5	43	66	72.1	1.5
Mf157	10.5	19	21	24.5	37.5	41.4	1.1
Mf158	11	14	19	21	29	40	0.5
Mf159	22	30.5	33	34.5	66	69.6	1.1
Mf160	21	28	32.5	34	B	B	1
Mf161	33.5	38	40	42	60	80	1.4
Mf162	14	16.5	22.5	24.5	28.5	32	1.2
Mf163	23	31.5	33	49	50.4	76.1	1.2
Mf164	29.5	34	37	47.3	67	70	0.9
Mf165	14.5	16.5	19.5	23	25.2	29	1
Mf166	26	33	34	38	55	66.7	1.6
Mf167	22	28	34	62	110	119.3	2.4
Mf168	29	40	41	45.5	98	103.6	1.8
Mf169	25	28.5	31.5	36	49	49.6	1
Mf170	27	36	39	43	47.5	63	1.5
Mf171	19	27.5	30	33	B	B	1.9
Mf172	20	25.5	28.5	33	38.6	52.4	1.1
Mf173	14.5	18	21	23	33.5	40	0.8
Mf174	16	19.5	21.5	27.6	54.5	58	1.1
Mf175	19	24.5	26	27.5	B	B	1
Mf176	25.5	33	39	43	B	B	1.1
Mf177	24	35	40	42	53	57	1.2
Mf178	21.3	28	31	34.5	54.6	71	1.2
Mf179	26	33	35	36	B	B	1.2
Mf180	24	30	34	37	63.5	67	1.4

Mf181	27.5	32	35	38	B	B	1.4
Mf182	25.5	33	40.5	43.2	50	55.6	1.1
Mf183	29	36	54.5	73	94	136.7	2.4
Mf184	21	28.5	49	76	108	120	3
Mf185	22	32.6	43.4	45.5	60.5	73	1.6

	Months and Date of measurements							
Date	2/2/1998	17/3/98	2/5/1998	17/6/98	2/8/1998	17/9/98	17/9/98	
SC	Tikimti	Hidar	Tir	Yekatit	Miyazia	Ginbot	RCD	
Cm1	20	23.5	28.5	29	36	43	0.8	
Cm2	12	20	24	28.2	32.5	36	0.4	
Cm3	15.5	18	22	22	32	35	0.5	
Cm4	19.5	23	27	27	33	36	1.1	
Cm5	20	22	25	26.5	40	45	0.9	
Cm6	15.5	18	22	25	30	32	0.9	
Cm7	19.5	22.5	22	23	30	35.7	0.8	
Cm8	14	16	18.5	20.5	25	28	0.6	
Cm9	18	22	28	32	62	75.6	2.1	
Cm10	15	18	18	21	30	32	0.4	
Cm11	17	19	22	23	36	38	1.1	
Cm12	14	18.5	19	20	29.5	31.5	0.6	
Cm13	16.5	20	23	23	26.5	28	1.2	
Cm14	13	16	17.5	23	28.5	30	0.4	
Cm15	16	18	20	20	31	37.5	1.6	
Cm16	24	27.5	29	31	31.5	34	0.5	
Cm17	13.5	16	16	21	24	26	0.6	
Cm18	18	20	20	21	25	27	0.3	
Cm19	17	20	22	24.5	26	30	0.6	
Cm20	22	25	30	32	37.5	39	0.9	
Cm21	16	18	24.5	25	31	31	1	
Cm22	17	20	20	22	33	37	0.9	
Cm23	29.5	32	33	33.5	38.5	40	1.2	
Cm24	30	34.5	35.5	36	42.5	45.5	0.9	
Cm25	27	30	32.5	35	39.5	43	0.6	
Cm26	21.5	22	26	28.5	36	38	1.1	
Cm27	29	30	36.5	41	44	49	1.1	
Cm28	33.5	35	36	39	41	44	1.4	
Cm29	27.5	31	33	35	43	45	1.2	
Cm30	30	34	37	38	38	40	1.5	
Cm31	21	24	28	28	32	33	0.5	
Cm32	25	28	32	34.5	50	55.3	1.2	
Cm33	19	21	21.5	21.5	27.5	31.5	0.5	
Cm34	22.5	26	28	29	33.5	36.3	0.7	
Cm35	37	40	43	44	54	66.3	1.7	
Cm36	16	19	20.5	21.5	22	cd	0.2	
Cm37	25.6	27	28	29	38.5	41	0.7	
Cm38	21.5	24	24	24.5	26	28	0.5	
Cm39	20	20	20.5	21.5	25	27.4	0.2	
Cm40	27	33	34	34.5	35	37	0.8	
Cm41	22	24	25	28	32	35	0.9	
Cm42	24	26	26	27	29	td	0.4	
Cm43	19.5	20.5	24	25	29	29	0.5	
Cm44	20	23	26	27	30	31.2	0.8	
Cm45	22	24	24	26	td	td	0.3	

Cm46	20.5	25	26	27	30	31.1	1.2
Cm47	25	29	29	32	34	37.8	1.6
Cm48	32	37.5	40	46.5	49.5	50	1.7
Cm49	25	30	36	42	50	52	1.3
Cm50	62.5	65.5	66.5	68	73	77	2
Cm51	16.5	17.5	20	21	td	td	0.3
Cm52	76	78	79.5	81.5	88	92.5	2.9
Cm53	14.5	18.5	20	21	22	25	0.1
Cm54	24	28	30	31	43	45	0.8
Cm55	13	16	18.5	23	24	25.1	0.1
Cm56	40	42.5	45	46	46	48	0.3
Cm57	38	40	41.5	41.5	43.5	45	1.2
Cm58	37.5	40	43	46	47	48	1.6
Cm59	29.5	31	32	32.5	37	39	0.8
Cm60	18.5	21	22	22.5	26	26.2	0.2
Cm61	13	15.5	17	18.5	20	22	0.2
Cm62	26.5	33	34.5	34.5	38	38	0.7
Cm63	16.5	19.5	20	20	21.5	td	0.3
Cm64	18	23	23	26	30	35.3	0.6
Cm65	30	23.5	33	34	37	39	0.4
Cm66	12.5	15	18	19	20	td	0.3
Cm67	14.5	19.5	20	20	22	td	0.1
Cm68	23.5	27	28	30.5	32	38.2	1.1
Cm69	20.5	21.5	23	26	B	B	0.4
Cm70	18	23	26	C.D	cd	cd	
Cm71	25.5	33	37	40	47	50	1.1
Cm72	29	36	39	56.5	67	80	2.8
Cm73	21	27	40	53.5	65	68	2.2
Cm74	23.5	29	34	35.5	49	54	1
Cm75	31	33	36	37	44	52.3	1.2
Cm76	31.5	33.5	34	35	35.5	td	0.4
Cm77	24.5	28	29	31.5	33	34.6	1
Cm78	35.5	40.5	42.5	43.5	48	52	0.9
Cm79	20.5	28	29.5	32	38.5	43.5	1.2
Cm80	16.5	20	26	28	32	36	1.3
Cm81	16	19	23	27	37.5	40	1.1
Cm82	14	17.5	21	26.5	31	38	0.9
Cm83	22	25	26	28	39	47	1.3
Cm84	24.5	28	32	33.5	40	45	1.1
Cm85	21.5	25	25	38.5	45	50.6	2
Cm86	24.5	25.5	27	28	34	38	1.1
Cm87	27	34.5	38.5	41	54	61	1.9
Cm88	26.5	33	38	38	51.5	67.3	1.5
Cm89	18	20	28	29	31	33.2	0.9
Cm90	12	13.5	14	15	19.5	23	0.4
Cm91	13	17	21	24	30	31	0.8
Cm92	21	22	24	27.3	35.5	38	0.9
Cm93	15.5	21	27	28.5	34	39	1.3
Cm94	14	16.5	23	26	38	43	1.3
Cm95	20	22	25	26.5	27	28	1.3
Cm96	15	17.5	20	20	25.5	27	0.2
Cm97	28.5	31.5	34	37	43	46.3	1.4

Cm98	23.5	27	28	33	45	54.3	0.9
Cm99	18.5	20	21.5	26.5	35.5	41.3	1.1
Cm100	17	19.5	20.5	22	24	27	0.4
Cm101	18	20	26	27.5	32.5	42.9	1.4
Cm102	20	24.5	27	28	31	34.3	0.5
Cm103	17.5	23	26	27	33	35.4	1
Cm104	29.5	38.5	45	53	59	69.8	2
Cm105	26	33.5	38	40.5	52	64.7	1.9
Cm106	18	23.5	27	28.5	39	46.8	1.3
Cm107	26	30	30	34	38	44.5	1.3
Cm108	28	33.5	35.5	37	38	41.6	1.2
Cm109	20	23.5	26	27.5	42.5	46.3	1.3
Cm110	49	54	63	65	75	84.5	4

Highlighted numbers in *C. macrostachyus* were those with similar height during two consecutive measurements.

Appendix 2 . Mean height increments of the five studied species across plots.

1. *Prunus africana*

Plot	H1	H2	H3	H4	H5	H6
1	38.05	44.13	48.64	53.76	63.81	68.64
2	38.55	43.93	48.45	52.49	56.09	58.71
3	38.99	45.26	50.74	55.98	62.12	66.06
4	40.13	47.11	50.54	53.54	58.58	62.81
5	41.28	46.62	50.47	54.72	64.28	70.31
6	43.97	50.02	54.36	60.92	69.03	75.01

2. *Podocarpus falcatus*

1	42.17	44.48	46.49	48.06	50.91	52.84
2	41.19	43.03	44.60	46.18	49.01	51.31
3	41.07	43.70	45.41	46.99	51.13	53.61
4	44.02	47.08	49.17	50.56	53.62	56.41
5	44.38	47.85	49.95	51.18	54.26	56.50
6	41.05	44.43	46.44	47.89	51.91	54.27

3. *Cordia africana*

1	40.80	42.45	43.63	45.53	48.93	50.50
2	40.69	43.23	45.42	47.98	49.67	51.60
3	40.25	42.90	45.19	46.63	49.57	52.70
4	41.67	44.05	46.59	50.40	54.16	59.27
5	41.43	44.58	47.18	49.78	53.40	60.08
6	41.20	45.94	49.86	55.03	62.21	69.23

4. *Millettia ferruginea*

1	21.79	28.71	33.44	40.78	59.94	71.15
2	23.99	30.23	34.44	41.96	64.53	73.31
3	21.24	26.11	30.18	34.74	51.17	61.81
4	22.27	28.30	33.34	38.53	55.10	64.63

5. *Croton macrostachyus*

1	20.99	23.85	26.14	27.83	34.21	38.07
2	25.96	28.84	30.91	32.89	37.19	41.64
3	22.66	26.73	30.20	34.01	41.23	46.79
4	22.44	26.61	30.14	32.64	39.56	45.37

DECLARATION

I, Tamene Belude Muleta hereby declare that this thesis was my original work and has not been submitted to any university for the same purpose. All sources of materials for this work have duly been acknowledged. The author and Addis Ababa University reserve all rights to this work.

Signature: _____

Date: _____