The Benefits of *Acacia abyssinica* (Hochst.) ex. Benth. (Fabaceae) in the Restoration of the Threatened *Juniperus procera* (Hochst.) ex. Endl. (Cupressaceae)

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This is to certify that the thesis prepared by Birhanu Kagnew, entitled: The Benefits of *Acacia abyssinica* (Hochst.) ex. Benth. (Fabaceae) in the Restoration of the Threatened *Juniperus procera* (Hochst.) ex. Endl. (Cupressaceae) and Submitted in partial fulfillment of the requirements for the Degrees of Masters of Science in Plant Biology and Biodiversity Management complies with the regulations of the University and meets the accepted standards with respect to originality and quality.

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ABSTRACT

The Benefits of *Acacia abyssinica* (Hochst.) ex. Benth. (Fabaceae) in the Restoration of the Threatened *Juniperus procera* (Hochst.) ex. Endl.(Cupressaceae)

Birhanu Kagnew

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The study was conducted in the "Center for Indigenous Trees Propagation and Biodiversity development in Ethiopia". This thesis presents analysis of the contribution of *Acacia abyssinica* for the restoration of the threatened *Juniperus procera.* The general purpose of the study was to examine the role of *A. abyssinica* in the restoration of the threatened *J. procera* on degraded and bare landscape. To achieve this objective, different size sampling plots were used for both tree and soil data collections, along the systematically laid transect lines. Accordingly, a total of 24 sampling plots were constructed, inside each sample plot, the growth parameters, viz. tree height, d.b.h, crown length, crown diameter, branch numbers, branch length and status of soil physicochemical properties in the two sub-sites was recorded and examined. The growth potential of the studied tree was analyzed. The findings of the study revealed that the mean growth difference of *J. procera* in the two sub-sites was significant ($p < 0.05$) and its growth potential in all parameters was considerably higher in *A. abyssinica* influenced sub-site than the control sub-site. The results showed that the presence of *A. abyssinica* were paramount important for the restoration of the endangered *J. procera.* The soil analysis result revealed that there is significant mean difference ($p < 0.05$) for soil organic carbon, total nitrogen and soil textures in the two soil depths and across the two sub-sites. Total nitrogen, organic carbon, EC, available phosphorus and CEC except soil pH were decreased with increasing soil depths which is an indication of surface soil fertility restoration. Soil fertility was different across the two sub-sites. This might be due to either the presence or absence of nitrogen fixing as well as necromass production of *A. abyssinica.* The significance of the study was to provide a basis for further restoration studies that contributes towards restoration, protection, regeneration and conservation of useful endangered tree in particular and biodiversity in general.

Keywords: Restoration, nitrogen fixation, growth performance, *J. procera*, Soil fertility.

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MOARD: Ministry of Agriculture and Rural Development Office.

EFAP: Ethiopia Forestry Action Programme.

DBH: Diameter at Breast Height

EPA: Environmental Protection Authority.

FAO: Food and Agricultural Organization of the United Nations.

CEC: Cation Exchange Capacity

ECEAP: Environment Canada's Eco-Action Program.

WMO: World Meterological Organization.

IUCN: International Union for Conservation of Nature.

AEC: Anion exchange capacity.

WBISPP: Woody Biomass Inventory and Strategic Planning Project.

Chapter One

1. Introduction

1.1. Background and justification

The Society for Ecological Restoration defines Restoration as "the process of assisting the recovery of an ecosystem that has been degraded, damaged or destroyed" as reported in (Lamb and Gilmour, 2003), because of extensive and unwise exploitation of natural resources (Reusing, 1998; Demel Teketay, 2001; Million Bekele, 2001; Eshetu Yirdaw, 2002; Kahsay Berhe, 2004; Legesse Negash, 2010; Nimmo, 2007).

Acacia abyssinica belongs to the family Fabaceae (Leguminoseae), and sub-family Mimosodeae. The species occurs in woodland, wooded grassland, and in moist highland, forest edges. The tree is widely distributed in the afromontane region of Africa (Asfaw Hunde and Thulin, 1989; Legesse Negash, 2010). The tree species is a very important component of the vegetation system in the drier, as well as in the wetter ecological zones of Ethiopia. It is highly used for conserving and improving degraded soils and landscapes. Nutrient pump by the tree from deeper soil horizons is an essential biological process that is vital for the regeneration of soil fertility and continued land productivity as well as economically useful, shade-loving plants such as coffee may be planted beneath the tree (Legesse Negash, 2010).

The bacterial or rhizobial populations associated with this valuable tree are taxonomically diverse. This might be related to the long term co-existence and gradual differentiation of the bacteria. The nitrogen fixing capacity of a leguminous tree is realized only if the tree is nodulated well with effective and diverse rhizobia (Tulu Degefu *et al.*, 2011). Thus, the nitrogen fixing ability and organic matter contribution of the tree improves soil fertility under its canopy (Getachew Tamiru, 2007; Legesse Negash, 2010). On the other hand, dissected leaves of *A. abyssinica* are important adaptive features believed to have evolved for conserving water. As drought intensifies, these leaflets are shed in large quantities, thus contributing substantially to the soil organic matter (Legesse Negash, 2010). However, its restoration role for the threatened tree is yet not explored at all.

Juniperus procera, commercially known as the African pencil cedar, is the largest *Juniper* in the world. The tree belongs to the Family Cupressaceae, and its occurence extends from Arabia to Zimbabwe, with approximately altitudinal range between 1750 and 2500 m.a.s.l (Friis, 1992; Legesse Negash, 1995, 2002, 2010). The species usually grows in mountainous areas and on rockey grounds (Friis, 1992; Legesse Negash, 2010). *J. procera* is an evergreen timber tree that thrives on well-drained soils of tropical montane area (Legesse Negash, 2002).

Forests in which *J. procera* are the dominant species are under increasing pressure from unsustainable utilisation and land use conversion, threatening the long term viability of the natural resource base. As local communities who depend heavily on them harvest the increasingly degraded *J. procera* populations, the borders of agricultural expansion are pushed into higher and higher altitudes (EshetuYirdaw, 2002; Nimmo, 2007). At Mankubsa, South Ethiopia, increased grazing pressure, agricultural expansion, commercial fuelwood and timber exploitation are threatening *Juniperus* forest persistence. Thus, heavy exploitation of *J. procera* has led to almost complete disappearance of the species from Mankubsa in recent years (Borghesio *et al.*, 2004).

This tree had become endangered due to the extensive and unwise exploitation for various services and products (Legesse Negash, 1995, 2010; Nimmo, 2007). The tree produces timber of economic importance. The wood is used for a great many purpose, including the manufacture of lead-pencil and pencil holders, the construction and lining of buildings, joinery, as well as for fence posts (Friis, 1992; Legesse Negash, 2010). In Ethiopia, timber from *J. procera* is highly valuable for the construction of Orthodox churches and houses mainly because of its durability, termite resistance, workability, beautiful grains and distinctive scent (Friis, 1992; Legesse Negash, 2002, 2010; Orwa *et al.*, 2009).

Unfortunately, those diverse uses of this tree have resulted in a widespread distraction of the tree. Consequently, the remaining trees are mostly found within church compounds, graveyards or other enclosed areas (Legesse Negash, 2010). Thus, *J. procera* is included on the IUCN red list of endangered species (IUCN, 2009), and the ecological and economic importance of the *juniper* forests of Ethiopia has resulted in a great interest in their restoration (Tigabu *et al.*, 2007). The near-total removal of *J. procera* is likely to have major effects on the ecosystem, because its large size and importance as a resource for frugivores make it a keystone species (Borghesio *et al.*, 2004).

Today, this tree of great value is facing three major problems: (1) it is literally being "hunted" down (by the people) for its diverse uses, and (2) the natural regeration under big- trees and at lower altitudes is rather poor, possibly because of aminal browsing, poor seed-setting, changes in land use patterns, wildfires, and prevalence of unfavourable climatic conditions (Legesse Negash, 2002). (3) Fostering its restoration through use of various biological resoration techniques is lacking. The main objective of this work is therefore, to address the problem stated under (3) above. Clearly, the existence of this valuable tropical montane tree species is threatened. Therefore, what is required is to develop and implement scientific solutions to the problem through biological restoration mechanisms using *A. abyssinica*. The study was conducted to evaluate the field level growth performances and establishment requirments of *J. procera* seedlings. The study also tries to examine and compare the contribution of *A. abyssinica* for the soil condition of the study area based on the soil analysis results.

1.2. Statement of the problem

Several studies reported that indigenous trees of Ethiopia are known for their multiple uses such as source of fuel wood, construction, tool handles, medicine, and fodder for animals, and bases for land improvement (Legesse Negash, 2002, 2010; Getachew Tamiru, 2007; Orwa *et al.*, 2009; Seblework Belaineh, 2009). Unfortunately, these vital trees have been seriously deteriorating. According to Legesse Negash (2010), the various reasons that resulted to the extinction of these valuable trees includes: (i) lack of awareness about the profound connection between native trees and social welfare to the absence of sound policy on their preservation, development and wise utilization; (ii) mistaken perception that natural forests are inexhaustible and that they are to be 'mined' and utilized freely; and (iii) lack of knowledge on the propagation biology, domestication and cultivation of indigenous trees lead to rapid depletion of native forest resources, thus triggering the chain reaction of scarcity-demand-destruction–further scarcity. This is mainly due to lack of knowledge on the environmental requirements of indigenous trees (Tesfaye Wubet *et al*., 2003).

J. procera is one of the most precious timber and economically most important indigenous tree species in Ethiopia (Azene Bekele, 1993; Legesse Negash, 2002, 2010; Tigabu *et al.,* 2007). Selective heavy commercial logging, inhabitants demands of large quantities of firewood and timber leads to the scarcity of this species and as these products are free of charge, the local people probably have no interest in making their lifestyles more sustainable (Borghesio *et al.*, 2004). The species grows in small scattered populations in most areas. As a result, this tree species has been subjected to threats in some provenances (Legesse Negash, 1995; Borghesio *et al*., 2004; Nimmo, 2007) and threatened from its entire habitat (IUCN, 2009).

Anthropogenic activities leading to heavy population disturbances can affect the genetic composition of the tree species considerably and therefore appear to be potential threats for the loss of genetic information particularly in spatially isolated small populations where genetic drift is possible (Demissew Sertse *et al*., 2011). Efficient mechanisms of gene dispersal via pollen and seed contributed to the maintenance of high genetic diversity within populations in the past, but significant genetic differentiation, a significant correlation between spatial and geographic distances, and evidence for natural barriers limiting gene dispersal of *J. procera*. Therefore, considering the geographic location and environmental barriers to set conservation priorities where genetic data are missing is of paramount importance (Demissew Sertse *et al*., 2011).

Decimation of *Juniperus* natural forests over the past 100 years, which is continuing, has halted the utilization of *J. procera*. Favoring *J. procera* in planting instead of *Eucalyptus spp.,* which provide low-quality wood, is a way to diversify species selection, and to supply durable timber of high local and national preference. The relatively low yield potential of the tree compared with exotics calls for national or international inputs for restoration. In order to understand restoration of *J. procera*, it will be necessary to conduct studies that explicitly reveal the restoration mechanisms. Thus, the study is subjected to the question, what mechanisms can work better to realize restoration of this native threatened tree? It is against these backdrops the study intends to assess the role of *A. abyssinica* in the restoration of the endangered *J. procera*.

1.3. Objectives of the study

1.3.1. General objective

The general objective of the study was to examine the role of *Acacia abyssinica* in the restoration of the threatened *Juniperus procera* on a degraded and bare landscape.

1.3.2. Specific objectives

The specific objectives of the study are:-

- ✓ To evaluate the effect of *A. abyssinica* on the soil physical and chemical properties of the study area and its impact on the growth of *J. procera* seedlings;
- ✓ To compare the growth performance differences of the threatened *J. procera* between *A. abyssinica*- influenced and non- *A. abyssinica*- influenced study sub-sites;
- ✓ To evaluate the role of *A. abyssinica* in assisting the restoration of the threatened *J. procera* on degraded landscapes;
- ✓ To measure the tree growth parameters which are used to quantify growth difference of *J. procera* between the two cluster sub-sites?

Chapter Two

2. Literature Review

2.1. *Forest resources of Ethiopia*

Forest is defined as a relatively continuous cover of trees, which are evergreen or semi-deciduous, only being leafless for a short period, and then not simultaneously for all species (Friis, 1992). Historical records indicated that Ethiopia's vast and contrasting landscapes had been covered by forests that were composed of various indigenous tree species including East African yellow wood, African pencil cedar, African wild Olive, large assortments of *acacia* species and a number of keystone fig tree species such as *Ficus vasta* Forssk and *Ficus sycomorus* L. Recently, however, almost all of these tree species are facing serious threats that range from widespread individual tree degradation to local extinction of species. As a result, Ethiopia's mountains, watersheds, plateaus, and vast expanses of lowlands are now so brutally stripped off their vegetation cover that sustainable social welfare is seriously at stake (Legesse Negash, 2010). It is further asserted that the highlands of contemporary Ethiopia are characterized by highly fragmented small patches of remnant forests in remote and protected areas (Alemayehu Wassie *et al*., 2010; Demissew Sertse *et al*., 2011).

The natural forests of Ethiopia comprise indigenous and endemic trees. The indigenous trees are those that can be found in Ethiopia and throughout the neighboring countries while the endemic ones are found only in Ethiopia. The latter have adapted to the relatively specialized ecological conditions of the country through evolution and have natural mechanisms to cope with the nature of the soil, climate and seasonality. Most of them are located in the Southern Region of the country and in the highland plateaus of (Table 1) Kaffa, Illubabor, Wollega and Gamogofa (Hiruy Simie, 2007). From Table 1, out of a total of 4,073,214 hectares of high forest in Ethiopia, about 95% is found only in three regions, namely, Oromia, SNNP and Gambella and Oromia region (about 63 % of the total). One of the reasons why natural forests have been dwindling is due to their conversion to arable lands coupled with unwise and excessive utilization triggered by increasing population growth.

Table 1. Extent of Ethiopia's high forests by region.

Region	Total (ha)	% total
Gambella	535,948	13.2
Amhara	92,744	2.3
Oromia	2,547,632	62.5
Tigray	9,332	0.2
SNNP	775,393	19.0
Benishangul-Gumuz	68,495	1.7
Somali	4,257	0.1
Afar	39,197	1.0
Harari, Dire Dawa	216	0.0
Total	4,073,214	100

Source: Adapted from WBISPP (2004b).

This had and continues to have serious consequences on various ecosystems in Ethiopia (Friis, 1992; Reusing, 1998; Badege Bishaw, 2001; Demel Teketay, 2001; Eshetu Yirdaw, 2002; Sucoff, 2003; Kahsay Berhe, 2004; Getachew Tamiru, 2007; Misrak Tesfaye, 2007; Nimmo, 2007; Kitessa Hundera, 2010).

The annual loss of natural forest cover has been estimated to be 150,000 - 200,000 ha/yr^{-1} (EFAP, 1993; EFAP, 1994). Forest areas have been reduced from 40% a century ago to an estimated less than 3 % today. Some five million hectares of savanna woodlands remained at that time, giving a total forest and woody vegetation area of 7% (EFAP 1993; 1994; Badege Bishaw, 2001; Demel Teketay, 2001; Abate Zewdie, 2007).

Despite the extensive deforestation that has taken place, there are still forests present in the less accessible and less populated areas of Southern and South-Western part of the country (Table 1). It is also this area that is being deforested the most at present (Bekele Lemma, 2006). For instance, this is evident when one drives on the road to Awasa and Arba Minch, to the South, where most of the native trees including acacia trees were removed and as a result the lakes, which once were not seen, are now easily seen from the road. The removal of these trees may result into siltation of the rift valley lakes, due to water and/or wind erosion.

Consequently, large forest areas of the country are now exposed to heavy soil erosion resulting in a massive environmental degradation and serious threat to sustainable agriculture and forestry. On the other hand, according to ministry of agriculture and rural development, Ethiopia has increased the country's forest cover by 9%, up from 3% and improves its biodiversity since the year 2000. This result is said to be from replanting deforested sites before and during the Ethiopian Millennium (MOARD, 2010).

Despite the growing need for forested lands, lack of education among locals has led to a continuing decline of forested areas (Parry, 2003). In a survey conducted for estimating forest resource assessment of Ethiopia, it was found that within 17 years (1973–1990) high-forest cover decreased from 54,410 to 45,055 km² or from 4.75 to 3.93% of the land area (Reusing, 1998). Reusing calculated a deforestation rate of 1,630 km² per year, which means that deforestation at the same rate would leave about 18,975 of the 45,055 km² in 2006. The FAO (2007) estimated a deforestation rate of 1,410 km² per year. Analyses shows that the forested land declined to 1,907 km², which equals 67% of the forest cover in 1973 (Dereje Tadesse, 2007).

Gessesse Dessie and Carl (2007) estimated the rate of deforestation between 1972 and 2000 using remote sensing techniques. Within the 28 year period, 80% (400 km²) of the 1972 forest cover (489.24 km²) was lost. They described that within the formerly closed forest, clearings created a speckled pattern of non-connected small forest patches. Between 2001 and 2005 another 55.4 km² of forest land was allocated for private coffee production and 20 km² for rubber plantations (Hein and Gatzweiler, 2006). Despite the slightly different estimates for deforestation in different regions of Ethiopia, if deforestation rates remain the same, the country will have lost its last tree of high forests within about 27 years (Table 1). And with it will go the world's only original wild populations of *Coffea arabica* (Hein and Gatzweiler, 2006). One of the major drivers of deforestation in Ethiopia is demand for fuel wood. Over 90 % of the country's total energy for households cooking is derived from biomass fuels of which wood provides 78 % (FAO, 2001; Hiruy Semie, 2007). By conserving the forest resources and putting more land under forest cover, one can hope for a relatively better deficit resulting from the negative consumption and supply gap (Hiruy Semie, 2007).

Forests are dynamic over the time scales of centuries (principally through cycles of disturbance and succession) and millennia (through shifts in the geographic ranges of species) and we are in a period of climate change that will shape both of these processes. Maintaining forest biodiversity in a period of unusual dynamism will require significant effort. To organize our thinking about how to maintain forest biodiversity we can envision a conceptual triad that recognizes the three basic ways that we use forests: as natural ecosystems, primarily in reserves where human activities are minimized; as managed ecosystems where both timber production and maintenance of biodiversity are pursued; and as cultivated ecosystems such as plantations, where intensive management for maximum timber production is undertaken (Hunter, 2010).

Forestry can and should play an important role in alleviating land degradation, which is most probably Ethiopia's most pressing environmental concern (Demelew Teketay, 2001). The review of the causes of land degradation in Ethiopia, as well as the lessons of previous soil conservation activities, suggest that forestry must be given an enhanced role in soil conservation for two reasons: (i) growing trees will help restore the nutrient cycle of the soil by substituting the amount of animal dung and crop residues being burnt to meet household energy requirements. As pointed out above, the major share of the cost Ethiopia incurs on account of land degradation originates with the loss of soil nutrients. Encouraging people to grow trees close to or on farmland is the most obvious solution; (ii) the relative importance of the various instruments to control soil erosion is increasingly changing in favour of forestry. Reliance on physical structures is giving way to improved conservation techniques for farmland, re-vegetation, and other biological measures, including such activities as individual farm forestry and community protection forestry. Forest vegetation is important for soil and water conservation, watershed protection, nutrient recycling, nitrogen fixation, amenity and recreation, creation of microclimate, wildlife habitat, gene conservation, and sequestering carbon dioxide from the atmosphere. Consequently, natural forests are the only known sources of rich gene pools and biodiversity (Demel Teketay, 2001; Hiruy Semie, 2007). Clearly, depletion of this important natural resource will affect other valuable and life supporting resources like water and soil. In addition to these, the climate change and biodiversity will also be greatly affected by deforestation. It is very strategic and wise approach to avoid other problems by solving this key problem (Netsanet Deneke, 2007). Protection and conservation of the remaining natural forests is critical to protect species and biodiversity in Ethiopia (Badege Bishaw, 2001).

The benefits of maintaining natural forests in mountain agriculture side by side with crop yield increment, soil protection, climatic improvement, provision of fodder for farm animals and in general improvements in rural livelihood had to be investigated to avert the predicament. In Ethiopia, biophysical resources essential for rural and agricultural development have already been severely degraded from vast areas of land. Sustainable rural and agricultural development must reverse this trend and rebuild and augment the productive capacity of the diminishing agricultural resources base (Mulugeta Lemenih, 2004).

2.2. *Causes and consequences of deforestation in Ethiopia*

Deforestation is land degradation in arid, semi-arid and dry sub-humid areas resulting from various factors, including climatic variation and human activities. Deforestation is a major issue in Ethiopia, since it is one of the main causes of the prevailing land degradation and loss of biodiversity. Tree cutting is a common occurrence which has been taking place for centuries (Abate Zewdie, 2007). The country’s forest and woodland resources have been declining both in size (deforestation) and quality (degradation) (Demel Teketay, 2001; Eshetu Yirdaw, 2002), and the rate of deforestation in Ethiopia, which amounts to 163,000 - 200,000 ha yr^{-1}, is one of the highest in tropical Africa (Reusing, 1998).

Deforestation in Ethiopia is due to locals clearing of forests for their personal needs, such as fuel, hunting, agriculture, past governmental and institutional changes, insecurity of land tenure, resettlement programs, population pressure, poverity, and housing development have all contributed to deforestation. The main causes of deforestation in Ethiopia are shifting agriculture, livestock production and fuel wood production. Deforestation is therefore, the process of removing the forest ecosystem by cutting the trees to suit different uses (Tewolde Berhan, 1989; Friis, 1992; Badege Bishaw, 2001; Demel Teketay, 2001; Eshetu Yirdaw, 2002; Sucoff, 2003; Kahsay Berhe, 2004; Abate Zewdie, 2007; Dereje Tadesse, 2007; Gessesse Dessie and Carl, 2007; Ababu Anage, 2009). As a result of deforestation, Ethiopia's forests and woodlands have been declining both in size and species richness eroding the biological diversity to such an extent that certain plants are faced with local extinction (Eshetu Yirdaw, 2002).

Moreover, although published accounts are not available, it is generally known that illegal felling for pit-sawing of certain valuable indigenous species such as *Juniperus procera, Allophylus abyssinicus, Podocarpus falcatus, Hagenia abyssinica, Prunus africana, Syzygium guineense, Cordia africana, Aningeria adolfi-friederici, Ekebergia capensis,* and *Millettia ferruginea,* to mention just a few, has been a very serious contributing factor to the decimation of the remaining afromontane forests of the country. Legesse Negash (2010) reported that *Podocarpus falcatus, J. procera* and *Prunus africana* are among the afromontane forest trees species that are locally threatened by extinction due to deforestation. These species have been extensively and unwisely exploited.

Due to the continuing encroachment, it is highly probable that the present fragmented forests in the highlands are much more impoverished in terms of floristic diversity than the forests which once occupied the same site. The number of species and intraspecific genetic diversity in fragmented forests will diminish over time after isolation owing to a variety of factors, such as inbreeding and genetic drift (Turner and Corlett, 1996).

Recently pressure comes from intensive management of forest coffee and semi-forest coffee which drastically changes the structure and functions of the original forests. More forest cover change was detected close to areas with good road networks and around settlements (Gessesse Dessie and Carl, 2007). Individual farmers do not have many other options than converting forests into agricultural land if they are exposed to severe food insecurity. Their time preference rates are short which means they prefer food today over tomorrow and they definitely cannot carry the costs of forest conservation for the larger national or global society (Rojahn, 2006; Gatzweiler *et al*., 2007).

Deforestation has a number of repercussions, many of which are: i) can lead to soil erosion or impoverishment, especially in tropical areas where soils tend to be thin and nutrient-poor; ii) linked to habitat loss, which is a leading cause of species endangerment and biodiversity loss, particularly in humid tropical forests; iii) affects the hydrological cycle through changes in evapo-transpiration and run-off; and finally deforestation, and particularly forest burning, contributes to green-house gas emissions that bring about climate change (Netsanet Deneke, 2007).

Generally, deforestation can result in the loss of biodiversity; which in turn results in declines in ecosystem integrity, and also genetic losses that may impede future scientific advances in agriculture and pharmaceutics (Kahsay Berhe, 2004). The trend can only be reversed if appropriate measures are taken to halt them. In order to maintain the ecological equilibrium and to meet the forest resources requirement of the population, scientific information is the basis. Without a full assessment of the properties of the various sites in a forest and their relation to vegetation growth the management of the forest will be severely handicapped. Therefore, ecological assessment of the existing forests is the basis for meaningful planning to rationally utilize the remaining forest resources (Abate Zewdie, 2007).

Because of the complex nature of the problem of deforestation, the Ethiopian government alone is not able to prevent deforestation. By now, we also know that markets alone are unable to prevent this either eventually local stakeholder participation will be required (James *et al*., 2000). Another problem is that the environmental issues in

Ethiopia have no (or a very weak) lobby and the current restrictive socio-political context for public engagement has detrimental effects on environmental education, awareness, advocacy and the building of an engaged and empowered civil society – assets which are necessary to conserve and use Ethiopia's forests in a sustainable way (Mekdes Girmaw, 2004). Prohibiting the people to cut trees, especially those who live in rural parts of the country will actually hurt their daily life since it makes meeting their daily needs more difficult. The government is trying to provide them with things such as fuel and electrical machinery so that the demand for forest resources is not as high. The government is also providing land which is flat and has no pre-existing forests to promote agriculture so that deforestation is not necessary for modern agriculture (Maddox, 2006). Also, one of the methods used to protect trees is to designate certain areas where trees may be chopped down and used, and other areas where trees are protected by law (Parry, 2003).

2.3. *Ecosystem restoration*

An ecosystem is an area where the processes of primary production, consumption, decomposition, and cycling of materials are largely self-contained. A forest stand or a watershed constitutes such an area. Although the scale varies, they have in common the basic compartments of a system- atmosphere, soil, vegetation, and animals-all of which are involved in the cycling of essential nutrients which develop and sustain an ecosystem (Wenger, 1984). The goal of ecosystem restoration is to recover the species composition, structure and function of the original ecosystem prior to disturbance (Bradshaw, 1990).

"Restoration" is defined as the situations where the intent is to recreate an ecosystem as close as possible to that which originally existed at the site. The site then contains most of the original plant and animal species and has a structure and productivity matching that originally present (Lamb and Gilmour, 2003). There are three concepts used in restoration ecology based on alternative targets. These alternatives are similar in that they all aim to re-create productive and functional ecosystems on an otherwise degraded landscape, but they differ in the extent to which they seek to re-establish the original ecosystem (Lamb and Gilmour, 2003). In order to get clarity of concepts, one needs to distinguish among restoration, reclamation.

*Restoration: R*e-establishing the structure, productivity and species diversity of the forest originally present. In time, ecological processes and functions will match those of the original forest. The quality of restoration refers to the extent to which ecosystem integrity has been regained. It includes ecological authenticity (e.g.ecological naturalness, viability, health) as well as the functional effectiveness of the restoration process (e.g. the extent to which watershed protection is established, key ecological processes are regained or the populations of biota are able to reproduce, etc). Ecosystem integrity is promoted more by restoration than by rehabilitation.

*Reclamation: R*ecovery of productivity at a degraded site using mostly exotic tree species. Species monocultures are often used. Original biodiversity is not recovered but protective function and many of the original ecological services may be re-established. The term "reclamation" is used for situations where productivity or structure is regained but biodiversity is not.

*Rehabilitation: R*e-establishing the productivity and some, but not necessarily all, of the plant and animal species originally present. For ecological or economic reasons the new forest may include species not originally present. In time, the original forest's protective function and ecological services may be re-established. In fact, native species may not be used at all. In such cases there are few, if any, benefits to landscape biodiversity but there may be social or economical advantages or functional gains such as improved watershed protection.

Underlying reasons for global interest in restoration of degraded landscapes include: (i) dwindling forest cover and forest products; (ii) environmental problems such as climate change, loss of biodiversity, pollution, desertification, etc. associated with natural forest cover reduction and conversion to intensive land use; (iii) decreasing land productivity owing to large areas of potentially productive lands languishing in a highly degraded state due to soil and water erosion, declining soil fertility and loss of soil organic matter; (iv) decreased infiltration and water retention capacity, increased runoff and disrupted hydrological cycles (floods and water shortages); and (v) increased sediment transport and water pollution (e.g., Ayoub, 1998; Salami, 1998; Cairns, 2002; Chamshama and Nduwayezu, 2003; cited in Mulugeta Lemenih, 2004). Landscape restoration might also be undertaken to facilitate the movement of plants and animals across a landscape (Lamb and Gilmour, 2003).

Restoration can be achieved through plantation on degraded landscape. Plantations are either of introduced species or indigenous species which meet a minimum area requirement of 0.5 ha; tree crown cover of at least 10 % of the land cover; and total height of mature trees above 5 m (FAO, 2001). Forest plantations established on degraded sites long devoid of a native tree cover can act as successional catalysts, facilitating the recolonisation of native flora through their influence on understory microclimate and soil fertility, suppression of dominant grasses and provision of habitats for seed dispersing animals (Parrotta, 1995, cited in EshetuYirdaw, 2002). When this natural process is augmented by silvicultural treatments intended to enhance the invasion of native species, plantations may be gradually converted to a forest which resembles a near-by natural forest (Eshetu Yirdaw, 2002).

Restoration actions through plantation include introduction of blocks of native woody vegetation and revegetation of field boundaries and way sides, rehabilitation and construction of water spots, installation of nest boxes, rehabilitation and construction of stone mounds and walls, and propagation and plantation of singular fruit trees. These restoration actions are accompanied by a variety of social and educational values including citizen science (Benayas, 2010). Restoration in the Ethiopian highlands, apart from providing economically and socially valued forest products and services, also facilitate the restoration of floristic and faunal diversity and eventually also the productivity of degraded lands. Plantations can play an important role in restoring the productivity, ecosystem stability, and biological diversity of degraded tropical lands (Eshetu Yirdaw, 2002). In a country like Ethiopia where a rapidly growing human population is inducing overexploitation of the available productive natural resources, restoration of the vast degraded landscapes that exist in the country will have a valid and important role in harnessing sustainable development (Mulugeta Lemenih, 2004).

In Ethiopia where the economy and 85% of its 70 million populations are heavily dependent on agriculture, ensuring sustainable food and biomass supply while maintaining ecological integrity requires two imperative efforts (Mulugeta Lemenih, 2006): (i) the sustainable use of the available productive land resources; and (ii) the effective regeneration/restoration of degraded ecosystems. Compelling reasons for ecosystem restoration in Ethiopia are many. Multiple and interwoven problems are challenging socio-economic development and ecological sustainability. Acute shortage of forest products, the biodiversity crisis, environmental pollution, soil and water resources degradation and deteriorating socio-economic status of the rural areas are some of the pressing problems of the country (Mulugeta Lemenih, 2006). Furthermore, cultivation and cropping are major causes of degradation and destruction of natural ecosystems, and farmlands (Benayas, 2010). Lamb and Gilmour (2003) and Eshetu Yirdaw (2002) reported that in the absence of major human disturbance the plant succession in the highlands of Ethiopia will result in the formation of closed afromontane forests that have a higher structural complexity and species richness on degraded landscape (Figure 1).

Regeneration of native woody species under the canopies of exotic plantations in moist montane forest areas suggests that it is possible to restore degraded areas in South-Western Ethiopia using these exotic plantation stands (Eshetu Yirdaw, 2002; Bekele Lemma, 2006; Kitesa Hundera, 2010; Zenebe Mekonin, 2010). Therefore, the lack of natural forests particularly in the degraded central and northern Ethiopian highlands will be the major factor retarding the natural succession in forest restoration. Ideally, a restoration site should be contiguous with a native forest seed source (Eshetu Yirdaw, 2002; Eshetu Yirdaw and Luukkanen, 2003; Kitesa Hundera, 2010). If this is not possible, consideration should be given to the development of forest or plantation corridors, through which forest-dwelling seed dispersers might pass to the restoration site.

The effect of deforestation followed by subsequent cultivation of different intensity on soil seed banks and the future of the forest flora are little documented in Ethiopia. Such knowledge on soil seed bank dynamics is particularly crucial in ensuring the conservation of biological resources in human-influenced ecosystems and also for planning successful restoration mechanisms for degraded land in the future (Mulugeta Lemenih, 2004).

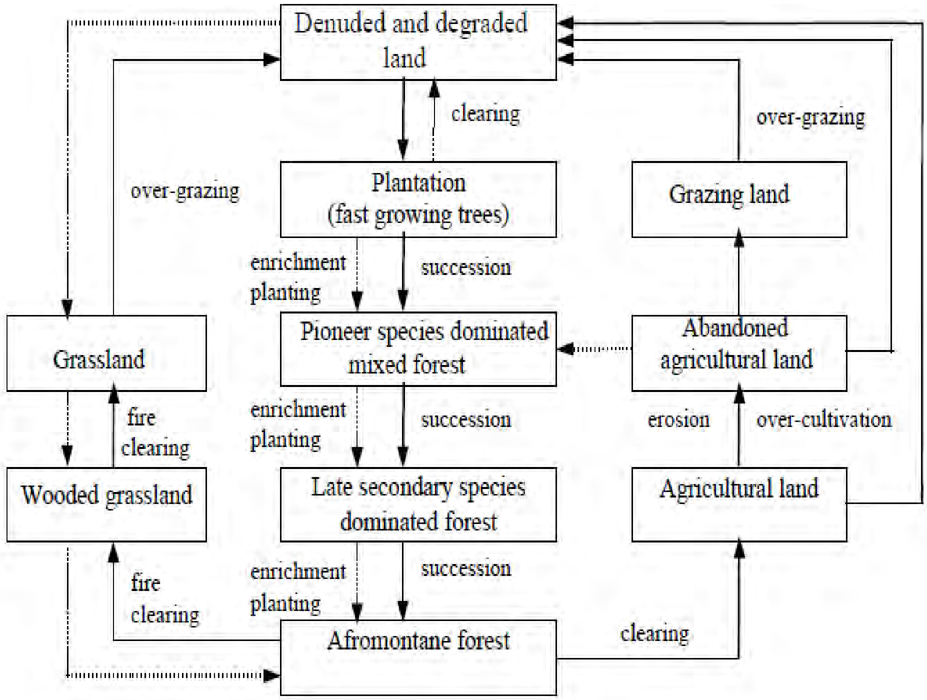

Figure 1. Schematic model of biodiveristy restoration using plantations to facilitate succession of native flora on a degraded highland site in Ethiopia. Dotted lines indicate minor relationships (Eshetu Yirdaw, 2002).

Therefore the prompt and strict protection of the scattered remnant forests existing today in the country is the very cornerstone of successful future restoration ventures, because plantation used to rapidly restore degraded lands sites and biodiversity (Sayer *et al.*, 2004; Mulugeta Lemenih, 2006). In the restoration of degraded areas, knowledge of ecological factors such as availability of seed sources, environmental factors for seed germination and seedling growth of the species under the canopies of exotic plantations is very important (Kitesa Hundera, 2010). Establishing fast growing tropical foster plantation forests can form a rapid and productive restoration strategy for rehabilitating heavily degraded lands and their native flora and fauna faster than leaving the degraded sites bare (Mulugeta Lemenih, 2006). Plantation species, after facilitating vegetation establishment and succession, usually fail to regenerate in their species-rich understory, since they are predominantly shade-intolerant pioneer species and eventually are replaced by the shade-tolerant local species. However, the lack of sufficient diaspores and highly degraded soils in Ethiopia may retard the succession process (Eshetu Yirdaw, 2002).

Lamb and Gilmour (2003) and Sayer *et al*., (2004) noted that extensive testing may be required before determining which species to use and the presence of the native species from the immediate area are clearly most considerable (Table 2). Restoration of those elements of biodiversity useful to local communities may often be a more socially viable goal than restoration of the full range of biodiversity that occurs naturally at the site. The rate at which restoration occurs depends on the extent of the existing environmental stresses. Sites with strongly seasonal climates or low soil fertility are likely to be more difficult to restore than these with favourable climates and better soil fertility (Lamb and Gilmour (2003).

Even though there are several challenges that hinder landscape restoration in Ethiopia, very few experts' shows efforts to restore of indigenous trees on degraded landscapes using scientific knowledge generated for some of these indigenous trees. In this regard, the "center for Indigenous Trees Propagation and Biodiversity Development in Ethiopia" is believed to serves as a model for future restoration efforts. Some of the planted speciesin the Center includes: *Juniperus procera, Allophylus abyssinicus, Podocarpus falcatus, Hagenia abyssinica, Prunus africana, Syzygium guineense, Cordia africana, Ekebergia,* and *Millettia ferruginea (*Appendix 1).

Encouraging farmers and small land owners to be involved in tree-growing schemes will help them generate household income. Monitoring composition, densities and the role of seed rain, soil seed banks and advance regeneration in the colonization of indigenous woody species following plantation establishment is of paramount importance. In addition, changes in the biotic and physical components of the plantation site, both temporally and spatially are gaps that need investigation in the future. Understanding of the processes that may allow us to develop plantation management for provision of urgently required goods and services, coupled with enhancement and maintenance of biodiversity, are very essential (Kitesa Hundera, 2010).

Table 2. Potential key plant species used for restoration or rehabilitation of degraded landscape

Species type	Purpose
1. Native species	1. To enhance biodiversity
2. Species attractive to frugivores	2. To encourage seed dispersal and enhance fauna biodiversity
3. Species forming mutualistic relationships with animals	3. To foster wildlife populations
4.Poorly dispersed species (species with large fruit)	4. To facilitate their colonization and to increase fauna biodiversity
5. Rare or threatened species	5. To increase their populations
6. Fast-growing species	6. To occupy site and exclude weeds; to sequester CO_2 and mitigate climate change
7. Species tolerant of poor soils	7. To facilitate rehabilitation
8. Nitrogen-fixing species	8. To improve soil fertility and soil biology
9. Economically or socially beneficial plants	9. To provide economic “goods” and services; to improve farmers lifelihoods
10. Fire tolerant trees	10. To use in fire-prone landscapes, to create new forests to form buffers around restored forests.

Source: Adapted from Lamb and Gilmour (2003) with modifications and/or some additions.

2.4. *Restoring degraded landscape with native trees*

In many degraded landscapes, the primary purpose of intervention is to provide functional benefits (such as soil and water conservation) rather than to restore biodiversity. In such cases, reforestation might target riparian strips to stabilise stream sides or target steep hillsides and areas with eroding soils (Lamb and Gilmour, 2003). Although forest loss is still a problem worldwide, estimated rates of deforestation have declined in the last decade, primarily because of an increase in the area of tree plantations. This leads to the central question of how suitable plantations are for indigenous species.

Native plantations are thought to have higher value for biodiversity than plantations of non-native trees because they may be more structurally similar to native forests, host species with particular adaptations, and maintain mutualistic interactions with other indigenous organisms; however, not all studies support this view (Pietrek and Branch, 2011). Planting exotic plants in degraded areas has now become unpopular and people are planting indigenous plants which are adapted to the environment and are suitable habitats for indigenous wildlife particularly ground cover vegetation, birds and insects which enhance the restoration of our biodiversity through healthy ecosystem functioning such as organic matter recycling, seed dispersal, pollination and disease protection (MOARD, 2010).

The Ethiopian environmental policy of 1997 has addressed the issue and it has an article which says that afforestation work with non-native or exotic species should be restricted to backyard woodlots, to peri-urban plantations for specific industrial and other projects until such time that reliable information and knowledge on exotic species are available and thus ensure its well-being. But the problem is lack of applicable strategy and limited effort to implement the policy (Getachew Tamiru, 2007). Given the thesis that native trees determine the basic structures of life on earth, it is imperative that Ethiopia strives to acquire specific knowledge on the reproductive and propagation biology of indigenous trees, as well as the physiological processes that determine their establishment on degraded landscape (Legesse Negash, 2010).

Some of the indigenous tree species such as *Millettia ferruginea*, *A. abyssinica* and *Syzgium guineense* have provided good early growth performances on extremely poor sites where that had been managed judiciously and were protected from human and animal disturbances (Figure 2). While undertaking restoration with native species, it is critical to note that the ones from the immediate area are most desirable (Figure 2; Table 2). Clearly, the preferred way to restore an area is to put back the species that make up healthy natural system (Lamb and Gilmour, 2003; Legesse Negash, 2010). Revegetation with native plants/trees brings back often rare plant communities and creates wild life habitats. Using the right plants for a particular site will also greately increase our plantating success (Getachew Tamiru, 2007).

Figure 2. Restoration of degraded landscape using *A. abyssinica* at Tulu korma the "Center for Indigenous Trees Propagation and Biodiversity Development in Ethiopia". Left-hand –side picture shows when the planting of *A. abyssinica* was undertaken over degraded and rock sites some five years ago. Right-hand-side picture shows the same site five years later. [Photographs; courtely of Prof. Legesse Negash].

Industrial monoculture plantations produce wood but do not provide a variety of non-timbers products such as fruits, gums or medicinal plants used by many rural communities. Plantations may be effective in sequestering carbon or helping restore hydrological cycles to overcome salinity, but they are not always as effective in preventing erosion on the slopes of hills above agricultural areas, protecting riparian strips or restoring soil fertility and water resources (Lamb and Gilmour, 2003).

From an environmental restoration stand point, and due to their unique usefulness to society, important native tree species should receive particular attention. However, several factors have made it difficult to use native tree species for large-scale afforestation programs. These include the lack or scarcity of information on seed biology of tropical forest trees, lack of technical skills and facilities for seed handling and treatments, incomplete knowledge about propagation biology and physiology, the influence of biotic factors such as pests and diseases on seeds and seedlings health and quality (Legesse Negash, 2002; 2010).

Although some efforts have been made towards improving some of the above factors, the problems remain in most of the cases. Thus, multifaceted efforts should be made in order to try to alleviate the problems by approaching them from different angles. Restoration of indigenous trees is much more than just planting them-it is about re-establishing (at landscape scale) the lost vital ecosystem functions that vegetation used to provide for both people and other organisms including wild life and lower forms of life (Legesse Negash, 2010). The advantages of restoration through plantation of indigenous trees includes: creates or restores habitat effectively, easily adaptability/tolerate to the environmental stresses; high timber quality and price; reconnecting the fragmented natural areas; restoring vital link in the water cycling; reducing wind and water erosion and enhancing soil fertility; reducing temperature extremes, and creating refuges for wild life (Legesse Negesh, 1995, 2010; ECEAP, 2000; Lamb and Gilmour, 2003). Native plants/trees have evolved to suite the local climate and soils. They tolerate disease and once re-established, often require little or no maintenance.

2.5. *Land restoration and soil fertility*

If the generalized quality of an ideal soil is considered, it would be discovered that any soil has a unique combination of many features. Among these are: a balanced supply of plant nutrients available to the roots from minerals and organic matter; absence of soils acidity; adequate rooting depth with good permeability for growth; capacity to store and release water to roots; optimum soil texture that provides adequate water infiltration with minimum waterlogging; structural stability such that it does not slip down the slope or cause no erosion hazard, etc (Mesfin Abebe, 2007). However, the good quality of soil is lost when native vegetations are deforested and soil degradations unleashed.

Native indigenous trees such as *Acacia abyssinica, Erythrina brucei, Croton macrostachyus, Ekebergia capensis,* and *Hagenia abyssinica* enhance soil fertility through litter, and necromass production as well as symbiotic association with nitrogen fixing bacteria (Legesse Negash, 2010). Though there have been efforts to solve problems associated with the use of indigenous trees in the reforestation activities, information on the mycorrhizal symbiosis is still lacking. Investigations of roots of 11 indigenous trees, *Albizia gummifera, Albizia schimperiana, Aningeria adolfi-friedericii, Croton machrostachyus, Ekebergia capensis, Hagenia abyssinica, Juniperus procera, Podocarpus falcatus, Prunus africana, Olea europaea L. ssp. cuspidata,* and *Syzygium guineense*, revealed arbuscular mycorrhizal colonization, that facilitate the decomposition processes (Tesfaye Wubet *et al.*, 2003*).* Soil property changes following plantation establishment on sites that were previously used for crop production and degraded landscape (Mulugeta Lemenih, 2004).

The chemical, physical and biological soil attributes determine the sustainable nutrient supply capacity of the soil for plant growth. Soil physical properties determine the capacity of the soil to provide plants with a foothold, moisture and air; and soil chemical conditions determine the capacity of the soil to provide plants with nutrition (Mulugeta Lemenih, 2004). The term sustainable soil nutrition implies that plant nutrients and the soil physical environment suitable for plant growth remain at a steady state for the long-term (Mulugeta Lemenih, 2004). One way to ensure sustainable soil nutrition is to make sure that much of the nutrients taken up by plants during growth are returned to the soil so that they can be used again by plants of the next production cycle. In this manner, a nutrient cycling is established.

2.6. Description of the study species

2.6.1. *Juniperus procera* (Hoechst.) ex.Endl.

Juniperus procera is an evergreen dioecious, more seldom monoecius and wind pollinated tree, which belongs to the family *Cupressaceae* known commercially as African pencil cedar is the largest juniper in the world (Pohjonen and Pukkala, 1992; Legesse Negash, 1995, 2002, 2010; Orwa *et al*., 2009; Seblework Belaineh, 2009*).* Several studies reported that *J. procera* originated from *J. excelesa* and are considered as sibling species (Adams, 1990; Orwa *et al*., 2009). Their divergence and continued separation has led to numerous, presumably genetically mediated, chemical differences. *J. procera* appears to have a unique common gene pool that it is maintaining in *J. excelesa*. The numerous differences in their leaf volatile oils and also few morphological changes lead to the divergence of the two species. Therefore, *J. procera* should be maintained at specific rank (Adams, 1990).

J. procera has two developmental phases, the juvenile and the adult stages. These two phases are characterized by their distinctive trunk and crown shapes. The juvenile phase has a pyramidal shape while the mature phase has a more spreading canopy shape (Legesse Negash, 2002, 2010). It can grow to 45 meter high and long–lived tree. The male cones of the tree are small, solitary, yellowish and rounded. They are borne individually and terminally on short branchlets. The female cones are berry-like, rounded and upon ripening, become fleshy and soft (Legesse Negash, 2002, 2010; Orwa *et al*., 2009). *Juniper* trees flower and give fruits throughout the year in Ethiopia without an interrupting resting stage (Achalu, 1995). They produce up to four pyramidal seeds (Legese Negash, 1995).

J. procera is commonly found in mountainous areas, on rocky ground of eastern Africa and in regions extending from Arabia to Zimbabwe. However outlying populations in Zimbabwe, the Democratic Republic of Congo and Malawi are extremely small and are thus threatened. In the Arabian Peninsula, existing populations represent small fragments of the woodlands that once existed. It is a characteristic tree of the Afromontane flora (Adams, 1990; Friis, 1992; Legesse Negash, 2002, 2010; Orwa *et al*., 2009). The tree is exotic to Australia, India, and South Africa (Orwa *et al*., 2009). This species is confined for the most part to the upper elevations and have widest distributions of any African tree, extending from the Nubian Hills in Southern Egypt all along the east African plateau west of the Nile Rift to Nyasaland. On rare occasions, it will extend down along ridges into very hot and dry country, but for the most part it prefers the cold high ridges regardless of the amount of rainfall present. It occurs throughout the central Ethiopian plateau, being absent only from the South-West, South-East and the Danakil plain (Couralet and Bakamwesiga, 2007; Legesse Negash, 2010).

The species approximate altitudinal range is between 1750 and 2500 meter above sea level (Pohjonen and Pukkala, 1992; Legesse Negash, 2002; 2010). The tree thrives on well- drained soils of tropical motane (Legesse Negash, 2002; Orwa *et al*., 2009). In the dry montane forests (at altitudes from 1500-2700 m) of Ethiopia, *J. procera* and *Olea europaea* subsp. cu*spidata* are the typicaly dominant species **(**EshetuYirdaw, 2002). In areas where *Podocarpus falcatus* is found, *J. procera* also occurs as a dominant species (Orwa *et al.*, 2009).

This species is not only the largest juniper in the world, but is also one of the two very important indigenous coniferous trees of Ethiopia the other one being *Podocarpus falcatus (*Thumb.*)* mirb (Pohjonen & Pukkala, 1992; Legesse Negash, 1995; 2002; 2010). Individual tree size of current *J. procera* population range from approximately 20 to 25 m (rarely 40 m) in length and approximately 1.5-2 m in d. b. h (Legesse Negash, 1995; 2010). According to Russ (1945, cited in Legesse Negash, 2010), the Ethiopian forest of *J. procera ,* "Tidd*"*, are unique in the country in that they tend to form pure stands, whereas all the other associations are of a mixed type. The formation of pure stands in Ethiopia promotes the efficiency of wind pollination (Legesse Negash, 1995). Clearly, *J. procera* once covered large areas of mountain forests in the country, but its populations have decreased with the deforestation that has taken place over the last century (Pohjonen and Pukkala, 1992). Human activities and natural causes leading to heavy population disturbances can affect the genetic composition of the species considerably (Demissew Sertse *et al*., 2011).

Currently much of the remaining *J. procera* trees are relic and are often found scattered as miserably lone trees or associated with *Olea europaea subsp. cuspidata*, *P. falcatus* and various *Eucalyptus* species. *J. procera* has the capacity to regenerate and effectively compete with *Eucalyptus* trees or their coppices. Also, much of *J. procera* in Ethiopia appears to have taken refuge in old Orthodox Church compounds, grave yards that surround the same or in remote and inaccessible areas the country (Legesse Negash, 2010). For instance, the Bale Mountains are the largest single area of Afroalpine habitat in Africa in which *J. procera* is the dominant species covering large areas of the region. But the forest area is decreasing as more land is cleared for agricultural expansion, and the remaining forests becoming increasingly degraded as they are harvested for construction and firewood, an important source of income for local people, despite a prohibition on cutting the trees (Nimmo, 2007). Clearly, forests in which *J. procera* are the dominant species are under increasing pressure from unsustainable utilisation and land use conversion, threatening the long term viability of the natural resource base (Nimmo, 2007). Over-exploitation of the resource presents a significant threat to the continued existence of the juniper forests (Borghesio *et al*, 2004).

2.6.1.1. *Field establishmment and performances of Juniperus procera*

J. procera thrives very well on well-drained (red) soil of tropical montane (Orwa *et al*., 2009; Legesse Negash, 2010). The tree doesn't do well in the often water logged vertisols, but can persist once established. It is sensitive to nutrient deficiency, particularly nitrogen and phosphorus. In soils where these two essential nutrient elements are deficient, seedlings growth is very slow, with their branches and branchlets bearing fewer and chlorotic needles (Legesse Negash, 2010). Successful field establishment require production of strong and good quality seedlings; follow up is needed by way of watering, hoeing and mulching. In areas with limited amount of rainfall and poor soil conditions which fail to foster speedy growth of seedlings, watering is necessary. Watering therefore, ensures better survival and growth of seedlings (Getachew Tamiru, 2007; Misrak Tesfaye, 2007; Legesse Negash, 2010).

In the face of the ongoing climate change, *J. procera* is likely to emerge as one of Ethiopia's persistent trees (Legesse Negash, 2010). For Ethiopia's to be successful in restoring its indigenous trees and biodiversity, the wrong and stifling perceptions of "slow growth", "difficult to germinate", "difficult to raise seedlings" and "difficult to establishing the in field" should first change (Legesse Negash, 2010).

2.6.1.2. *Economic and ecological importance of Juniperus procera*

The *J. procera* forests of the Afromontane areas of Ethiopia have considerable economic value at a local and national level, whilst their ecological importance is an issue of global concern (Nimmo, 2007). The tree produces timber of economic importance. Therefore, juniper is the most preferred multipurpose tree in Ethiopia for construction, furniture, firewood, joinery, fencing, flooring (strip and parquet), roofing shingles, water flumes and transmission poles and medicinal uses (Chaffey, 1982; Legessse Negash, 2002, 2010; Couralet and Bakamwesiga, 2007; Orwa *et al*., 2009). In Kenya the wood is used for making fire sticks, beehives and salt-troughs (Couralet and Bakamwesiga, 2007; Orwa *et al*., 2009). The wood is also suitable for making hardboard and particle board (Orwa *et al*., 2009).

Essential oil distilled mainly from the sawdust ('cedar wood oil', 'cedar oil') is used in the cosmetic industry in soaps and perfumes (Adams, 1990). Since *J. procera* can grow in extreme conditions, it is replanted in deforested areas for soil conservation or improvement and for erosion control, e.g. in Eritrea, Ethiopia and Kenya. It is also a useful shade tree, and is frequently planted as an ornamental tree and in windbreaks (Couralet and Bakamwesiga, 2007; Legesse Negash, 2010).

2.6.2. *Acacia abyssinica* (Hochst.) ex. Benth.

Acacia abyssinica belongs to a family Fabaceae and sub family mimosodeae. It is usually found between 1500 and 2800 m a. s. l (Asfaw Hunde and Thuli, 1989; Legesse Negash, 2010). The tree is widely distributed in most parts of the country, especially in the North –Western highlands and in the Southern parts of the South-East highlands of Ethiopia (Azene Bekele, 2001) and it is often characterized as a very good example of Afromontane endemic tree (Friis, 1992; Legesse Negash, 2010). Furthermore, woodland, wooded grassland, forest margins and along sides of streams and rivers are the main distribution area of this species (Asfaw Hunde and Thuli, 1989).

A. abyssinica is a valuable tree for ecosystem restoration of extensively degraded landscapes. It is capable of establishing itself on bare and degraded spots with its "advance-retreat growth strategy" and is uniquely resilient trees species adapted to wide ranges of soil, moisture, and temperature conditions (Legesse Negash, 2010). The tree's nitrogen fixing capacity and necromass contribution enhance soil fertility (Getachew Tamiru, 2007; Legesse Negash, 2010; Tulu Degefu *et al.*, 2011). As the tree is monoecious, loneliness has no effect on tree's seed production, but absence of cross-pollination does deprive the species of its genetic diversity. This species is characterized by the short boles developed as a result of animals browsing on young trees, humans removing young stems (thus allowing the development of coppices) as well as harsh climatic conditions such as drought killing tips of seedlings (hence removing apical dominance and creating the conditions for the development of multiple shoots during the rainy season) (Legesse Negash, 2010).

A. abyssinica is an elegant tree that can develop into large flat and wide-crowned or straight and long tree with spreading or a narrow crown. When mature the tree attains a height of over 20 m, often possessing a distinctively wide and flat top up to 30 m, with interlocking or spreading branchlets (Asfaw Hunde and Thuli, 1989; Legesse Negash, 2010). In some individuals and certain locations, the crown can be as wide as 33 m in diameter (Legesse Negash, 2010). Factors such as genetic (e.g., long branches with large numbers of pinnate leaves; large numbers of fresh pods), and environmental (e.g., wind impacting on the canopy, birds repeatedly perching on the branches, and climbers developing on the flexible branches) contribute to the flat top of the tree.

The most important challenge encountered during *A. abyssinica* seedling development in the nursery, is the fast development of taproots, penetrate the ground rapidly (Legesse Negash, 2010). But, if pruning is a must, prune seedlings before seedlings send their taproots down into the nursery bed and seedlings are very sensitive to late pruning and so quite number of them may die because of the operation.

Field establishment of seedlings is best done during the rainy season, when mortality due to transplantation shock is minimal. Strong and big seedlings have better chance of survival and grow faster they are supplied with water. *A. abyssinica* is a fast growing tree, particularly during its easily growth and development stages (Legesse Negash, 2010). This fast growth forces the young tree to assume a horizontal growth habit due to the rate of ligning synthesis is lagging behind the fast growth of the tree. Ligning is a highly branched polymer of phenylpropenoid groups, and is an integral part of plant cell wall, which constitutes trachieds, xylem fibres, and sclereids. However, as the seedling tree grows into a mature one, it develops a strong erect habit (Legesse Negash, 2010).

2.6.2.1. *Ecological importance of Acacia abyssinica*

Acacia abyssinica has many ecological uses (Million Bekele, 2001; Legesse Negash, 1995; 2010):

- It is used as a shade for people and animals
- Immature pods and young shoots are good sources of fodder for animals.
- Its thorny branches are good materials for fencing of crop fields, homestead, and for making livestock enclosures.
- Its flowers are highly visited by honey bees.
- It is one of Ethiopia's fastest growing trees suited for planting on degraded landscapes, hence highly used for conservation and improving degraded soil and landscape.
- It has the capacity for tolerating drought because of its "advance-retreat" type of growth strategy.
- The nitrogen fixing ability of the tree improves soil fertility under its canopy.
- Its umbrella shaped crown is preferred nesting place for many bird species.
- It is a good source of quality fire wood and charcoal.
- Young stems and big, well-formed branches of the mature trees can be used for poles and posts.

2.6.3. Biological nitrogen fixation systems

Nitrogen, in one form or another, accounts for about 80% of the total mineral nutrients absorbed by plants (Marschner, 1995; Grattana and Grieve, 1999*)*. Next to oxygen, carbon, and hydrogen, nitrogen is one of the most abundant essential nutrient elements in plants. It is a key constituent of the DNA, chlorophyll molecules, amino acids, proteins, vitamins and other numerous biologically active molecules. Consequently, nitrogen is one of the most critical elements upon which plants and animals depend for completing their life cycles (Legesse Negeash, 2010). In the case of plants, completion of life cycle means to have the capacity for: i) properly germinating from the seeds, growing and development; iii) flowering and producing seeds that would start the life cycle again (Marschner, 1995; Legesse Negeash, 2010).

Despite nitrogen being one of the most abundant elements on earth, nitrogen deficiency is probably the most common nutritional problem affecting plants worldwide (Thomas, 1943**)**. Nitrogen deficiency in plants leads to lack of chlorophyll molecules synthesis. A chlorotic plant (i.e., a plant that lacks chlorophyll molecules) is incapable of trapping and transforming electromagnetic radiations that comes from the sun intochemical enery (Legesse Negash, 2010).

The terrestrial input of nitrogen from biological N_2 fixation is held to be in the range of 139-170 x 10^6 total nitrogen per year as compared with 65 x 10^6 total nitrogen per year provided by fertilizer (Peoples and Craswell, 1992). The conversion of the inert N_2 molecule into combined nitrogen (NH_3, $N0^{-3}$, etc) which can be utilized as a mineral nutrient is brought about either by reduction to (NH_3) or oxidation to nitrate ($N0^{-3}$). This conversion is referred to as nitrogen fixation. In both biological and industrial conversion the reaction $N_2 \rightarrow 2NH_3$ dominates (Marschner, 1995).

Nitrogen, despite its abundance in the atmosphere (78%) is not available to plants in the form of that is suitable for metabolism until it is converted to ammonia (NH_3) or nitrate ($N0^{-3}$) or other reduced oxidized forms. This process of converting nitrogen into it's corresponding reduced or oxidized form (called mineralization) is accomplished by special partnership called symbiosis established between a group of bacteria known as rhizobia and the corresponding leguminous plants (Marschner, 1995; Grattana and Grieve, 1999*;* Camberato, 2001; Mesfin Abebe, 2007; Legesse Negeash, 2010). Biological nitrogen fixation is therefore a process by which nitrogen is reduced to NH_3. The major aims of the symbiosis between the plants and the bacteria is to complement each other in a productive ways i.e., the leguminous plant provide energy in the form of photosynthetic products (e.g., carbohydrates such as sucrose and metabolites, root exudates, plant residues.. etc) to the rhizobium while the rhizobium supplies the plant with the reduced forms of nitrogen (Marschner, 1995; Legesse Negash, 2010).

The plant uses these reduced forms of nitrogen for the synthesis of proteins and other biologically active molecules such as chlorophylls, vitamins, ATP, coenzymes. On average the relative contribution of symbiotic association and free-living bacterial nitrogen fixing systems is in the order of 70% symbiotic and 30% non–symbiotic (Peoples and Craswell, 1992). The habitat of these bacteria is the root surface and intercellular spaces of cortex cells. Leguminous plants are rarely fertilized with nitrogenous fertilizer because they contain root nodules in which the complex process of nitrogen fixation occurs (Fitter and Hay, 1987; Legesse Negash, 2010).

Marschner (1995) noted that as current knowledge permits, only prokaryotic cells namely, bacteria and cyanobacteria have the capacity to carry out biological nitrogen fixation; that is in collaboration with leguminous plants. The major nitrogen fixers includes certain free–living soil bacteria, free-living blue–green algae that are found on soil surfaces or in water, cyanobacteria that are in symbiotic association with fungi in lichens or with ferns, mosses, and liverworts, as well as rhizobial bacteria that are associated with roots of various leguminous plant species such as, *Acacias, Erytrina, Millettia*, and *Sesbenia* species. *A. abyssinica* is a good nitrogen fixer since it is associated with both Rhizobia and the Bradyrizobia group of nitrogen fixing bacteria (Legesse Negash, 2010; Tulu Degefu *et al.*, 2011). Thus, the trees are nodulated well with effective and diverse rhizobia (Tulu Degefu *et al.,* 2011). For instance, the two single genotypes (AC21a2 and AC21c2) isolated from *A. tortilis* and genospecies III subgroup from *A. Senegal* were unable to nodulate homologous host species from a different provenance suggesting, that strain specificity at provenance level may occur in Acacia species (Tulu Degefu *et al.*, 2011).

"Rhizobia" is a functional term used to designate soil bacteria that fix nitrogen (diazotrophy) after becoming established inside the root nodules of legumes. This provides nitrogen to the soil through leaf fall and root/nodule turnover, thus improving the fertility of the soil and its physical properties. Rhizobia are taxonomically diverse and have been found in many species and genera of the Alpha proteobacteria (Sawada *et al.*, 2003, cited in Tulu Degefu *et al.*, 2011).

2.7. Description of soil physical and chemical properties

2.7.1. *Available phosphorus*

Phosphorus is an important element essential for life and growth of forest vegetation. It is also present in plant tissues and in soils in smaller amounts than nitrogen and potassium (Mesfin Abebe, 2007). The amount of phosphorus in the soil is highly dependent upon the content of the soil parent material and is absorbed by most plants as the orthophosphate ion (Wenger, 1984; Marschner, 1995). The availability of inorganic phosphorus for forest vegetation largely depends on (i) soil acidity and its effects on the solubility of iron, aluminium, and manganese, which form insoluble phosphorus precipitates in acid soil; (ii) the availability of calcium, which may react with phosphorus to reduce its solubility in basic soils; and (iii) the activity of microorganisms that control the rate and amount of organic matter decomposition (Wenger, 1984; Mesfin Abebe, 2007). If acid soils are limed, aluminium and iron could be inactivated so as to increase the level of soil pH. Then, phosphate availability to plants will be increased (Mesfin Abebe, 2007).

Phosphorus is an essential mineral element that is usually found in nature combined with oxygen as phosphate. Phosphorus is a nutrient required by all organisms for the basic processes of life. Inorganic phosphorus in the form of phosphate ($PO4^{-3}$) plays a major role in biological molecules such as DNA, RNA and coenzyme, where it forms part of the structural backbone of these molecules. Living cells also utilize phosphate to transport cellular energy via adenosine triphosphate (ATP). Nearly every cellular process that uses energy gets it in the form of ATP. Phosphorous found in the plant (0.1-0.4%) or 1000-4000 ppm, plants absorb these nutrients in the form of $H_2SO_4^-$ from the acidic soil and $HPO4^{2-}$ at higher pH level soils. Phosphorous is important for plants root proper growth and for early maturity, one adaptation mechanism to escape the drought. Low nitrogen content followed by phosphorous are the next limiting factor for production (Belay, 1998).

The ecological implications of plant growth in response to available phosphorus over a range of edaphic conditions have received less attention (Rorison, 1968). Phosphorus deficiency is more difficult to diagnose than a deficiency of nitrogen or potassium. A major visual symptom is that the plants are dwarfed or stunted. Phosphorus deficient plants develop very slowly in relation to other plants growing under similar environmental conditions but without phosphorus deficiency. Phosphorus deficient plants are often mistaken for unstressed but much younger plants.

The slow rate of diffusion of phosphate in soil results in a zone of depletion of phosphate ions in solution around the roots of plants in low phosphate soils. Transfer of phosphate to the site of uptake into the root symplasm limits phosphate uptake in such soils. This transfer involves movement across the depletion zone and through the root apoplasm (Frank, 2002). Similarly to nitrogen, phosphorus is lost through plantation practices that disturb the soil and degrade the soil organi matter component because both elements depend on soil organic matter (Rosoman, 1994).

2.7.2. *Total nitrogen*

Nitrogen is an integral component of amino acids that make up the protein and enzymes in all living organisms. Nitrogen surrounds the magnesium atom in chlorophyll, which captures the sun's energy and allows sugars to be created from Co_2 and water (Camberato, 2001; Legesse Negash, 2010). The kind, form, and concentration of plant nutrients available for plant uptake strongly influence the growth of the forest vegetation. Probably the nutrient most often deficient in forest soil is nitrogen (Wenger, 1984).

Nitrogen in forest soils is mostly contained in the organic fraction and is converted by soil microorganisms to the mineral form of ammonium and nitrate available for uptake by plants. This is known as nitrogen mineralization (Wenger, 1984; Rosoman, 1994; Camberato, 2001; Mesfin Abebe, 2007). While total quantities of nitrogen in forest soils may range from less than 500 kg/ha to more than 22,000 kg/ha, rates of mineralization ranges from 0.8 % to1.4 % annually in temperature climates (Wenger, 1984).

Nutrient inputs of nitrogen to the forest ecosystem are totally dependent upon biological symbiotic and non-symbiotic atmospheric nitrogen fixation, particularly fallout, and solutes in precipitation (Wenger, 1984; Marschner, 1995). Nitrogen is probably more often deficient than any other essential element in soils. Firstly, loses due to erosion is high. Secoondly, annual burning or removal of vegetation or plant residue under the traditional system of land preparation or the use of fire to initiate new grass growth for livestock are also major contributors to the loss. Thirdly, no less important is leaching which leads to substantial losses of available nitrogen under high rainfall and highly permeable soil conditions (Rosoman, 1994; Mesfin Abebe, 2007).

Under nitrogen deficiency, the older mature leaves gradually change from their normal green appearance to a much paler green. As the deficiency progresses these older leaves become uniformly yellow (chlorotic). Leaves approach a yellowish white color under extreme deficiency whereas the young leaves at the top of the plant maintain a green but paler color and tend to become smaller in size. Branching is reduced in nitrogen deficient plants resulting in short, spindly plants. As the deficiency progresses, the older leaves also show more of a tendency to wilt under mild water stress and become senescent much earlier than usual. Lower leaves show symptoms first, since the plant will move nitrogen from older tissues to more important younger ones (Thomas, 1943).

2.7.3. *Soil physical properties*

Maintenance of physical properties is crucial to sustaining a soil. A soil’s physical condition can be the major factor limiting plant growth. Forests will generally maintain a soil’s physical properties by providing a buffer from climatic extremes, contributing to soil organic matter turnover, and aerating the soil to considerable depths through their roots (Rosoman, 1994). Soil consists of organic and inorganic materials. The organic fraction is made up of plants and animals residues in all stages of decomposition. The stable phase formed through biological degradation is termed as humus. The inorganic fraction is composed of primary and secondary minerals.

Soil texture is a physical indicator of the size ranges of particles within a soil. In fact, its components are: the sand of 2 mm, silt of 20 µ (microns) plus clay and humus of less than 2 µ effective diameter (Fernandez-Illescas *et al.*, 2001; Mesfin Abebe, 2007). It is within the inorganic and humus colloidal solid phase that the essential elements for plant growth originate. Though slow, mineral weathering and organic matter decomposition furnish nutrients to plants through the soil solution and the soil solid-liquid interface. The usual path to the plant root is from the solid phase to the surrounding liquid phase or the soil solution (Mesfin Abebe, 2007).

2.7.4. *Soil organic matter*

Soil Organic matter (SOM) raises pH and thereby causes the precipitation of some aluminium ions as aluminum hydroxide. Manure amended soils correct acidity while at the same time provide mineralized ammonium-nitrogen and nitrate-nitrogen with increased availability of other nutrients at higher pH values. This can be attributed to buffering from organic acids and bicarbonates (Mesfin Abebe, 2007). The study which is limited to the upper 0-10 cm soil layer for SOM and 0-20 cm layer for soil nutrients in Ethiopia quantify the loss of SOM and changes in other soil properties when a native forest is converted to arable land (Mulugeta Lemenih, 2004).

SOM plays a major role in soil productivity because it represents the dominant reservoir and source of major plant nutrients (*e.g.* N, P, and S). It also influences pH, cation exchange, CEC, AEC, water status and soil structure (Lal, 2003, cited in Bekele Lemma, 2006). SOM is a critical soil component: supplying most of the nutrients held in the soil, in particular nitrogen, phosphorous and many trace elements; aiding the release of nutrients from mineral sources through the action of acidic compounds; maintenance of soil structure; maintaining moisture-holding capacity; maintaining aeration and soil porosity; heat absorption, and deactivation of chemicals and heavy metals (Rosoman, 1994). With standard planting regimes peak above ground SOM production occurred at ages 5–7 years when canopy closure is reached, followed by a peak in litter breakdown on the forest floor at ages 7–9 (Rosoman, 1994).

2.7.5. *Cation exchangable capacity*

Cation exchange capacity (CEC) is the quantity of exchangeable cations that are necessary to neutralize the negative charge of unit quantity of soil under a given set of conditions. The, cation exchange that retains ions against loss is the reversible process by which positive ions or exchangeable cations are exchanged between the negatively charged solid and the liquid phase of soils. Thus presence of CEC is paramount important for the nutrients not to be lost through leaching since retained and become available to plants (Mesfin Abebe, 2007).

Interaction and exchange of ions between the solid and liquid phase take place continuously. Ions are continuously removed by plants roots from the soil solution, from an assortment of minerals and inorganic compounds, and those released from the decomposition of soil organic matter. Simultaneously, other ions renew this solution through the slow breakdown of minerals as well as ion exchange and from the decomposition of organic matter. Another phenomenon is that if two solid phases are in contact, ion exchange may take place between their surfaces through what is known as contact exchange (Rosoman, 1994, Mesfin Abebe, 2007). Potassium (K), calcium (Ca) and magnesium (Mg) are major macronutrients for plant growth. They are largely supplied by soil parent material weathering (Rosoman, 1994).

2.7.6. *Soil pH*

In an ideal solution, pH is related to hydrogen-ion concentration in a straight forward manner. Soil is said to be acid when the activity of the hydrogen ions exceeds that of the hydroxyl ions. Mostly, soil acidity is associated with the presence of hydrogen and aluminum ions in exchangeable form (Troer and Thompson, 1993; Tan, 1996; Mesfin

Abebe, 2007). The transfer of nutrients to the plant roots occurs either by mass flow or diffusion or contact exchange. In this soil-plant interrelationship process, nutrient absorption and accumulation by plants requires the transfer of the nutrient ions across the interfaces of soil and root into the cellular structure of the plant (Mesfin Abebe, 2007).

The surfaces of roots, like soils, carry negative charges and exhibit cation exchange properties. Roots also vary in their ‘feeding power’ or their capacity to absorb nutrients. The presence of younger tissue with the capability for growth and elongation, the extensiveness of the root system, and the volume of soil they trap do matter. All plant growth occurs through the net uptake of negatively charged ions leaving more positive ions such as hydrogen and aluminium in the soil. This process could be viewed as acidifying (lowering the pH).

The acidifying effect will be exacerbated by removal of the stored negatively charged ions (anions), such as through wood storage in trees and subsequent harvesting, livestock and crop production, or leaching (Tan, 1996; Mesfin Abebe, 2007). However, in a forest situation: a tree dies and decomposes, the cations are returned to the soil counteracting the acidifying effect. Rainfall is a key factor, where a higher rainfall increases cation leaching and subsequent soil acidification (Rosoman, 1994).

It is generally considered that acidification is of critical concern to sustaining soil fertility – a lower pH reduces the availability of many key nutrients such as P, Ca, Mg, N and boron, but may increase the weathering of parent material and mineral rock within the soil. A significant negative effect of acidification of soils is the release of toxic aluminium (and also hydrogen and manganese) compounds into the soil solution, subsequently inhibiting root growth, and Mg, Ca and K uptake (Rosoman, 1994).

Chapter Three

3. Materials and Methods

3.1. *Description of the study area*

The study was conducted at Tulu Korma within the "Center for Indigenous Trees Propagation and Biodiversity Development in Ethiopia". The center was founded on 10 July 2004 and is located on the high way to the Ambo town, 52 km South West of Addis Ababa and 4 km past the town of Addis Alem (Ejera Woreda West Shewa Zone, Oromiya Regional State; 9^0 01`25``N latitude, $38^0$ 21`46``E longitude) (Figure 3). The site is located within midland agro-climatic zone, average altitude of 2166 m. a. s. l. It has a gentle slope gradient with average slope of 10-15% (Getachew Tamiru, 2007).

According to the National Metrological Service Agency of Ethiopia, five years data, the site had annual rain fall of averages 1140 mm, most falling between May to October with peaks in July and August, and mean annual minimum and maximum temperature are 7^o C and 26^o C respectively (Figure 4). The highest rainfall was recorded in the year 2010, where the annual rainfall was 1367.8 mm, much higher than the average.

The area receives annual rainfall in two short seasons: short rains *(Belig)* from February to May and long rains (*Meher)* from mid-June to mid –September. The short rains are mainly used only to break and prepare the soils for crop cultivation. The pattern of rainfall dictates the single cropping period, starting in March and ending in December. The soil type is dominated by clay in texture and dark brown in color i.e.vertisol which is characterized by high clay content; swell when moist, then dry and cracks. Before the establishment of the center in 2004 by prof. Legesse Negash, the site was partly covered with *Eucalyptus* plantation and was a highly degraded farm and grazing land. The site is confined within an area of 60 hectares and the grazing land was highly degraded and affected by erosion (Legesse Negash, personal communication).

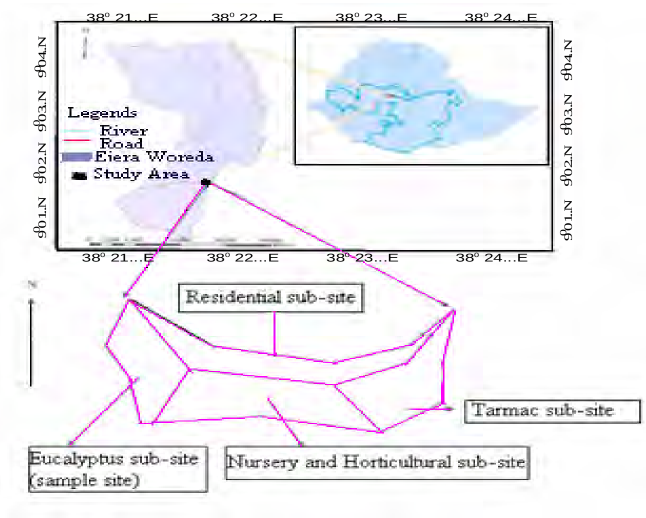

Figure 3. Map of Ejera Woreda and the study area at the “Center for Indigenous Trees Propagation and Biodiversity Development in Ethiopia”.

In addition, the site was affected by excavation and Tarmac dumping as a consequence of the highway construction that leads to Western Ethiopia. The Tarmac sub-site for instance, was later removed by Chinese road Construction Company as a result of the relentless pressure exerted by the Center. The natural forest is almost totally removed by human interference and now few scattered trees remained. The few remnant natural tree species in the area are *Acacia abyssinica, Juniperus procera, Podocarpus falcatus, Croton macrostachyus, and Olea europaea L. subsp. cuspidata*. Some of the shrub species are *Maytenus* spp., *Carissa spinarum*, and *Myrsine africana*. Grasses such as *Cynodon dactylon* and *Digitaria spp*. are inhabitants of the area (Appendix 1). Recently, there are two additional *Acacia* species namely, *Acacia seyal* and *Faidherbia albida.*

The Center is classified into nine sub-site categories namely, Highway sub-site, Nursery and Horticulture sub-site, Teff sub-site, *Podocarpus* sub-site, *Prunus* sub-site, Tarmac sub-site, *Eucalyptus* sub-site, Millennium sub-site and Residential area (Figure 3). Of these sub-sites based on the previous land uses and preliminary visual assessments on the growth performance of *J. procera* and distribution of *A. abyssinica*, the researcher identified and categorized the areas designed for this study into two cluster study sub-sites namely, *A. abyssinica*- influenced, non– *A. abyssinica*- influenced cluster sub-sites. This site was selected because the restoration of the threatened *J. procera* at the site was started and relatively well protected and documented.

After the planting of more than ten most important indigenous trees on 10 July 2004, the Center had been almost protected from any human and animal interference and management practices like weeding, cultivation and watering at pick of drought periods have been carried out (Legesse Negash, personal communication). Nevertheless, impact from local people such as collecting litter, fuel wood, farm materials and grazing their cattle in the Center has remained a formidable challenge. At the beginning of the study, the area was completely bare, but today these planted beautiful young trees have set the stage for co_2 sequestration, soil and water regeneration, as well as biodiversity development (Legesse Negash, 2010). Recently, the Center serves as a home for many wild animals, including Gazelles, Warthogs, Wildcats, insects and birds, as well as a variety of tree species including the recently planted indigenous trees. Therefore, the center's objectives are to fight against biodiversity loss at genetic, species, and ecosystem levels, and to increase the capacity to provide timely, innovative and practical solutions to the challenges of conservation and watershed restoration.

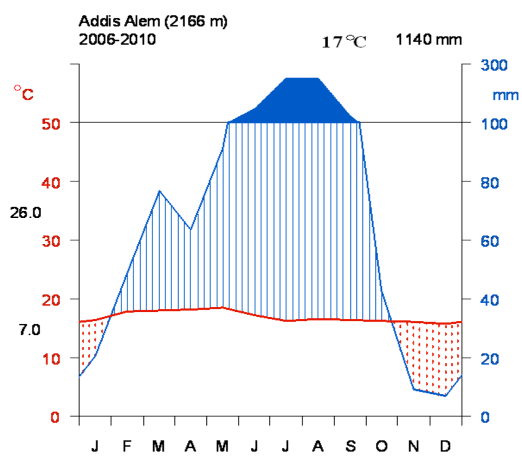

Figure 4. Klimadiagram showing the mean monthly rainfall (mm) and mean minimum and mean maximum temperature (0C) of the study area, during five different years. [Source: National Metrological Service Agency, Addis Ababa, Ethiopia (2006-2010].

3.2. *The study species*

The data collection was conducted on seven- year- old *J. procera* planted in mix with other trees in the study area. The major tree species planted in the Center were, *Podocarpus falcatus*, *Juniperus procera, Hagenia abyssinica, Millettia ferrugenea, Syzigium guineense, Acacia abyssinica, Ekebergia capensis, Prunus africana, Ficus vasta, Cordia africana, Croton macrostachyus, Olea europaea L. subsp. cuspidata, Vernonea amygdalina* (Appendix 1). However, except for *J. procera* and *A. abyssinica*, other planted indigenous tree species as well as the human and animal disturbed *J. procera* young tree were not included in this study. The subjects of the present study were, therefore, *J. procera* and *A. abyssinica* (Figure 5*).*

Figure 5. The studied tree species in the study area, in a period of seven years, after restoration at the Center for "Indigenous Tree Propagation and Biodiversity Development in Ethiopia". [Photo taken at 2 m distance, 28 /11 /2011].

3.3. *Sampling techniques*

Both tree data i.e, tree height, d. b. h, mean crown diameter (average of two perpendicular diameters), crown depth/length, branch length and numbers of braches of the entire sampled young tree and soil samples were collected from the two cluster sub-sites namely, *A. abyssinica* influenced and non–influenced sub-sites which are found in *Eucalyptus* sub-sites using a stratified sampling techniques. The stratification was based on observations of the study site such as growth performance differences of the planted *J.*

procera young trees, the presence or absence of *A. abyssinica*, slope and soil conditions. To avoid the edge effects, sampling plots was established at least 10 m far from the boundary of the sub- site. For tree data collection, different sampling intensity was used based on slope differences and area of interests. Sampling plots were selected from 30 m x 7 m and 40 m x 40 m area; along the systematically laid transect line (Figures 6 & 7). Systematic plot sampling was selected because of the need to ensure that sufficient representative samples from all the two study sub-sites were included (Eshetu Yirdaw and Luukkanen, 2003; Popescu *et al.*, 2003).

The initial plot in all stands sampled was selected randomly. Accordingly, a total of 24 sampling plots i.e., 12 from *A. abyssinica* influenced and 12 from non- influenced cluster sub-sites were constructed, inside each sample plot, the growth parameter, viz. height, d.b.h, crown length, crown diameter, branch numbers, branch length and status of soil physicochemical properties and establishment of stecklings of *J. procera* in all the two study cluster sub- sites was recorded and examined. There are about 172 sampled trees from the two study cluster sub-sites.

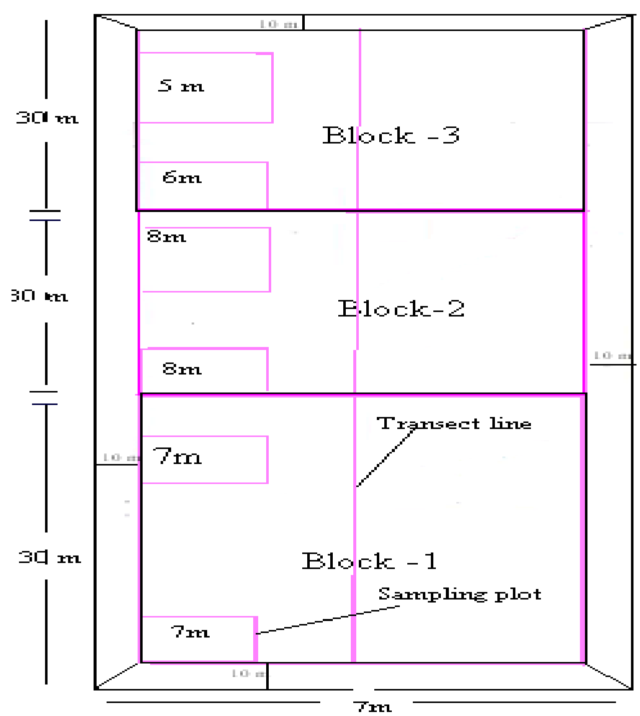

Figure 6. Layout of study area showing the location of sampling plots used for tree data collection in *A. abyssinica*- influenced experimental sub-site.

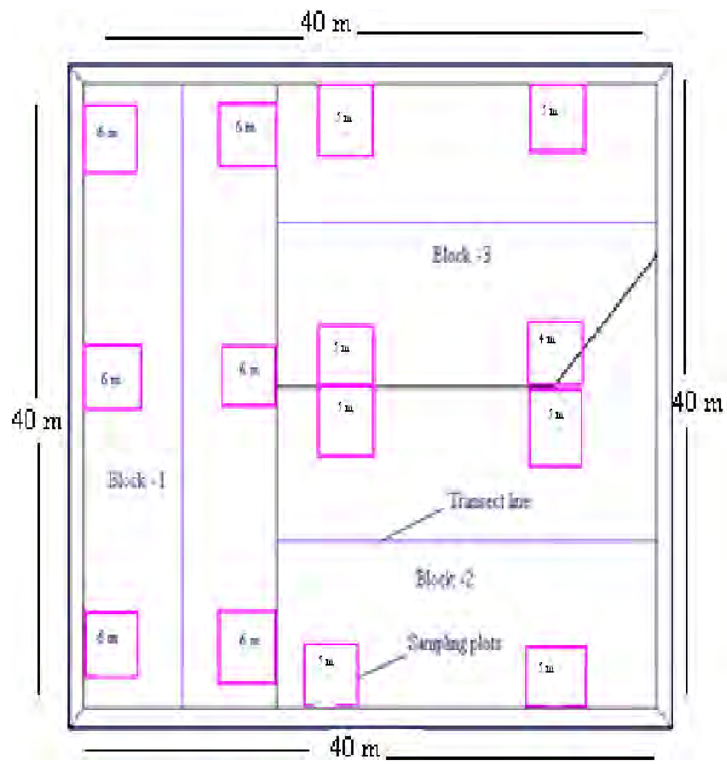

Figure 7. Layout of study area showing the location of sampling plots used for tree data collection in non- *A. abyssinica*- influenced experimental sub-site area.

3.3.1. *Data collection*

In all study plots, tree height, d.b.h, mean crown diameter (average of two perpendicular diameters), crown depth/length, branch lengh and numbers of branches of the entire sampled young tree were recorded and evaluated. Relevant notes on soil types, soil texture, soil color, and soil modification indicators, level of weeding, restoration, cultivation, and establishment and management conditions of the site were considered. The main techniques for the measurements of the growth status of the study tree were the following:

Tree height

All trees found in the sampling plots were measured from the base of the tree to the tip of the leading shoot with the help of either leader or graduate stick made for this purpose (Getachew Tamiru, 2007). "The total tree height is the perpendicular distance from the tip of the tree"(Shrivastava, 1997). Height of trees and shrubs greater or equal to 2 m was measured using hypsometer for taller trees and shrubs and measured pole marked at 0.5 m intervals and 4 m long (Tuxill and Nabhan, 2001). The height of sample tree was measured using measuring tape and graduate stick when the tree had a height of bigger than the height of the data collector. The height of the tallest tree was measured using a telescopic pole (up to 16 m) or with a range finder for trees 416 m (Alemayehu Wassie *et al.*, 2010). But for this study, measuring tape and graduate stick were employed well.

Diameter at breast height (DBH)

Diameter is the width of a circle or cylinder; in this case the stem of the tree. Tree stems have taper (they are slightly cone-shaped), such that they are wider at the base and narrower further up. Thus, diameter will vary based on how high up on the stem of the tree we measured. A standardized height for measuring tree diameter has been established. This is known as diameter at breast height, which is defined as 4.5 feet (1.3 m) above the ground level (Martin, 1995; Tuxill and Nabhan, 2001; Asner *et al.*, 2002; Eshetu Yirdaw and Luukkanen, 2003; Popescu *et al.*, 2003; Macki and Matthews, 2006; Abate Zewdie, 2007; Alemayehu Wassie *et al.*, 2010; Arzai and Aliyu, 2010).

To determine the diameter of a tree, measuring the circumference of the tree at 4.5 feet above the ground by tightly wrapping a tape around the tree main trunk and dividing the circumference by pi (3.14) gives the diameter i.e., d.b.h =circumference/π (Metcalf, 1959; Wenger, 1984; Arzai and Aliyu, 2010; Dinkissa Beche, 2011).

There are two ways to measure d.b.h. The most accurate way is to use a special measuring tape known as a diameter tape. Second, in the absence of diameter tape, regular cloths measuring tape is used (Wenger, 1984; White, 1998; Macki and Matthews, 2006; Dinkissa Beche, 2011). The two most common instruments used to measure diameter are a girthing (or diameter) tape and callipers **(**Wenger, 1984; Kalliovirta and Tokola, 2005). To measure diameter, wrap the diameter tape around the tree at breast height, making sure the tape is level and not twisted. The diameter measurement is read where the tape overlaps with the zero marker.

Crown length

Tree crown depth or length is a distance from the lower branch to the tip of the tree or crown (Schreuder *et al.*, 1993; Brack, 1999, cited in Getachew Tamiru, 2007). Crown depth was estimated as the difference in tree height from the top to bottom of crown (Asner *et al*., 2002). Based on this definition, the crown depth of all trees in the sample plots was measured using measuring tape and graduated stick made for this purpose.

Crown diameter

Measurements of tree crown diameter, area, or depth are notoriously difficult to acquire, especially in tall, humid tropical forests (Asner *et al.*, 2002). As with tree stems, crown diameter is an ill-defined characteristic due to lack of circularity. The crown diameter is the average of two values measured along two perpendicular directions from the location of the tree top using canopy height model (CHM) for forest trees (Popescu *et al*., 2003). It is measured directly by projecting the edges of two opposite sides of the crown vertically to ground, making them on the ground, and measuring the horizontal distance between them using a linear tape (Schreuder *et al*., 1993).

Each tree was viewed from all sides to determine the side where the canopy was widest. Two range poles were then erected to mark the extreme edges of the canopy. The distance between the two perpendicular poles was measured with a measuring tape, recorded and averaged as the canopy width (in meters) (Arzai and Aliyu, 2010). The study also intended to evaluate branch number differences between the two sites. The primary live branches of each sample trees arising from the main stem were counted and recorded (Schreuder *et al.*, 1993). Branch length was also measured using measuring tape at 40-50 cm above the ground.

3.3.2. *Voucher plant specimen collection and identification*

A plant specimen was collected, numbered, dried and placed in a reference collection following standard Herbarium procedures (Bridson and Forman, 1992). Specimens were collected within the designed plots along the transect line and whenever new species is faced. The specimens were then identified by comparing them with already identified specimens in the National Herbarium of Ethiopia (ETH) at Addis Ababa University, College of Natural and Compititional science Faculty and by referring to the Flora of Ethiopia and Eretria, vol.1-8 (Annex 1).

3.4. *Soil sampling and soil property analysis*

Composite soil sampling method was used in soil sample collection. Systematic sampling was also employed to collect soil samples. However, the soil sampling was based on the "W" pattern form of sampling using Auger and Trowel. Three to five centimeter thick cores of soil samples from each pit at two depth cores were dug (Binkley *et al*. 2004), and taken at the middle and each tip of "W" from the two sub-sites.

Composite sample from 0-15 cm and 15-30 cm soil depth were collected separately following (Binkley *et al.*, 2004; Mekonin Kindu *et al*., 2006). These samples collected from the two sub- site plots were mixed separately. A total of 12 composite samples from all sub-sites and the two soil depths were prepared for soil physicochemical property analysis.

Soil samples for chemical analysis were passed through a 2 mm soil sieve after drying. Soil organic carbon content was determined following the Walkley and Black method (Walkley and Black, 1934). Total nitrogen was determined using the Kjeldahl digestion method (Bremner and Mulvaney, 1982). The available phosphorus was determined by sodium bicarbonate extraction following (Olsen *et al*., 1954) procedures. Soil pH was estimated by potentiometrically in a supernatant suspension of 1:2.5, soil: liquid ratio and the liquid were water and 1M KCl solution. CEC was estimated by ammonium acetae (1 N NH4OAc) extraction whereas electric conductivity was measured following conductometric analysis method using conductive meter. The soil samples were analysed at Jije Analytical Service Laboratory (JASL), Addis Abeba, Ethiopia.

3.5. *Data analysis*

All the data collected were subjected to analyses of variance (ANOVA) test (SPSS, Statistical package and version 17.0). Multiple comparisons of means were carried out using Tukey's Honestiy Significant Difference (THSD) test to detect significance differences. Means differences were considered significant at $p < 0.05$. Paired samples-T-test was employed. The results were presented in figures, graphs and table forms. In addition, descriptive statistics such as percentage, standard error, Pearson correlation coefficient test (r^2) and standard deviation were used to present the results.

Chapter Four

4. Results and Discussion

4.1. *Comparison of growth parameters*

The collected and identified specimen of plant taxa, such as trees, shrubs, and herbs of the study area are presented in (Appendix 1). For each of the tree growth parameters sampled, the means, standard deviation and standard error were computed and the results are given in (Appendixes 2 and 3). The results of the correlation analysis for all growth parameters relationships are summarized in Table 3.

Table 3. Correlation coefficient (r^2) analysis results, showing correlations, among different tree growth parameters in *A. abyssinica* influenced and non- *A. abyssinica* influenced study sub-sites.

	Height	D.B.H	Crown length	Crown diameter	Branch number	Branch length
Height	1					
D.B.H	.893**	1				
Crown length	.926**	.876**	1			
Crown diameter	.871**	.797**	.834**	1		
Branch number	.816**	.897**	.831**	.789**	1	
Branch length	.830**	.891**	.821**	.704**	.742**	1

**, * = Correlation is significant at the 0.01 and 0.05 level respectively. Where, D.B.H= Diameter at breast height.

4.1.1. *Tree height*

Mean height growth differences between the two sub-sites were significant ($p < 0.05$) (Figure 9; Appendixes 2 & 3). The mean height growth differences in *A. abyssinica*-influenced sub-site were higher than the corresponding growth in non- *A. abyssinica*-influenced sub-sites (Figure 9; Appendx 6 (a & b). Better height growth performances of *J. procera* in *A. abyssinica*- influenced site could be attributed to the presence of nitrogen fixing *A. abyssinica* with high necromass production, low evapotranspiration, better moisture conditions and hence better minineralization and uptake of nutrients by plants. Tree height growth is correlated with the amount of total nitrogen, organic matter, and other favourable soil physical and chemical properties (Getachew Tamiru, 2007). As a tree increases in height, it's metabolic and growth requirements would increase too (Arzai and Aliyu, 2010). Increasing in height of *J. procera* in *A. abyssinica*- influenced site represents good reproduction status and regeneration potential of native trees in the presence of *A. abyssinica* in the study area (Figures 8, 9 & 10). This agrees with the work of (Dinkissa Benti, 2011) at Menagesha suba forest which reported that *J. procera* with much higher height than the remaining trees of his study area.

A. abyssinica influenced area *J. procera (a)* Non- *A. abyssinica* influenced area *J. procera (b)*

Figure 8. *Juniperus procera* young tree growth difference across the two study cluster sub-sites of the study area after seven years of restoration at the "Center for Indigenous Trees Propagation and Biodiversity Development in Ethiopia". [Photo taken at 2 m distance, 28 /11 /2011].

In contrast, the non- *A. abyssinica*- influenced sub-site had the lowest height growth, compared to *A. abyssinica*- influenced sub-site (Figures 8 & 9). The seedlings of *Juniperus* grew better in the forest interior/ closed canopy than outside of the forest, whereas seedlings of *Ekebergia* and *Prunus* exhibited better growth in the outer forest edge (Alemayehu Wassie *et al.*, 2009). *Juniperus* had the highest survival in the outer forest edge and the lowest in the inner edge. This agrees with the high light requirements of this species (Legesse Negash, 2002; 2010), but also suggests that this species suffers from drought in the open field (Alemayehu Wassie *et al.*, 2009). Therefore, the slow growth in the open field is probably due to water stress during the dry season (Alemayehu Wassie *et al.*, 2009).

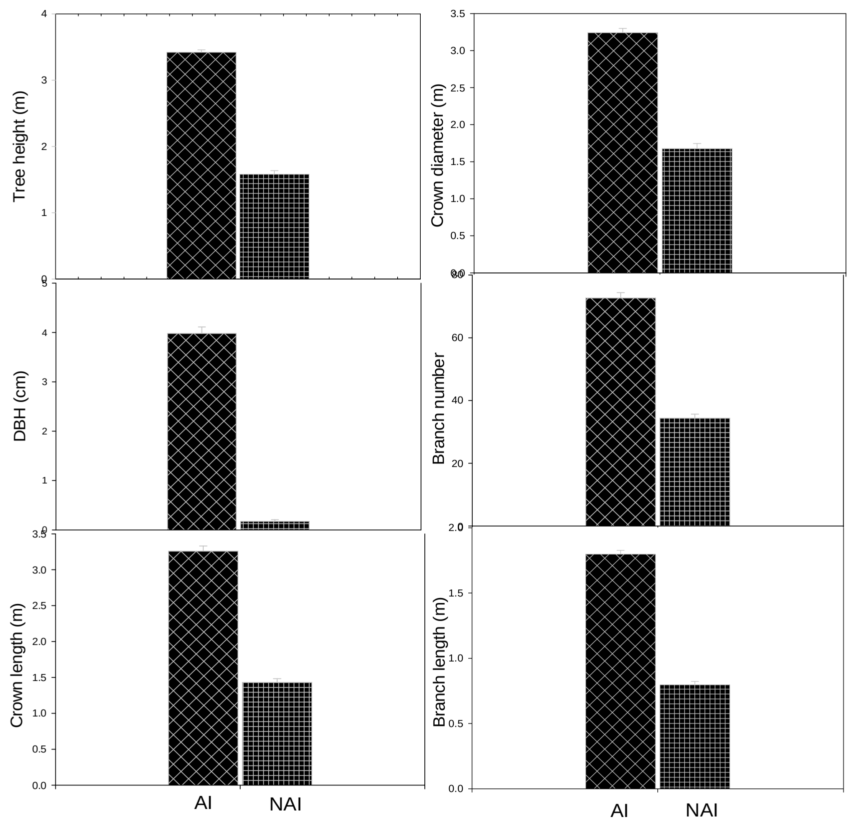

Figure 9. Mean (±SE) growth parameters of *J. procera* young tree between the two study sub-sites of the study area seven years after planting the seedlings.Where, AI= *A. abyssinica*- influenced, and NAI= Non-*A. abyssinica*- influenced cluster sub-sites.

The relationship between tree height and d. b. h appeared to be a linear one (Arzai and Aliyu, 2010). The present study result showed that the relationship between crown width and tree height is likewise linear in the two sub-sites (Table 3). In other words, taller trees have crown diameter (Arzai and Aliyu, 2010). Table 3 also indicated the strong relationship of crown length, crown diameter, d.b.h, branch number and branch length with tree height ($P < 0.05$, $r^2 = 0.926$, $r^2 = 0.871$, $r^2 = 0.893$, and $r^2 = 0.816$, $r^2 = 0.830$)

respectively. Attaining higher height is an adaptation to plants to escape from animal disturbance and to tolerate environmental stresses such as compitition for light with other trees, and water scarcity. Height differences across the sub-sites also indicate the availability of nutrient to the growing plants and suitable conditions for growth of this specific study sub-site.

4.1.2. *Diameter at breast height (DBH)*

The present study result revealed that *A. abyssinica*- influenced sub-site has higher d. b. h than the corresponding non- *A. abyssinica*- influenced sub-site (Figure 9; Appendix 6 (a & b). The statistical analysis out put showed that the mean diameter differences between the two sites were significant ($p < 0.05$; Appendixes 2 & 3). The mean diameter in *A. abyssinica* influenced site was higher than open land field (Figure 9). The lower growth performance of *J. procera* in open land might be associated with the unavailability of nutrient to the plant (K. Habtegebrial and Singh, 2006) and either the presence or absence of *A. abyssinica* (Figure 10).

A prefect linear relationship was observed between height, crown lengh, crown diameter, branch number, branch length and d. b. h for *A. abyssinica* influenced and non- *A. abyssinica*- influenced sites ($P < 0.05$, $r^2 = 0.893$, $r^2 = 0.876$, $r^2 = 0.797$, & $r^2 =0.897$, $r^2 = 0.891$) respectively (Table 3). This relation was found to be independent of age, but differed slightly between tree species (Kalliovirta and Tokola, 2005). There is a strong relationship between tree stem diameter, tree height and crown diameter (Kalliovirta and Tokola, 2005). That is, trees with larger trunks have wider canopies. This relationship is of adaptive significance to the trees because canopy size also contributes immensely to a trees total weight (Arzai and Aliyu, 2010). Thus, huge diameter can enable trees support wide canopies. Further, Arzai and Aliyu (2010) also noted that the presence of large diameter/trunk is required to buttress its height while too small diameter/trunk is incapable to perform the same function.

In *Adansonia digitata* for instance, tapering trunk/diameter is known, to give support, water storage and resistance to desiccation functions (Arzai and Aliyu, 2010). Diameter is used in estimating the amount of timber volume in a single tree or stand of trees utilising the allometric correlation between stem diameter, tree height and timber volume (Mackie, 2006). It can also be used in the estimation of the age of veteran trees, given that diameter increment is the only, "constant non-reversible feature of tree growth" (White, 1998).

In contrast, to the *A. abyssinica*- influenced site, the d. b. h were measured for few open land *J. procera*, because, most of *J. procera* young trees in this open land area were below the standard requerment of d.b.h or 1.3 m above the ground. The result clearly showed the potential contribution of *A. abyssinica* towards growth and restoration of this threatened tree species on degraded landscape by facilitating field establishment and growth requirements.

4.1.3. *Crown length*

The mean crown length growth of *J. procera* in *A. abyssinica*- influenced site was significantly different ($p < 0.05$) from their corresponding crown length growth in non- *A. abyssinica*- influenced site (Figure 9; Appedixes 2 & 3). The mean crown length growth in *A. abyssinica*- influenced site was relatively very high than their corresponding crown length growth in the open land site (Figure 9; Appendix 6 (a & b). The study result revealed that the mean crown length increased with increasing tree height and d. b. h. This result agrees with Getachew Tamiru (2007) finding, tree crown length and crown diameter increased with increasing the tree height and root collar diameter.

The present study correlation test showed that the crown length was highly correlated with tree height growth (r^2 =0.926), crown diameter (r^2 =0.834), branch number (r^2 = 0.831), branch length (r^2 = 0.821) and d. b. h (r^2 =0.876) (Table 3). The green crown percentages, crown length ratio expressed as percentage of the all tree studied in the two sub-sites of the study area were 96.4% in *A. abyssinica* influenced and 79.7% in open land sites. The increase in crown length growth with the increasing tree height might have assumed a good cover that improves moisture conservation, rain drop interception and improvement of microclimate of the area. The distribution of *A. abyssinica* (44.8 % in *A. abyssinica* –influenced and 18.5 % in non- *A. abyssinica*- influenced) sub-site, clearly create growth and site condition differences (Figure 10). The result of crown length growth evaluation strengthened the better growth performances of *J. procera* in *A. abyssinica* –influenced area than open land area.

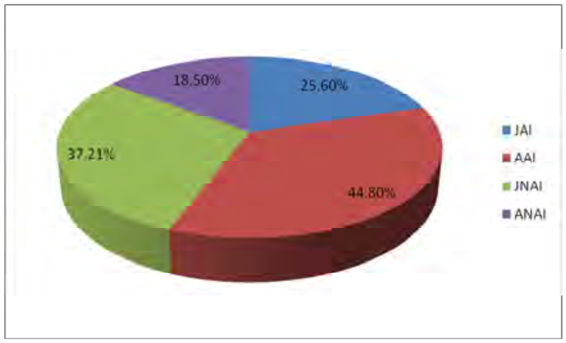

Figure 10. Distribution of *J. procera* and *A. abyssinica* in *A. abyssinica*- influenced and open land sites. Where, JAI= *J. procera* in *A. abyssinica*-influenced, AAI= *A. abyssinica in A. abyssinica* -influenced, JNAI= *J. procera* in Non- *A. abyssinica*-influenced, ANAI= *A. abyssinica* in *A. abyssinica*-influenced sub-sites.

4.1.4. *Crown diameter*

In the study, similar to other growth parameters, the mean crown diameter growth of *J. procera* in *A. abyssinica*- influenced site was significantly different ($p < 0.05$) from their corresponding mean crown diameter growth in open land site (Figure 9; Appendixes 2 & 3). The mean crown diameter in *A. abyssinica*- influence site, were much higher than open land site (Figure 9; Appendix 6 (a & b). The same area study result indicated that *A. abyssinica*, *M. ferruginea* and *J. procera* had better crown diameter growth which indicates that these tree species had a capacity to create early good vegetation cover for bare landscape restoration (Getachew Tamiru, 2007). Higher Canopy height, tree density and cover of trees can be considered an axis of increasing forest density (Borghesio *et al.*, 2004).

The mean crown diameter increased with the increase in growth of other tree growth dimensions, viz. tree height, crown length, branch numbers and branch length. The result showed the better crown diameter and height growth performance of the tree in *A. abyssinica*- influenced site. The reason is similar to reasons given for better height growth performances, since growth of trees crown diameter is highly correlated with tree height growth. The correlation between tree height and mean crown diameter of the two sites was statistically tested, and the test result showed that the growth of mean crown diameter was highly correlated (r^2 =0.871) with the growth of tree height (Table 3) whereas other study carried out by Getachew Tamiru (2007) found that correlation between tree height and crown diameter was (r^2=0.715). Tree crown diameter also strongly correlated with branch number (r^2=0.789), branch length (r^2=0.704), d. b. h (r^2=0.789) and crown length (r^2=0.834) (Table 3).

A weak correlation was found in the open land area, due to poor growth performance of this valuable indigenous tree. This revealed that in all tree growth parameters so far considered in this study, the growth of *J. procera* in the open land was significantly lower than their corresponding growth in *A. abyssinica*- influenced site (Figure 9). Similar to other growth parameters, the reason for the mean crown diameter growth differences between the two sites could be due to either the presence or absence of *A. abyssinica* (Figure 10), nutrient availability, moisture and evapotraspiration differences. Trees in nutrient-rich site and favourable condition have greater crown diameter than open land. Crown diameter varies with tree species, tree height, the availability of light, site factors and stand density or competition between trees which tends to reduce the size of the live crown **(**Kalliovirta and Tokola, 2005).

Accordingly, the growth of *J. procera* provided higher crown diameter growth in *A. abyssinica*- influenced site given good moisture, enhanced decomposition, low transpiration and higher nutrient uptake. Study carried out in Nigeria revealed that as trees have evolved wide crown diameter, there is maximize light interception and thus increase their photosynthetic rate (Arzai and Aliyu, 2010). Moreover, competition for light is important, especially in groups of trees. To tackle this problem, trees with wide crown diameters have probably evolved high postures. Thus, the linearity of the canopy versus height relationship is possibly an adaptation favoured by natural selection (Arzai and Aliyu, 2010).

The crown structure in plantations affected the quantity and quality of the light reaching the forest floor. Although there was a significant decrease in red and far red light under the canopies of all the plantations, the reduction was considerably higher under *J. procera* and *C. lusitanica* (Eshetu Yirdaw, 2002). As a result of the canopy structure of *C. lusitanica* and *J. procera* plantations the proportion of photosynthetically active radiation reaching the forest floor is low (Eshetu yirdaw, 2002).

Estimates of crown diameter are used for several purposes, namely used to derive one measure of stand density called the crown competition factor, which is potentially useful in growth and yield studies because it is independent of age (Schreuder *et al.,* 1993*).* Crown structural data could be used to improve timber harvest plans by aiding in tree selection and by excluding damaged trees (Asner *et al*., 2002). The above mentioned factors clearly indicate growth variation across the two sites and the contribution of *A. abyssinica* for restoration of endangered tree and landscape.

4.1.5. *Branch Number*

Like all other tree growth parameters, the mean number of branches of *J. procera* in *A. abyssinica*-influenced site was significantly different ($p < 0.05$) from their corresponding number of branches in open land site (Figure 9; Appendixes 2 & 3). The statistical analysis result revealed significant branch number difference across the two sub-sites (Appendix 3). The lowest branch number was counted in open land field which indicates stunted growth and less branching of *J. procera* (Figure 8 (b).

The number of branches was correlated with their corresponding mean crown diameter growth (r^2 =0.789). This result agreed with the study carried out at Tulu korma, the mean number of branches and mean crown diameter was highly correlated (r^2 = 0.65 to 0.86) for *J. procera* (Getachew Tamiru, 2007). The linear relationship also observed between tree height (r^2 =0.816), d. b. h (r^2 =0.897), branch length (r^2 =0.742) and crown length (r^2 =0.831) with branch number (Table 3). The result showed that *J. procera in A. abyssinica*- influenced site had higher mean branch numbers (Figure 9; Appendix 6 (a & b). This indicated that this tree had denser crown even at early stages of growth than *S.*

guineense, H. abyssinica, P. africana, M. ferruginea, and *P. falcatus* trees which have an implication in establishing early good vegetation cover in restoration (Getachew Tamiru, 2007). Therefore, the present study concludes that, the presence of *A. abyssinica* was the key biological restoration mechanism for the endangered *J. procera* seedlings establishment and growth performances on degraded landscape.

4.1.6. *Branch length*

Mean branch length growth differences between the two sub-sites were significant ($p < 0.05$) (Figure 9; Appendixes 2 & 3). *J. procera* in *A. abyssinica*- influenced site had a branch length relatively very higher than open land area (Figure 11). This revealed that the growth of *J. procera* in the open land site was significantly lower than their corresponding growth in *A. abyssinica*- influenced site (Figures 8, 9 & 11). This branch length difference across the two sub- site was an indicator of growth difference, since stunted growth leads to short branch length. Strong relationship was observed between tree height (r^2 =0.830) and d. b h (r^2 =0.891), with branch length (Table 3). In non- *A. abyssinica*- influenced site, not only branch length, both branch number and tree height showed dwarfed growth performance possibly due to drought stress and nutrient unavailability to the growing plant (Appendix 6 (d).

A. abyssinica influenced area *J.procera (c)* Non- *A. abyssinica* influenced area *J.procera* (d)

Figure 11. Comparison across the two sub- sites, showing *J. procera* branch length growth difference seven years after planting of the seedlings at the Center for "Indigenous Trees Propagation and Biodiversity Development in Ethiopia". [Photos taken at 2 m distance, 16 / 05/ 2012].

4.2. *Soil analysis results*

Among the soil parameters analysed, the variables that showed significant differences across the two sub-sites and depthwise were soil organic carbon, soil EC, soil CEC, total nitrogen and available phosphorus except pH (Figure 12; Table 4; and Appendixes 4 & 5). Results of soil physicochemical analysis (composite samples from the study site) at a depth of 0- 15 cm and 15-30 cm are presented in (Table 4). The correlation analysis output showed that the soil parameters are either negatively or posively correlated to each other (Table 5).

Table 4. The mean (S.D) soil physical and chemical property analysis result of the study area at two depths. Numbers in parentesis are standard deveations.

	A.abyssinica influenced site		Open land site	
Parameters	0-15 cm	15-30 cm	0-15 cm	15-30 cm
Soil pH	6.64 (0.31)	6.72 (0.19)	6.72 (0.07)	6.81 (0.05)
EC (ms/cm)	0.40 (0.35)	0.15 (0.40)	0.11 (0.02)	0.08 (0.01)
CEC(cmol/kgsoil)	32.53 (5.6)	25.56 (5.00)	39.55 (9.8)	35.5 (6.90)
AV.P (mg/kgsoil)	13.19 (2.11)	11.05(10.52)	5.40 (0.96)	3.85 (0.50)
% OC	4.11 (0.26)	1.0 (0.36)	3.17 (0.48)	1.69 (0.07)
% TN	0.35 (0.04)	0.10 (0.04)	0.22 (0.05)	0.11 (0.02)
% Clay	28.67 (2.31)	28.67 (1.15)	59.33 (1.15)	63.3 (1.15)
% Silt	24.33 (1.15)	30.33 (1.15)	17.67 (3.06)	17 (0.00)
% Sand	46 (3.46)	40 (0.00)	22 (3.46)	8.6 (1.15)
Soil Classes	Clay Loam		Clay	

Where, EC= Electrical conductivity, CEC= Cation exchange capacity, Av.P= Available phosphorous, Oc =Organic carbon, TN= Total nitrogen.

Comparison of the major soil properties of the study sub- site indicated that the area is well restored (Table 4) compared to the previous stud results (e. g. Getachew Tamiru, 2007; Misrak Tesfaye, 2007), total nitrogen (0.1% compared to 0. 22- 0.35 % of the present study and the standard average value of 0.2-0.5%), organic carbon (1.2%, compared to 3.17- 4.11 % of the present study and the standard average value of 4-10%), and available phosphorus (2.3 ppm, compared to 5.4- 13.19 ppm of the present study and the standard average value of 14-19 ppm) (Misrak Tesfaye, 2007).

Table 5. Correlation coefficient (r^2) results of soil chemical and physical property of study area.

	pH	EC	CEC	Av.P	OC	TN	Clay	Sand	Silt
PH	1								
CE	-.820**	1							
CEC	-.289	.221	1						
Av.P	-.448	.587*	-.069	1					
OC	-.315	.533	.427	.273	1				
TN	-.422	.678*	.365	.422	.965**	1			
Clay	.252	-.427	.463	-.612*	-.078	-.295	1		
Sand	-.235	.250	-.629*	.479	-.301	-.091	-.884**	1	
Silt	-.241	.477	-.346	.626*	.253	.456	-.975**	.758**	1

**,* = Correlation is significant at the 0.01 and 0.05p level respectively.

Where, EC= Electrical conductivity, CEC= Cation exchange capacity, Av.P= Available phosphorous, OC= Organic carbon, and TN= Total nitrogen.

4.2.1. *Total nitrogen*

The study conducted by Getachew Tamiru (2007) indicated that some essential macronutrients such as total nitrogen, available phosphorus and organic carbon in both 0-15 cm and 15-30 cm soil depth were found at lower level for plant growth in the study area because of previous land use system, over grazing, *Eucalyptus* stand, absence of vegetation cover and exposure to severe erosion. One study conducted on cleared and cultivated site indicated that a reduction in soil nutrients. The loss of nitrogen amounted to 60% for 0-10 cm soil depth (Bekele Lemma, 2006).

The result of the present study revealed that the amount of total nitrogen in both soil depths was found at higher level for plant growth in the two sub-sites (Table 4). Statistical analysis using analysis of variance and Turkey- HSD were done to compare the mean values of total nitrogen among the two sub-sites. The analysis showed that there was significant difference ($p < 0.05$) in total nitrogen content across the two sub-sites (Figure 12; Table 4; Appendixes 4 & 5).

The correlation coefficient test result indicated that total nitrogen is correlated strongly ($r^2 = 0.965$) with organic carbon (Table 5). Further comparison of total nitrogen content between two depths of soil at each site was carried out. The result strengthened that there was a percentage total nitrogen content difference between the two depths ($p < 0.05$; Appendixes 4 & 5). Total nitrogen decreased with increasing soil depth in all study sub-sites which showed the restoration of the surface soil fertility of the study area (Figure 12; Table 4). The result agrees with (Getachew Tamiru, 2007), as the soil depth increases, total nitrogen content decreased.

This surface soil nitrogen percentage improvement might be due to the existed site management such as weeding and decomposition of litter falls and the presence of nitrogen fixing trees such as *A. abyssinica.* A recent review of northern hemisphere tree and forest systems found that soil organic matter and nitrogen content appear to be higher in stands with nitrogen fixing species (typically 10-40%), and concluded that: "...the major effect of nitrogen fixing trees on ecosystem production and nutrient cycling probably derive more from the input of high-quality litter than from the proportional increase in the ecosystem nitrogen capital" (Rosoman, 1994). The common organic nitrogen substances are; soil humus, plant leaf clippings and root tissue, and sludge (Camberato, 2001).

The presence of moisture enhances the mineralization of nitrogen. Warm, moist and soil pH greater than 5.5 enhance mineralization (Camberato, 2001). The present soil analysis result indicated pH value of greater than 6.64 (Table 4). The most difecient nutrient in the forest is nitrogen because of its conversion to ammonium and nitrate by micro-organisms (Wenger, 1984). Mineralization facilitated nutrient uptake by plants and plants require sufficient supply of nitrogen during the growth period when their metabolic activities are at their peak to maximize biomass and yield production (K. Habtegebrial and Singh, 2006). At sufficient moisture conditions uptake of nutrients increases, enhancing root and shoot growth, which result in higher production (Lopez- Bellido *et al*., 2005, cited in K. Habtegebrial and Singh, 2006), and ensure the survival rate of seedlings (Tang *et al.*, 2010). Thus, the higher growth performance of *J. procera* in *A. abyssinica*- influenced site was due to availability of nutrients and moisture as well as low evapotranspiration loss of water (Figures 8, 9 & 10). Most tropical soils are characterized by significant leaching and poor nutrients (Moreira *et al.,* 2011). Nitrogen and phosphorus are often referred to as the primary macronutrients because of the probability of plants being deficient in these nutrients and because of the large quantities taken up by plants from the soil relative to other essential nutrients of the soil (Marschner, 1995).

In non- *A. abyssinica*- influenced site, nitrogen content is slightly lower than *A. abyssinica*- influenced site, but relatively high compared to the previous study (0.1% compared to 0. 22- 0.35 % of the present study) (Getachew Tamiru, 2007) (Figure 12; Table 4; and Appendixes 4 & 5). This might be due to the presence of grasses and herbs with short turnover. Nitrogen is present in grass plants in greater quantities than any other essential nutrient other than carbon, oxygen, and hydrogen (Camberato, 2001). The increase in total nitrogen in soil under pasture/open land could be because of the entry of nitrogen from fixation by free living bacteria (*Azotobacter*) associated with grasses (Fernandes, 1999). There was accumulation of total nitrogen level in the open land soil. This might be due to dry conditions, where the mineralized nitrogen was retained in the soil (K. Habtegebrial and Singh, 2006). The lower the mineralization of nitrogen is, the higher its accumulation (Camberato, 2001; Moreira *et al*., 2011). Factor such as temperature, low CEC, high soil moisture, and vegetation accelerate volatilization (Clain and Kathrin, 2010). But the present result showed the opposite of the above mentioned factors of volitalization for the open land area (Figure 12; Table 4). For instance, CEC is very high in this cluster sub-site.

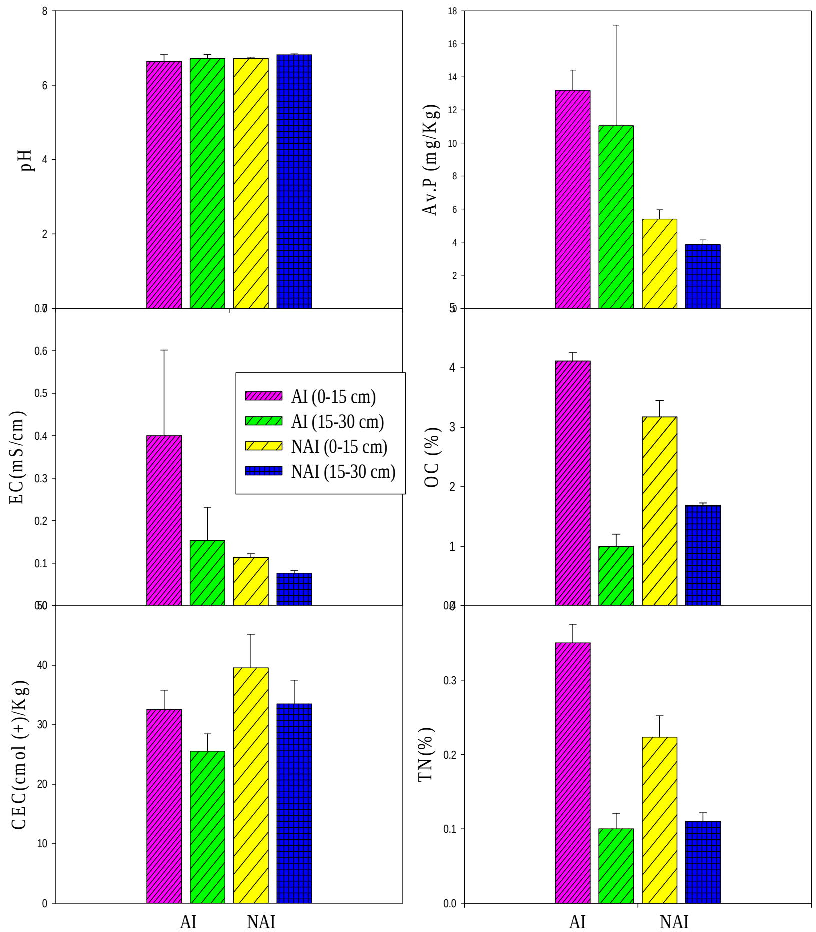

Figure 12. Mean (± SE) comparison of soil chemical and physical property parameters at different study cluster sub-sites and soil depths. Where, EC= Electrical conductivity, CEC= Cation exchange capacity, Av.p= Available phosphorus, OC= Organic carbon, TN= Total nitrogen and AI= *A. abyssinica*- influenced, NAI =Non- *A. abyssinica*-influenced cluster sub-sites.

From this point of view the present study concludes that the slight storage of nitrogen in open land site was due to the absence of moisture, low uptake by plants, relatively very small number of nitrogen fixing *A. abyssinica* (Figure 10, Appendix 6(a & b), and the presence of short turnover grasses. The moisture content of the two sub-sites was measured to be 22% and 12% for *A. abyssinica* influenced and open land experimental sites respectively. In these open land with nitrogen difecient area, the nornmal older mature green leaves of *J. procera* seedlings was become uniformly yellowish (Chlorotic) and branching is reduced as difeciency progresses whereas the top leaves remain green (Appendix 6(d). It is possible to conclude that the nitrogen difeciency is accelerated by water stress in this open land area. Nitrogen and phosphorus are the most limiting plant nutrient (Marschner, 1995), which gets exacerbated by water stress and poor soil status (Legesse Negash, 2010).

4.2.2. *Availability of phosphorus*

Based on the laboratory analysis, the amount of available phosphorus in the soil and its variation across the two sub- sites was evaluated and compared statistically. The analysis result revealed that the mean difference in the amount of available phosphorus was insignificant ($p > 0.05$) across the two sub- sites from both 0-15 cm and 15- 30 cm soil depths (Appendixes 4 & 5). The previous study result within similar study area showed available phosphorus content was inadequate for plant growth (2.23 ppm to 1.5 ppm) from soil depth of 0-15 cm to 15-30 cm compared to the present study 13.19 ppm - 11.05 ppm for *A. abyssinica*- influenced site and 5.4 ppm - 3.85 ppm for open land) and standard plant tissue phosphorus content 5-15 ppm (Getachew Tamiru, 2007).

But, the present study result indicated high storage of available phosphorus in the study area especially in *A. abyssinica* influenced site (Figure 12, Table 4). This could be due to higher pH value of the study area (Table 4). A pH between 6.5 and 7.0 is usually best for phosphorous availability (Troeh and Thompson, 1993). The mean value of available phosphorus decreased with increasing soil depth in the two sub-sites (Figure 12; Table 4). The slower rate of nutrient release during decomposition indicates the slower exposue to erosion, leaching, and nutrient uptake by plants (Frank, 2000). There was higher level of available phosphorus from the surface soil (Getachew Tamiru, 2007). This might be the case for the slightly higher level of surface phosphorus content in these two sub-sites.

Like nitrogen, phosphorus is a key nutrient with a close association to the soil organic matter (Table 5). More than 50 % of the total phosphorus in surface soils is present in the soil organic matter fraction (Rosoman, 1994). The correlation coefficient result showed available phosphorus is correlated with electric conductivity ($r^2 = 0.587$), organic carbon ($r^2 = 0.273$) and silt ($r^2 = 0.626$) (Table 5).

The soils of tropical rainforests are characterized by rapid recycling of fallen leaves and other organic matter due to the large biomass of the rainforest. This high rate of decomposition is the result of phosphorus levels in the soils, precipitation, high temperatures and the extensive microorganism communities (Cory and Alan, 2006). Root mycorrhizae play an important role in the phosphorus absorption, and can be especially so in low fertility soils. Other soil fauna and flora are a source of phosphorus through decomposition, emphasising the importance of a healthy soil biological component, encouraged through diversity rather than single species (Rosoman, 1994).

4.2.3. *Soil organic carbon*

Deforestation of native forest followed by continuous cultivation depleted the soil organic carbon by 43% (Bekele Lemma, 2006). Continuous cropping and removal of crops residues, rare addition of animal manure often depletes soil organic matter (K. Habtegebrial and Singh, 2006). The soil analysis result revealed high level of organic carbon content in the study area due to restoration of the sudy area (Table 4). The statistical analysis out put revealed that there was significantly ($p < 0.05$) mean percentage organic carbon content difference across the two sub-sites from both soil depths (Figure 12; Table 4; Appendixes 4 & 5). The coerrelation test result indicated that soil organic carbon was highly correlated with nitrogen (Table 5).

The soil organic carbon content was decreased with increasing soil depths in all sub-sites which is agree with (Getachew Tamiru, 2007) result and higher in *A. abyssinica*-influenced site (Figure 12; Table 4). This could be most probably due to the presence of *A. abyssinica* with its necromass production, regeneration and decomposition of short turnover weeds, grasses and herbs. The accumulation of organic carbon content from leaves litter and other organic materials, increase water holding capacity of the soil (Tang *et al.*, 2010). High temperatures and precipitation increase decomposition rate, which allows plant litter to rapidly decay in tropical regions, releasing nutrients that are immediately taken up by plants through surface or ground waters. The seasonal patterns in respiration are controlled by leaf litter fall and precipitation, the deriving force moving the decomposable carbon from the litter to the soil. Respiration rates are highest early in the wet season because the recent dry season results in a large percentage of leaf litter and thus a higher percentage of organic matter being leached into the soil (Cory and Alan, 2006; Tang *et al*., 2010). This might be the reason for the accumulation of surface organic carbon in *A. abyssinica*- influenced site.

In fact the higher clay content of the soil of the two sites might have also contributed to a higher accumulation of organic carbon. Relatively higher clay content was observed in open land site (Table 4). Bonds between the surface of clay particles and organic matter retard the decomposition process. Soils with higher clay content increase the potential for aggregate formation; physically protect organic matter molecules from further mineralization caused by microbial attack (Wild, 1993). Absence of enough moisture may hinder mineralization ability of soil microbe.

The improvement in organic carbon content following the enclosure is an important sign of soil fertility restoration. A number of factors and processes are believed to determine the direction and rate of change in soil organic matter storage when plantations are established on arable land. Thus factor includes: (i) litter production (both above- and below-ground); (ii) litter quality; (iii) placing organic matter deeper in the soil either directly by increasing below-ground inputs or indirectly by enhancing surface mixing by soil organisms; (iv) increasing physical protection through either intra-aggregate or organo-mineral complexes; and (v) microclimate change (Lugo & Brown, 1993; Post & Kwon, 2000; cited in Bekele Lemma, 2006).

As vegetation coverage of area increased the amount of soil organic matter accumulation also increased (Appendixes 6 (b & e). The presence of organic matter content affects the physicochemical properties of the soil and its overall quality/ health. Soil properties influenced by organic matter include; soil structure, moisture holding capacity; diversity and activity of soil organisms. Basically organic matter reacts in the soil like a tiny, spongy solid with a large amount of negative charge. Because of its complex and open structure, the ability of humus to pull water from the surrounding saturated atmosphere of the soils approaches 80 to 90 % of its weight, as compared to 15 or 20 % for soil clays (Bot and Benites, 2005). Organic matter may provide nearly all of the CECs and pH buffering in soils (Bot and Benites, 2005).

Clay and organic matter in the soil have negative charge; naturally it attracts positively charged nutrients and repels negatively charged nutrients (easily leached away). The active fraction of soil organic matter has been most closely associated with nutrient supply. However, the stable soil organic matter pool also improves soil fertility by holding plant nutrients and preventing them from leach into the subsoil. Since soil organic matter has a net negative charge, nutrients such as calcium, magnesium, potassium and ammonium can be attracted without trouble and held by soil organic matter (Cooperband, 2002).

4.2.4. *Soil physical properties and their spatial variability*

The result of the soil texture analysis of the study area indicated that it was dominantly clay loam in texture in *A. abyssinica* influenced site whereas clay in open land sites (Table 4). The mean percentage of clay content at the surface soil (0-15 cm) were 16 % in *A. abyssinica* and 33% in open land site (Table 6). The mean values increased with increasing soil depths from 59.33 (0-15 cm) to 63.33 (15-30cm) in nonopen land site whereas remained the same (28.67) in *A. abyssinica*- influenced site (Table 4).

To investigate the significance of the variations, ANOVA and LSD methods were employed. The comparison of clay, silt and sand percentage content between the two sub-sites and surface soil and sub-surface soil depths revealed that the mean difference was significant ($p < 0.05$) (Appendixes 4 & 5). The texture of the soil was found to be 16 % clay, 27.2% sand and 36.3 % silt for *A. abyssinica* influenced and 33% clay, 20% sand and 17.4% silt for open land site compared to, 67 % clay, 21 % silt and 11 % sand (Misrake Tesfaye, 2007).

Table 6. Soil physical property description across the two study sub-sites from (0-15 cm) depth.

Physical properties	Unit	AI	NAI
Clay(<2 µm)	%	16	33
Silt (2-50 µm)	%	27.2	20
Sand (>50 µm)	%	36.3	17.4

However, clay percentage in the open land was higher than in *A. abyssinica* influenced site, whereas silt and sand percentages were higher in the *A. abyssinica* influenced site than the open site. These textural differences may reflect the difference in soil erosion rate between the two sub- sites (Table 4). The higher clay content in the open land means that there is relatively low soil erosion in the sub- site, while the lower clay means there is relatively higher soil erosion in these sub-sites (Kibret mamo, 2008).

Soil characteristics affect the distribution and duration of water stored in the soil, and these, in turn, affect plant distribution and vegetation structure (Fernandez-Illescas *et al.*, 2001), because soil physical propery affects soil porosity, water holding capacity and their influence on soil water movement and the energy state of the water in the soil column, determine the soil wetness values which in turn establish the water condition of the plant. Clay soils, with higher mean values of soil moisture, are associated with larger amounts of runoff whereas sandy soils have the lowest levels of stressed evapotranspiration, while unstressed evapotranspiration is highest for the silty (Fernandez-Illescas *et al.,* 2001).

4.2.5. *Soil Ph*

A soil pH of 7 is considered as neutral. Soil pH values greater than 7 signify alkaline conditions, whereas those with values less than 7 indicate acidic conditions (Troeh and Thompson, 1993). Considering, pH values with associated soil reactions, slightly acidic (7.0-6.0), moderately acidic (6.0-5.0), strongly acidic (5.0-4.0), very strongly acidic (4.0-3.0), and slightly alkaline (7.0-8.0), moderately alkaline (8.0-9.0), strongly alkaline (9.0-10.0), very strongly alkaline (10.0-11.0) (Tan, 1996).

The result of laboratory analysis showed that the pH of the soil in the study area was within the range of 6.64 and 6.81 which is grouped in slightly acidic pH scale (Tan, 1996) (Table 4). The neutrality of pH of the soil may be attributed to lower break down of the soil organic matter due to higher clay percentage (Kibret Mamo, 2008). The mean difference in soil pH between the two sub-sites was insignificant ($p > 0.05$; Appendixes 4 & 5). The mean pH value increased as soil depths increased in both sub-sites (Figure 12; Table 4). The increase in the pH value with the increasing soil depth might be due to the increase of cation in the sub- surface soil (Getachew Tamiru, 2007). The slightly lower pH values at the surface layer of the two sub-site compared to sub-surface pH correspond to the larger amounts of organic matter in the topsoil, reflecting organic matter is responsible for acidity through litter decomposition (Abdu *et al.*, 2010).

Soil pH directly affects the solubility of many nutrients in the soil needed for proper plant growth and development. A lower pH reduces the availability of many key nutrients such as P, Ca, Mg, N and boron, but may increase the weathering of parent material and mineral rock within the soil. A significant negative effect of acidification of soils is the release of toxic Al^{3+}, H^{+} and mn^{2+} compounds into the soil solution, subsequently inhibiting root growth, and Mg, Ca and K uptake (Rosoman, 1994; Mesfin Abebe, 2007). It was concluded that, even though there was variation in the mean values of the soil pH between the two sub-sites and soil depths, pH of the soil in the entire study area could not be a problem for tree growth in the study area.

4.2.6. *Cations exchangable capacity (CEC)*

CEC is a measure of the soils capacity to exchange ions. The CEC of the soil is determined by the amount of clay and/or humus that is present. These two colloidal substances are essentially the cation reservoir of the soil. Sandy soils with very little soil organic matter have a low CEC, but heavy clay soils with high levels of soil organic matter have a much greater capacity to hold cations. The disadvantages of a low CEC include the limited availability of mineral nutrient to the plant and the soil's inefficient ability to hold applied nutrient. Soluble mineral salts (e.g. potassium sulfate) applied in large doses to soil with a low CEC cannot be held efficiently because the cation warehouse is too small (Wild, 1993). There is a positive correction between soil organic matter and exchangeable cations, as soil organic matter increase, available cations increase and available to plants (Wild, 1993).

The statistical analysis result revealed that the CEC mean defference between the two cluster sub-sites was insignificant ($p > 0.05$) depthwise and between these sub-sites (Appendixes 4 & 5). Soil in open land site showed higher in CEC than the soil in the *A. abyssinica* influenced site (Figure 12; Table 4). This could be attributed to soil organic matter and clay percentage acummulation of the soil in this sub-site as a result of poor moisture, higher clay cantent and short turnover grasses. CEC is related to percent of clay (r^2=0.463) and organic matter (Table 4). As the percent of clay and organic matter content increase, the CEC also increases (Wild, 1993; Grisso *et al.*, 2009). Thus, slight difference in organic matter and clay can make a big difference in soil CEC as observed in this study.

4.2.7. *Electric conductivity of soil*

Electrical conductivity (EC) is the ability of a material to transmit (conduct) an electrical current. Soil EC is a measurement that correlates with soil properties that affect crop productivity, including soil texture, pH, CEC, available water-holding capacity/drainage conditions, organic matter level, salinity, and subsoil characteristics (Grisso *et al.*, 2009). The EC of soils varies depending on the amount of moisture held by soil particles. Sands have a low conductivity, silts have a medium conductivity, and clays have a high conductivity (Figure 13). Consequently, EC correlates strongly to soil particle size and texture (Grisso *et al.,* 2009*).*

The statistiacal analysis of variance result indicated that there is insignificant mean difference ($p > 0.05$) from the two soil depths and across the two sub-sites (Appendixes 4 & 5). EC correlation with pH (r^2=0.584) and available phosphorus (r^2 =0.382) (Table 4). According to (Grisso *et al.,* 2009*)* and table 4 above, the present study result showed that the EC of the study area was very low. Droughty areas typically have distinct textural differences from those with excess water; these can be identified using EC. Soils in the middle range of conductivity, which are both medium-textured and have medium water-holding capacity, may be the most productive. Since water holding capacity typically has the single greatest effect on crop yield, this is likely the most valuable use of EC measurements (Grisso *et al.,* 2009*).* The present result showed that the EC of both soil depth and study sub-site has below the medium EC value for plant growth especially in the in non- *A. abyssinica*-influenced sub-site (Table 4).

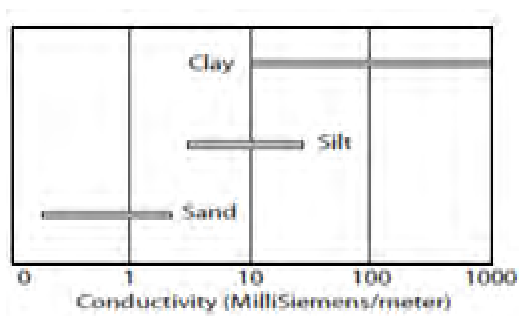

Figure 13. Soil electric conductivity map showing the electric conductivity range of soil particles. Adapted from (Grisso *et al.*,2009).

Compared to the *A. abyssinica* influenced site (0.15 to 0.4 mS/cm), the open land site has very low EC (0.08 to 0.11 ms/cm) which clearly indicated the low conductivity (Table 4). Soils had different electrical conductivity measurements, but these differences were due to soil water content and not soil properties and soil water content create growth differences (Grisso *et al.,* 2009*).* The greater total soil porosity, the more easily it conducts electricity. Soil with high clay content has more total pore space than sandier soils when other soil parameters remain constant. EC also used to determine soil salinity. An excess of dissolved salts in the soil is readily detected by electrical conductivity. Mineral soils containing high levels of soil organic matter (humus) and/or 2:1 clay minerals have a much higher ability to retain positively charged ions such as Ca, Mg, K, Na, NH_4^+, or H^+ than soils lacking these constituents. The presence of these ions in the moisture-filled soil pores will enhance soil EC in the same way that salinity does (Grisso *et al.*, 2009*)*. Based on the information it could possible to conclude that the sudy area more affected by water stress (especially the open land sub-site) rather than salinity.

4.3. *Overall growth parameters and soil condition evaluation*

Growth parameters of *J. procera* were compared between the two sub-sites to assess the impact of *A. abyssinica* on the growth of *J. procera*. In all considered growth parameters, such as tree height, d. b. h, crown length, crown diameter, branch length and number of branches, the growth of *J. procera* in *A. abyssinica*- influenced site was significantly ($p < 0.05$) higher than their corresponding growth in non- influenced sub-sites (Figures 9 & 12; Appendixes 2 & 3). The most warning result is the extremely smaller growth of seedlings in open land site as compared to the other sub-site (Figures 8 & 12; Appendix 6 (a & b). This may be attributed to unavailability of sufficient water and nutrient (El Atta and Aref, 2010), and high evapotranspiration loss of water. The overall tree growth difference is due to soil fertility difference and the distribution of *A. Abyssinica* (Appendix 6 (c).

Soil chemicophysical properties are strongly related to above ground productivity and forest structure and dynamics. The physical properties of soil control the tree turnover rates whereas chemical properties such as available nitrogen and phosphorus control forest growth rates (Moreira *et al*., 2011). All soil parameters i. e., total nitrogen, organic carbon, EC and available phosphorus except CEC and pH in the *A. abyssinica*-influenced site from 0-15 cm and 15-30 cm soil depths were found relatively higher when compared with their amounts in the open land site (Table 4; and Figure 12). This might be due to erosion and absence vegetation cover. A horizontally spreading and strong taproots deep into the ground of *A. abyssinica* play an important role to hold and protect the surface soil from erosion in *A. abyssinica* influenced site (Legesse Negash, 2010) (Figure 14). Since total runoff and soil erosion were much higher in abandoned terraces, it is anticipated that more nitrogen and phosphorus were lost due to abandoning and damage to terraces due to inefficient rainwater harvesting, soil erosion, and leaching (El Atta and Aref, 2010). Soil erosion causes a decrease in soil fertility and its ability to sustain plant growth (Bekele Lemma, 2006).

The present work result showed that this study area restored well which might be as a result of the contribution of *A. abyssinica* that plays a great role in restoration of the threatened *J. procera* and soil fertility. The restoration role might be associated with (Legesse Negash, 2010): (i) the nitrogen fixing and root interaction with other tree species (Figure 14); (ii) the tree improve soil fertility under its canopy through decomposition of its necromass (dead fine roots, outer bark components, secondary branches, leaflets, flowers, pods, and seeds), as well as microsite improvement through provision of its shade.

Nitrogen and potassium content was higher in the foliage than in the wood. Tree species with high content of foliar nitrogen can be potential sources of organic resources for improving depleted soils (Mekonnin Kindu *et al.,* 2006). The decomposition of leaf litter from trees enhances the surface soil fertility through releasing nitrogen, phosphorus, potassium and exchangable cations (Bekele Lemma, 2006, Tang *et al.*, 2010). (iii) Its association with diverse nitrogen fixing microorganisms (Tulu Degefu *et al.,* 2011); and the flat and expanded canopy help to reduce evapo-transpiration loss of water (Appendix 6 (c). (v) Its ability in keeping soil moisture, temperature regulation, and protection of the growing seedlings of *J. procera* from animal browsing with its sharpening spines.

The regeneration of grasses and different herbs may enhance soil fertility of the study area that favoures the restoration of endangered trees. The site fertility might be enhanced using a short-lived, and nitrogen fixer that eventually enables native species to be re-introduced (Lamb and Gilmour, 2003). Plantation of key species like *Acacia saligna* in extremely degraded lands is widely practiced by GOs and NGOs in Southern Wello before planting indigenous trees and other exotic tree species that do not tolerate the environmental stresses like water shortage and poor soil condition of degraded areas. In these cases introducing such species help to hasten the process of natural recovery that would find it difficult to re-establish under the passive restoration approach. The presence of *Acacia* species improves soil quality and facilitates the quick increment of the population of other plant species that provide income plus protection of the watersheds (Kibret Mamo, 2008).

A. abyssinica has a natural tendency to develop root system that spreads horizontally, while at the same time sending its strong taproot deep into the ground. This attribute is useful for holding the surface soil together as well as for supporting the potentially massive plant body (Figure 14). It is also critical for pumping nutrients up from deep in the soil surface. The tree has the capacity for tolerating drought due to trees an “advance-retreave” type of growth strategy. As a result, the species is useful for restoring degraded soils and landscapes where xeric conditions are prevalent (Legesse Negash, 2010).

Figure 14. *Acacia abyssinica* with it’s horizontally and vertically down growing roots. Photo taked at 2 m distance in the “Center for Indigenous Trees Propagation and Biodiversity Development in Ethiopia” seven years after restoration. [Photo taken at 2 m distance, 16/ 05/ 2012].

4.4. Conclusion and recommendations

4.4.1. Conclusion

Several studies reported that the indigenous conifer tree *J. procera* was threatened but appropriate biological restoration mechanism for the species is lacking. Also, the ecological and economic importance of the juniper forests of Ethiopia has promoted a great deal of interest in their restoration. A key question, however, is how to successfully and quickly restore this endangered tree.

The present findings revealed that the presence of *A. abyssinica* was crucial in the restoration of degraded land soil fertility as well as the endangered tree. The mean growth performances in *A. abyssinica*- influenced sub-site were significantly ($p < 0.05$) higher than the corresponding control sub-sites. In contrast, the growth performance of *J. procera* in open land site was stunted and less branched.

The growth performances were evaluated by different growth parameters, viz. tree height, d. b. h, crown length, crown diameter, branch length and number of branches in which all of these growth parameters clearly showed higher growth performances in *A. abyssinica*-influenced sub-site than the control sub-site. This difference might be due to either the presences or absence of *A. abyssinica* which is potentially important for the restoration of the threatened *J. procera* on degraded landscapes. Clearly, the distribution of *A. abyssinica* in the two sub-sites, (44.8 % in *A. abyssinica* –influenced and 18.5% in open land site), create growth and site condition differences. Thus, growth also varied with site conditions.

The soil physicochemical properties analysis results for all parameters showed significant ($p < 0.05$) mean differences in both soil depths and across the two sub-sites except pH and CEC. When the soil physical and chemical properties were correlated between the two sub-sites, there had been a significant improvement of surface soil fertility of the study area. Soil quality like soil organic carbon, soil EC, total nitrogen, available phosphorus, and pH were significantly higher in the two sub-sites. This clearly indicates the restoration of the study area.

The texture of the soil was found to be 16 % clay, 27.2% sand and 36.3 % silt for *A.abyssinica* influenced and 33% clay, 20% sand and 17.4% silt for open land site from 0-15 cm soil depth. Therefore, the textural classes of the study area were, clay loam for *A. abyssinica*- influenced site whereas clay for open land site.

Management practices such as protection from external disturbance as well as nitrogen fixation and necromass production by *A. abyssinica* are critical for improvement of surface soil fertility of the study area. Also, *A. abyssinica* does facilitate the colonization and establishment of native woody species and eventually the restoration of biodiversity. Restoration can play an important role in restoring the productivity, ecosystem stability, and biodiversity of degraded lands. Therefore, the present study in this Center, contribute something in that direction.

4.4.2. *Recommendations*

The present study findings revealed that the presence of *A. abyssinica* is very crucial for the restoration of the threatened *J. procera* on bare and degraded landscapes. The presence of *A. abyssinica* improves soil fertility through nitrogen fixation, decomposition of its necromass, as well as microsite improvement through provision of its shade and facilitates the quick increment of the population of other plant species that provide income plus protection of the watersheds. It is also critical for pumping nutrients up from deep in the soil surface because of its root system that spreads horizontally, and sending its strong taproot deep into the ground.

For the restoration of the threatened trees to be effective, it is essential that sound land restoration policy be put in place and implemented as urgently as possible. Often, individual trees of *J. procera* were degraded for several purposes. Therefore, restoration and protection of this valuable tree species must be considered as a higher priority task of both government and non-governmental organizations.

This research contribution a lot for the limited knowledge on the restoration of the endangered *J. procera* using *A. abyssinca* and the contribution of *A. abyssinica* for overall improvement of soil fertiliy, similar, extensive and detail studies in different areas is very essential. The study area, the “Center for Indigenous Trees Propagation and Biodiversity Development in Ethiopia” is a model site for indigenous trees propagation, restoration and /or rehabilitation on degraded lands. It is ideal site to conduct similar researches on indigenous trees.

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Appendixes

Appendix 1. List of plant taxa collected in the study area with corresponding collection number, family, vernacular name and habit.

Coll. No.	Species Scientific Name	Family	Habit	Local Name
01BK	*Ocimum lamiifolium* (Hochst.) ex.Benth.	Lamiaceae	Shrub	Yemichi medanit
02BK	*Maesa lanceolata* Forssk	Myrsinaceae	Tree/shrub	Qelaho/Abeyii
03BK	*Citrium schimperi* (Vatke) Cuf.	Asteraceae	Herb	Kosheshla
04BK	*Millettia ferruginea (Hochst.) Bak.*	Fabaceae	Tree	Birbira
05BK	*Entada abyssinica* Steud.ex A. Riech	Fabaceae	Tree	Hambelta
06BK	*Calpurnea aurea* Benth.	Fabaceae	Shrub	Digixa/Checka
07BK	*Jasminum grandiflorum L.*	Oleaceae	Climber	Tembelel
08BK	*Maytenus undata* (Thumb.)Blakelock	Celasteraceae	Shrub	
09BK	*Pterolobium stellatum* Forssk.	Fabaceae	Shrub	Arengama
10BK	*Premna schimperi* Engl	Verbenaceae	Shrub	Chocho/ Urgecha
11BK	*Myrsine africana* L.	Myrsinaceae	Shrub	Kechemo
12BK	*Osyris quadripartita* Decn.	Santalaceae	Tree	Watoo/qerx
13BK	*Olea europaea* subsp *cuspidata (*Wall. ex DC.) Cifferri	Oleaceae	Tree	Weyira/Ejersa
14BK	*Euclea racemosa subsp. schimperi* (Murr)	Ebenaceae	Shrub	Dedeho/qurqura
15BK	*Rhus vulgaris* Meikle	Anacardiaceae	Tree	Xaxecha
16BK	*Rhus sp.* Friis *etal.*	Anacardiaceae	Shrub	
17BK	*Asparagus africanus* Lam.	Asparagaceae	Shrub	Seritii
18BK	*Clematis simensis* Fresen	Ranunculaceae	Climber	Yazoareg
19BK	*Rosa abyssinica* Lindley	Rosaceae	Shrub	Kega/ **Qaqawwee**
20BK	*Carissa spinarum* L.	Apocynaceae	Shrub	Agam/Agemssa

21BK	*Hypericum quartinianum A. Rich.*	Hypericaceae	Shrub/T	
22BK	*Eucalptus camaldulensis* Dehnh.	Myrtaceae	Tree	Key beharzaf
23BK	*Kalanchoe marmorata* Bak.	Crassulaceae	Subshrub	Emboqaqilla
24BK	*Syzygium guineense* (Willd.) DC.	Myrtaceae	Tree	Doqima/Goya
25BK	*Croton macrostachyus* Del.	Euphorbeaceae	Tree	Bisana/mekenissa
26BK	*Hygrophila auricuta* (Schum.) Heine	Acanthaceae	Herb	Yeset Milas
27BK	*Clausena anisata (*Willd.)Benth.	Rutaceae	Shrub	Limich
28BK	*Vernonia amygdalina* Del.	Asteraceae	Shrub	Gerawa
29BK	*Solanum melangena L.*	Solanaceae	Shrub	Enbuy/Hiddii
30BK	*Capparis tomentosa* Lam	Capparidaceae/	Shrub	Gumoro
31BK	*Ficus vasta* Forssk	Moraceae	Tree	Shola/Harbuu
32BK	*Grewa ferruginea* (Hochst.) ex. Rich	Tiliaceae	Shrub	Lenquax/dhoqanu
33BK	*Prunus africana* (Hook.f.) Kalkm	Rosaceae	Tree	Tiku Inchet
34BK	*Dodonaea angustifolia* L.	Sapindaceae	Shrub	Kitkita
35BK	*Albizia schimperiana* Oliv.	Fabaceae	Tree	Sessa
36BK	*Ekebergia capensis* Sparrm	Meliaceae	Tree	Lol/ Sombo
37BK	*Anethum graveolens* L.	Apiaceae	Herb	Selan
38BK	*Bersama abyssinica* Fresen.	Melianthaceae	Tree	Lolchiisaa
39BK	*Heliotropium zeylanium* (Burm.f,)Lam	Boraginaceae	Herb	Maxxannee
40BK	*Podocarpus falcatus (Thunb.) Mirb.*	Podocarpaceae	Tree	Zigba/ Birbirssa
41BK	*Kohautia coccinia Royle.*	Rubiaceae	Herb	
42BK	*Juniperus procera (* Hochst.) ex.Endl.	Cupressaceae	Tree	Tidd/Gaatira
43BK	*Acacia abyssinica* Hochst.ex Benth.	Fabaceae	Tree	Girar/Laftoo
44BK	*Sida schimperiana* Hochst	Malvaceae	Shrub	Cifriggii/Guftee
45BK	*Allophylus abyssinicus* (Hochst.) Radlk	Sapindaceae	Tree	Enbus

Appendix 2. ANOVA table of tree growth parameters at each sub-site in the study area.

ANOVA

		Sum of Squares	df	Mean Square	F	Sig.
Height (m)	Between Groups	66.427	1	66.427	283.051	.000
	Within Groups	15.958	68	.235		
	Total	82.385	69			
(DBH) Diameter at breast height (m)	Between Groups	362.157	1	362.157	840.701	.000
	Within Groups	29.293	68	.431		
	Total	391.450	69			
Crown length (m)	Between Groups	69.461	1	69.461	240.503	.000
	Within Groups	19.639	68	.289		
	Total	89.101	69			
Crown diameter (m)	Between Groups	40.341	1	40.341	88.010	.000
	Within Groups	31.169	68	.458		
	Total	71.510	69			
Branch number	Between Groups	22536.229	1	22536.229	97.322	.000
	Within Groups	15746.343	68	231.564		
	Total	38282.571	69			
Branch length (m)	Between Groups	17.567	1	17.567	646.291	.000
	Within Groups	1.848	68	.027		
	Total	19.415	69			

Appendix 3. Mean differences of tree growth parameters between the two sub-sites of the study area.

Paired –samples –T-test

		Paired Differences					.		
		Mean	Std. Deviation	Std. Error Mean	95% Confidence Interval of the Difference Lower	Upper	t	df	Sig.
Height	*A. abyssinica* influenced Non-influenced	1.88092	.63547	.07289	1.73571	2.02613	25.804	75	.000
Diameter	*A. abyssinica* influenced Non-influenced	3.81974	1.13299	.12996	3.56084	4.07864	29.391	75	.000
C.length	*A.abyssinica* influenced Non-influenced	1.84395	.82325	.09443	1.65583	2.03207	19.526	75	.000
C.diameter	*A.abyssinica* influenced Non-influenced	1.60645	.77311	.08868	1.42978	1.78311	18.115	75	.000
B.number	*A.abyssinica* influenced Non-influenced	39.73684	17.87614	2.05053	35.65197	43.82172	19.379	75	.000
B.length	*A.abyssinica* influenced Non-influenced	1.00191	.24188	.04089	.91883	1.08500	24.505	34	.000

Appendix 4. ANOVA table and LSD analysis for different soil physical and chemical characteristics examined between the three sub-sites at two depths (0-15 cm and 15-30 cm) of the study area.

ANOVA

		Sum of Squares	df	Mean Square	F	Sig.
pH	Between Groups	.047	3	.016	.447	.726
	Within Groups	.281	8	.035		
	Total	.328	11			
EC	Between Groups	.192	3	.064	1.826	.220
	Within Groups	.281	8	.035		
	Total	.473	11			
CEC	Between Groups	295.776	3	98.592	1.960	.199
	Within Groups	402.494	8	50.312		
	Total	698.270	11			
Av.p	Between Groups	178.854	3	59.618	2.049	.186
	Within Groups	232.826	8	29.103		
	Total	411.681	11			
OC	Between Groups	17.933	3	5.978	56.574	.000
	Within Groups	.845	8	.106		
	Total	18.778	11			
TN	Between Groups	.123	3	.041	27.232	.000
	Within Groups	.012	8	.002		
	Total	.135	11			
Clay	Between Groups	3225.333	3	1075.111	460.762	.000
	Within Groups	18.667	8	2.333		
	Total	3244.000	11			
Silt	Between Groups	354.667	3	118.222	39.407	.000
	Within Groups	24.000	8	3.000		
	Total	378.667	11			
Sand	Between Groups	1612.000	3	537.333	84.842	.000
	Within Groups	50.667	8	6.333		
	Total	1662.667	11			

Appendix 5. Mean (±SE) of different soil physical and chemical characteristics in the three sub-sites of the study area.

Multiple Comparisons

Tukey HSD

Dependent Variable	(I) Depth	(J) Depth	Mean Difference (I-J)	Std. Error	Sig.	95% Confidence Interval	
						Upper Bound	Lower Bound
pH	A (0-15cm)	A (15-30 cm)	-.08000	.15293	.951	-.5697	.4097
		AN (0-15 cm)	-.08000	.15293	.951	-.5697	.4097
		AN (15-30 cm)	-.17667	.15293	.669	-.6664	.3131
	A (15-30cm)	A (0-15cm)	.08000	.15293	.951	-.4097	.5697
		AN (0-15 cm)	.00000	.15293	1.000	-.4897	.4897
		AN (15-30 cm)	-.09667	.15293	.919	-.5864	.3931
	AN (0-15cm)	A (0-15cm)	.08000	.15293	.951	-.4097	.5697
		A (15-30 cm)	.00000	.15293	1.000	-.4897	.4897
		AN (15-30 cm)	-.09667	.15293	.919	-.5864	.3931
	AN(15-30cm)	A (0-15cm)	.17667	.15293	.669	-.3131	.6664
		A (15-30 cm)	.09667	.15293	.919	-.3931	.5864
		AN (0-15 cm)	.09667	.15293	.919	-.3931	.5864
EC	A(0-15cm)	A (15-30cm)	.24667	.15297	.424	-.2432	.7365
		AN (0-15cm)	.28667	.15297	.310	-.2032	.7765
		AN (15-30 cm)	.32333	.15297	.228	-.1665	.8132
	A(15-30cm)	A (0-15cm)	-.24667	.15297	.424	-.7365	.2432
		A (15-30cm)	.04000	.15297	.993	-.4499	.5299
		AN (15-30 cm)	.07667	.15297	.957	-.4132	.5665
	AN(0-15cm)	A (0-15cm)	-.28667	.15297	.310	-.7765	.2032
		A (15-30cm)	-.04000	.15297	.993	-.5299	.4499
		AN (15-30 cm)	.03667	.15297	.995	-.4532	.5265
	AN(15-30cm)	A (0-15cm)	-.32333	.15297	.228	-.8132	.1665
		A (15-30cm)	-.07667	.15297	.957	-.5665	.4132
		AN (0-15cm)	-.03667	.15297	.995	-.5265	.4532
CEC	A(0-15cm)	A (15-30cm)	6.97000	5.79148	.642	-11.5763	25.5163
		AN (0-15 cm)	-7.02333	5.79148	.637	-25.5697	11.5230
		AN (15-30 cm)	-.97333	5.79148	.998	-19.5197	17.5730
	A(15-30cm)	A (0-15cm)	-6.97000	5.79148	.642	-25.5163	11.5763
		AN (0-15 cm)	-13.99333	5.79148	.151	-32.5397	4.5530
		AN (15-30 cm)	-7.94333	5.79148	.548	-26.4897	10.6030
	AN(0-15cm)	A (0-15cm)	7.02333	5.79148	.637	-11.5230	25.5697
		A (15-30cm)	13.99333	5.79148	.151	-4.5530	32.5397
		AN (15-30 cm)	6.05000	5.79148	.730	-12.4963	24.5963
	AN(15-30cm)	A (0-15cm)	.97333	5.79148	.998	-17.5730	19.5197
		A (15-30cm)	7.94333	5.79148	.548	-10.6030	26.4897
		AN (0-15cm)	-6.05000	5.79148	.730	-24.5963	12.4963

Avp	A(0-15cm)	A (15-30cm)	2.14333	4.40479	.960	-11.9624	16.2490
		A (15-30cm)	7.79000	4.40479	.353	-6.3157	21.8957
		AN (15-30 cm)	9.33667	4.40479	.226	-4.7690	23.4424
	A(15-30cm)	A (0-15cm)	-2.14333	4.40479	.960	-16.2490	11.9624
		AN (0-15cm)	5.64667	4.40479	.598	-8.4590	19.7524
		AN (15-30 cm)	7.19333	4.40479	.414	-6.9124	21.2990
	AN(0-15cm)	A (0-15cm)	-7.79000	4.40479	.353	-21.8957	6.3157
		A (15-30cm)	-5.64667	4.40479	.598	-19.7524	8.4590
		AN (15-30 cm)	1.54667	4.40479	.984	-12.5590	15.6524
	AN(15-30cm)	A (0-15cm)	-9.33667	4.40479	.226	-23.4424	4.7690
		A (15-30cm)	-7.19333	4.40479	.414	-21.2990	6.9124
		AN (0-15cm)	-1.54667	4.40479	.984	-15.6524	12.5590
OC	A(0-15cm)	A (15-30cm)	3.11667*	.26540	.000	2.2668	3.9666
		AN (0-15cm)	.94000*	.26540	.031	.0901	1.7899
		AN (15-30 cm)	2.42667*	.26540	.000	1.5768	3.2766
	A(15-30cm)	A (0-15cm)	-3.11667*	.26540	.000	-3.9666	-2.2668
		AN (0-15cm)	-2.17667*	.26540	.000	-3.0266	-1.3268
		AN (15-30 cm)	-.69000	.26540	.117	-1.5399	.1599
	AN(0-15cm)	A (0-15cm)	-.94000*	.26540	.031	-1.7899	-.0901
		A (15-30cm)	2.17667*	.26540	.000	1.3268	3.0266
		AN (15-30 cm)	1.48667*	.26540	.002	.6368	2.3366
	AN(15-30cm)	A (0-15cm)	-2.42667*	.26540	.000	-3.2766	-1.5768
		A (15-30cm)	.69000	.26540	.117	-.1599	1.5399
		AN (0-15cm)	-1.48667*	.26540	.002	-2.3366	-.6368
TN	A(0-15cm)	A (15-30cm)	.25000*	.03171	.000	.1485	.3515
		AN (0-15cm)	.12667*	.03171	.017	.0251	.2282
		AN (15-30 cm)	.24000*	.03171	.000	.1385	.3415
	A(15-30cm)	A (0-15cm)	-.25000*	.03171	.000	-.3515	-.1485
		AN (0-15cm)	-.12333*	.03171	.019	-.2249	-.0218
		AN (15-30 cm)	-.01000	.03171	.988	-.1115	.0915
	AN(0-15cm)	A (0-15cm)	-.12667*	.03171	.017	-.2282	-.0251
		A (15-30cm)	.12333*	.03171	.019	.0218	.2249
		AN (15-30 cm)	.11333*	.03171	.030	.0118	.2149
	AN(15-30cm)	A (0-15cm)	-.24000*	.03171	.000	-.3415	-.1385
		A (15-30cm)	.01000	.03171	.988	-.0915	.1115
		AN (0-15cm)	-.11333*	.03171	.030	-.2149	-.0118
Clay	A(0-15cm)	A (15-30cm)	.00000	1.24722	1.000	-3.9940	3.9940
		AN (0-15cm)	-30.66667*	1.24722	.000	-34.6607	-26.6726
		AN (15-30 cm)	-34.66667*	1.24722	.000	-38.6607	-30.6726
	A(15-30cm)	A (0-15cm)	.00000	1.24722	1.000	-3.9940	3.9940
		AN (0-15cm)	-30.66667*	1.24722	.000	-34.6607	-26.6726
		AN (15-30 cm)	-34.66667*	1.24722	.000	-38.6607	-30.6726
	AN(0-15cm)	A (0-15cm)	30.66667*	1.24722	.000	26.6726	34.6607
		A (15-30cm)	30.66667*	1.24722	.000	26.6726	34.6607
		AN (15-30 cm)	-4.00000*	1.24722	.050	-7.9940	-.0060
	AN(15-30cm)	A (0-15cm)	34.66667*	1.24722	.000	30.6726	38.6607
		A (15-30cm)	34.66667*	1.24722	.000	30.6726	38.6607

		AN (0-15cm)	4.00000*	1.24722	.050	.0060	7.9940
Silt	A(0-15cm)	A (15-30cm)	-6.00000*	1.41421	.012	-10.5288	-1.4712
		AN (0-15cm)	6.66667*	1.41421	.007	2.1379	11.1955
		AN (15-30 cm)	7.3333*	1.41421	.004	2.8045	11.8621
	A(15-30cm)	A (0-15cm)	6.00000*	1.41421	.012	1.4712	10.5288
		AN (0-15cm)	12.66667*	1.41421	.000	8.1379	17.1955
		AN (15-30 cm)	13.33333*	1.41421	.000	8.8045	17.8621
	AN(0-15cm)	A (0-15cm)	-6.66667*	1.41421	.007	-11.1955	-2.1379
		A (15-30cm)	-12.66667*	1.41421	.000	-17.1955	-8.1379
		AN (15-30 cm)	.66667	1.41421	.963	-3.8621	5.1955
	AN(15-30cm)	A (0-15cm)	-7.33333*	1.41421	.004	-11.8621	-2.8045
		A (15-30cm)	-13.33333*	1.41421	.000	-17.8621	-8.8045
		AN (0-15cm)	-.66667	1.41421	.963	-5.1955	3.8621
Sand	A(0-15cm)	A (15-30cm)	6.00000	2.05480	.074	-.5802	12.5802
		AN (0-15cm)	24.00000*	2.05480	.000	17.4198	30.5802
		AN (15-30 cm)	27.33333*	2.05480	.000	20.7531	33.9135
	A(15-30cm)	A (0-15cm)	-6.00000	2.05480	.074	-12.5802	.5802
		AN (0-15cm)	18.00000*	2.05480	.000	11.4198	24.5802
		AN (15-30 cm)	21.33333*	2.05480	.000	14.7531	27.9135
	AN(0-15cm)	A (0-15cm)	-24.00000*	2.05480	.000	-30.5802	-17.4198
		A (15-30cm)	-18.00000*	2.05480	.000	-24.5802	-11.4198
		AN (15-30 cm)	3.33333	2.05480	.419	-3.2469	9.9135
	AN(15-30cm)	A (0-15cm)	-27.33333*	2.05480	.000	-33.9135	-20.7531
		A (15-30cm)	-21.33333*	2.05480	.000	-27.9135	-14.7531
		AN (0-15cm)	-3.33333	2.05480	.419	-9.9135	3.2469

* The mean difference is significant at the .05 level. Where, A = *A. abyssinica*-influenced and AN= Non- *A. abyssinica*- influenced study sub-sites with 0-15 cm and 15-30 cm soil depths.

Appendix 6. Partial view of photos of the study tree species and study area

(A) ***A. abyssinica*** **influenced sub-site** **(B) Open land**

(C) Contribution of *A. abyssinica* for restoration of *J. procera*

(D) Water and nutrient stressed (left) and normal (right) seedlings of *J . procera* in open land sub-site.

STATEMENT OF THE AUTHOR

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