Addis Ababa University

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Assessment on the Recent Drying-Up of *Eucalyptus* Species in Selected Areas of the Highland of Arsi and Wollo, Ethiopia

  

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Acronyms

AAU	Addis Ababa University
AGROFOREP	Agroforestry and Environmental Protection Project
ANOVA	Analysis of Variance
CA	Case Area
CFSCDD	Community Forests and Soil Conservation Development Department
DBH	Diameter at Breast Height
ENFRC	Ethiopian National Forestry Research Center
FAO	Food and Agricultural Organization of the United Nations
HoAREC	Horn of Africa Regional Environment Center
KATVTC	Kombolcha Agricultural Technical Vocational Training College
NSW	New South Wales
SQDEEDI	State of Queensland, Department of Employment, Economic Development and Innovation

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Abstract

Drying-up of Eucalyptus species is not a common phenomenan in Ethiopia. The objective of this study was to assess the possible causes of the drying-up of the trees of major Eucalyptus plantations in two selected case areas and to make a recommendation for remedial measures. Systematic sampling was employed and 20m×20m quadrats at 100m interval were laid out along transect. In each quadrat vegetation and soil were assessed for biotic & abiotic factors. Among the abiotic factors soil depth, soil texture, bulk density, water holding capacity of the soil, slope, and aspect were assessed. Among the biotic factors soil and root pathology and stand density were assessed. Pearson correlation coefficient was used to compare the strength of the relationship of the parameters with mortality rate of the trees. ANOVA was also used to compare rooting depth of the live and dried trees. Mortality rate of Eucalyptus camaldulensis is negatively correlated with soil depth with a correlation coefficient (pearson coeff.= -0.8507, P=0.0157) and (Pearson coeff.=-0.9393, P=0.0175) for both case area I and case area II, respectively. There were no correlation between all other soil physical factors and mortality. The rainfall was very much below the average or complete failure of rain (i.e., 0 mm in the months of February & March and 18.1mm in April of 2008) and the temprature went above the average, i.e, 27^{0}c for 6 consecutive months. According to litreature such climatic pattern resulted in drying-up in the following year. Root and soil samples test for phytophtora, which is known to cause root rot were assessed and found negative for both the healthy and dried sample trees. On the other hand a comparative disease symptom assessment of the stems of the live and dried trees were made and the result showed that there was no indication of disease. Among the parameters taken only soil depth found to be the likely cause of Eucalyptus drying-up. All the other possible causes assessed didnt correlated significantly. As the result indicated from this study, it can be concluded that shallow soil depth through its effect on moisture availability resulted in Eucalyptus dry-up in the long term.

1. INTRODUCTION

1.1.Background

In Ethiopia, planting exotic species commenced 110 years ago with the introduction of *Eucalyptus glubulus* (Pankhurst, 1968) . Currently, several exotic species including those of *Eucalyptus, Pinus, Acacia* and *Cupressus* have been planted in Ethiopia. The government, the community and individual small-scale farmers own these plantations. These plantation contribute to the production of round wood for sawn timber, poles and posts and to meet wood requirements for local use, such as for construction material and fuel wood. *Eucalyptus* species are the preferred planting stock, especially for fuel wood and immediate economic return owing to their rapid growth, required little attention, and when cut down grew up again from the roots. It could be harvested every ten years; the tree proved successful from the onset. Due to this fact by now it is common to see *Eucalyptus plantation or* woodlot throughout the country. According to FAO (1995) out of the total area of plantation found in Ethiopia *Eucalyptus* takes 35 percent and planted mainly in the highland areas of the country.

In Ethiopia *Eucalyptus* plantations have been considered to be of great importance in providing opportunities for subsistence farmers to earn extra money in a way that is more flexible as regards working hours and can be adjusted to the needs of their rain fed crops (Becker and Desta, 1989). Dryland agriculture provides employment only for five months of the year to the family members of small and marginal farmers; while in the case of *Eucalyptus* plantations it would provide them with some remunerative work during the off-season (Rajan, 1987). In addition *Eucalyptus* spp. are praised as increasing biomass and providing ground cover, the sale of its poles and products has substantial potential to raise farm income, reduce poverty, increase food security and diversify-smallholder-farming systems in less-favored areas such as northern Ethiopia (Jagger & Pender, 2000).

Even the sustainability and productivity of area enclosures, which is a rehabilitation measure that involves exclusion of degraded lands from animal and human interference to restore to their pre-existing productive status in degraded highlands, depend on a number of factors of which one is availability of necessity materials such as human food, livestock feed, and fuel and construction wood and other socioeconomic problems (Betru Nedessa, *et al*, 2005). To overcome this challenge what has been proposed as a solution is to intensify the inter plantation of short term tree/shrub species (e.g. *Eucalyptus* spp.) along with the big and long term tree species and / or to develop a separate eucalyptus woodlot. Consequently, by now it has become common to see *Eucalyptus* woodlot plantation and *Eucalyptus* as component of area enclosures in the country mainly in the highlands.

Monoculture plantations, i.e., consisting of one species, be it *Eucalyptus* or other species although they have ecologic and economic importance, they are susceptible to pest attack as they are simplified ecosystems unlike that of natural forests. Massive programs in areas where *Eucalyptus* has grown as exotic have failed from pest attack; for instance, *Eucalyptus* plantations in lowland tropical Malaysia have been disappointing because of problems associated with insect such as termites and stem borers and fungal pathogens. Even planting of *Eucalyptus deglupta* ceased in 1982 due to lower performance than other species because of sufferings of periodic damage from insect pest of wood borers identified as *Endoclita hosei* and *Zuezera coffeae* (Tan, 1987). Incidence of termite attack is also common in *Eucalyptus* plantations in the dry zone of Sri Lanka, but it is relatively low in the Wet zone. Recent disease surveys conducted in Ethiopian *Eucalyptus* plantations have identified a fungal disease known as *Mycosphaerella* leaf disease (Gezahagn *et al*, 2006) whose characteristic symptoms are leaf spot, premature defoliation, shoot and twig dieback.

In addition to pest attack there is also strong competition for light, soil moisture and nutrients as the trees of monoculture plantation occupy more or less the same niche unlike that of natural forests in which there is niche stratification. Due to this fact there are countries in which monoculture tree plantations are irrigated and fertilized.

1.2. Statement of the Problem

Eucalyptus plantation in Ethiopia has been popularly expanding in many parts of the country since its introduction to Ethiopia more than a century ago. *Eucalyptus* spp. have been massively planted in most parts of the highland mountains and hilly tops during the 1980s community forest campaign by the then CFSCDD of the ministry of agriculture. During the first introduction there were 15 different *Eucalyptus* species and now there are 55 different species in Ethiopia (Demel Teketay, 2000). Then *E. globulus* and *E. camaldulensis* became the widely planted species in both in the highlands and in the lowlands of Ethiopia. Recently, in 2007 and in 2008, there has been an incident of drying-up of large populations of Eucalyptus plantation in many parts of Ethiopia. Similar incidents have been reported to have happened in *Eucalyptus globulus* plantations established on farmland in south-western Australia from 2006-2009 that is attributed to factors indicative of poor soil water storage capacity. But there had no scientific explanation on what caused this large scale drying-up of plantations of the Ethiopian case. Therefore, the purpose of this study was to investigate the possible cause of this incidents and forward remedial measures.

1.3. Objectives

1. 3. 1. General Objective

The general objective of this study was:

- To assess the possible causes and to identify the most closely related causal agent(s) of the dry-up of the trees of *Eucalyptus* plantations and to make a recommendation for remedial measures.

1. 3. 2. Specific Objectives

The specific objectives of this study were:

- To investigate whether there is causal relationship between the soil physical properties (rooting depth/soil depth, bulk density,water holding capacity, and soil texture,) and the drying-up of the trees of *Eucalyptus* species,
- To investigate the correlation between topographic features (slope & aspect) and the drying-up of the trees of *Eucalyptus* species,
- To investigate the relative contribution/importance of drought to the drying-up of trees of *Eucalyptus* species,
- To investigate whether planting space caused the drying-up of the trees, and
- To investigate whether there is evidence of presence of root and soil pathogen as a cause to the drying-up of the trees of *Eucalyptus* species.

2. LITREATURE REVIEW

2.1. Causes of Tree Diseases

The many reasons for the disruption of the healthy growth of a tree can be divided into two main categories: non-living (abiotic) and living (biotic) factors. More than one factor can affect the health of a tree at any time. For instance, a useful distinction can be made between primary pests, which first and principally affect the health of the tree, and secondary pests, which have a less important influence and usually affect trees already weakened by a predisposing factor. The impact of insect pests is often increased by a previous weakening of the tree's vigour and a lowering of its natural resistance to infestation, for example through waterlogging or nutrient deficiencies. One of the most common predisposing factors is poor nursery management. Trees that become pot-bound as saplings do not develop a healthy root system and therefore grow poorly when planted.

Stress and off-site factors undoubtedly have a major role in determining the health or condition of trees, as do poor soil and drainage. However, undue emphasis on poor sites or adverse climatic events such as drought and frosts as primary causes of observed symptoms and damage to trees may prevent a more careful search for possible biotic influences.

2.1.1. Abiotic Causes

Eucalyptus is the most widely planted genus in tropical regions but the sustainability of those plantations is of concern since they are usually established on low-fertility soils and large nutrient exports occur every 6–7 years with biomass removal (Gonçalves *et al.*, 1997; Corbeels et al., 2005; Laclau, 2005). The effects of poor soil and generally adverse growing conditions on the health of trees, and their causal association with observed symptoms, needs careful examination. Nutrient disorders produce symptoms similar to those of virus diseases and other pest infestations or infections, and a lack of information often makes it difficult to make even a preliminary diagnosis of a problem. Abiotic factors that impair the health of trees are reviwed and discussed as follows:

2.1.1.1.Soil Conditions and Water Use

The soil in the root zone is a storage medium for a tree’s water supply, and the conduit which brings water in to contact with root surfaces. The physical and chemical condition of the soil are therefore profoundly important as influences on plantation water use. Equally important in both an ecological and a plantation management context are the effects of tree water uptake on the soil moisture and ground water conditions.

In rainfed plantations the amount of water that infilitrates the soil is significantly less than rainfall, due to evaporation of intercepted rain from the tree canopy and soil and litter surfaces. Besides, evapotranspiration in arid and semi arid area such as 'Wollo' is high and usually exceeds because of high temperature which is normally over 25^0C during the rainy season with occasional strong winds.

In rainfed plantations that can't access ground water, annual water use can't exceed soil infilitration for more than a few years. Young trees established on farmland may deplete soil water reserves for a period as the root system extends to greater depth, but use of this stored water becomes increasingly difficult as the rooting depth required increases. When the aceessible stored water reserve is exhausted, the plantation must depend on the current year's rainfall for its water supply. If rainfall is not sufficient to maintain an adequate supply, the growth of the trees will be reduced, leaf area will decrease, and in conditions of extreme water deficit the trees will die. To improve survival through prolonged periods of high water-stress (drought) it might be essential to locate the trees either where the soil is deep enough to store a sufficient reserve of water or where they can access ground water or irrigation.

2.1.1.2. Soil Conditions and Water Availability

Physical properties of the soil have a major influence on water availability and root water uptake, whether the water is derived from rain, irrigation or ground water. For a given volume of infiltrating rain water or irrigation entering the soil of the root zone, the fraction available for trees depends on the capacity of the soil to store water, how tightly it is held by the soil pores, and how readily it can flow to the roots. These are determined by the physical properties of soil texture and structure. Soil chemical properties, among which salinity is particularly important, may also profoundly affect the growth and water use of trees and other vegetation.

Moisture-Storage Capacity of the Soil

The plant-available water holding capacity of soil varies from arrond 50 to 400mm per meter of soil depth (Morris and Benson 2005). The maximum volume of water available to a plantation therefore depends on the depth of its root zone and on the water storage properties of the soil. In general, light coarse-textured soils drain quickly and store less water, but have higher matric potential (release water more readily) and greater hydraulic conductivity, than do soils with a larger percentage of clay, at the same moisture content. However, this is subject to the effects of soil structure and compaction, and it is possible for clay soils to have higher hydraulic conductivity than sandy loams in some condition. Trees and other plants can only extract water held at more than a certain minimum matric potential (the "wilting point"). Although the total amount of water stored by clay soils at field capacity is greater than the amount stored by sandy soils, a more rapid decrease in matric potential as moisture content falls may make the volume of available water actually less in some clay soils.

Therefore, Soil is the main indicator of a site's tree growth potential. The soil's physical properties determine the flow and retention of soil moisture and either enhance or hinder proper root development. The primary soil properties that affect the fertility of the soil includes texture, depth, organic matter content, and pH and water holding capacity of the soil. Texture and depth together determine how much soil moisture can be stored for tree survival through the dry seasons and growth during the wet seasons.

Soil Texture

Soil texture can influence plant growth and survival through its effects on soil moisture (Saxton, 1986), temperature (Fang and Moncrieff, 2001; Lloyd and Taylor, 1994), and nutrient availability (Reich *et al*, 1997), all of which influence microbial and root activity. Water retention and availability are affected by the soil texture (pore size distribution determines the amount of soil water available to the plant). Thus, soil texture is one of the more useful variables for predicting water relations. Changes in soil texture alter soil moisture, the potential for frost heaving where frost is present and surface soil erosion and compaction. *Eucalyptus* can grow in a wide variety of soil conditions but requires deep, fertile, well-drained loamy soil with adequate moisture for best growth.

Texture is determined by varying combinations of sand, silt and clay and influences the rate at which water and oxygen move through the soil. Optimum texture is essential for root growth enabling trees to take up nutrients and water. A high clay content in the soil inhibits moisture retention and proper root development. Such soils are subject to sealing and surface crusting when exposed to raindrop impacts. Light, sandy soils tend to lose moisture quickly, yet permit rapid root development. Sandy clay loams provide the superior medium for moisture and root growth, but are only found on the best sites.

Changes in soil texture create barriers to root growth. In addition, textural differences can create drainage problems. Either the soil is too dry or too wet. Soils with good porosity are capable of handling large quantities of water with no harmful effects to plant roots. Most landscape soils do not have ideal drainage conditions and thus rainy weather may be a challenge. Water-logged soils may lead to root decay and fungal root diseases. Consistently wet soils will have a foul odor caused by the anaerobic bacteria growing in it and roots may appear brown or black.

Soil Depth

Soil depth is the distance to an impenetrable layer, such as massive clay or rock, indicating the amount of soil potentially available for exploitation by plant roots. An important attribute of a soil is the amount of plant available water it will hold, which is largely determined by soil depth as well as soil texture and structure. The deeper a soil, the more available moisture it can hold. Soils less than one metre deep in a low rainfall belt (600 mm per annum or less) are likely to be 'droughty' and unsuitable for plantation forestry (SQDEEDI, 2010). Even soils with a high clay content but a shallow depth will have a small capacity to store water. Where the annual rainfall is more than1000 mm, soils less than a metre deep may be quite suitable for productive tree growth (SQDEEDI, 2010). Soil depth alone affects a tree's ability to anchor itself and influences the total amount of available nutrients. Furthermore, root development will be hindered in areas with shallow soils. Heavy clay layers or compacted layers or "pans" near the surface will restrict rooting and infiltration of rainwater. The depth of the soil profile exploited by roots will change with plantation age as the roots grew deeper.

Limited Growing Space and Soil Compaction

Tree roots need sufficient volume of soil to forage for the necessary nutrients as well as oxygen and water. Compacted soils have greatly reduced air spaces and poor drainage and barriers physically limit the area for roots to obtain needed resources from the soil. If the growing space for a tree roots is confined due to barriers or compacted soil it can cause the crown will die back until the tree is in balance again. The effects of restricted root growth last for years and can cause the death of even established trees. Compaction causes a decrease in porosity and an increase in soil bulk density and consequently in soil strength. Poor aeration, and reduced permeability to water (and therefore available soil water), may cause decreased tree growth (Rab, 1996; Grigal, 2000), but detrimental effects are not universal, and are affected by soil type (Gomez *et al*, 2002), climate (Miller et al, 1996), and the level of compaction (Jansson and Wa¨sterlund, 1999; Kabzems and Haeussler, 2005; Sanchez, 2006).

A greater distribution of roots through the soil profile was found in cultivated plots where bulk density was lower. Other studies have reported similar root distribution responses to limiting soil conditions (Gomez, 2002).

Compaction typically alters soil structure and hydrology by increasing soil bulk density; breaking down soil aggregates; decreasing soil porosity, aeration and infiltration capacity; and by increasing soil strength, water runoff and soil erosion. Appreciable compaction of soil leads to physiological dysfunctions in plants. Often, but not always, reduced water absorption and leaf water deficits develop. Soil compaction also induces changes in the amounts and balances of growth hormones in plants, especially increases in abscisic acid and ethylene. Absorption of the major mineral nutrients is reduced by compaction of both surface soils and sub soils. The rate of photosynthesis of plants growing in very compacted soil is decreased by both stomatal and non-stomatal inhibition. Total photosynthesis is reduced as a result of smaller leaf areas. As soils become increasingly compacted respiration of roots shifts toward an anaerobic state. Severe soil compaction adversely influences regeneration of forest stands by inhibiting seed germination and growth of seedlings, and by inducing seedling mortality. Growth of woody plants beyond the seedling stage and yields of harvestable plant products also are greatly decreased by soil compaction because of the combined effects of high soil strength, decreased infiltration of water and poor soil aeration, all of which lead to a decreased supply of physiological growth requirements at meristematic sites (Kozlowski, 1999).

Soil Bulk Density affects pore space; an increase in bulk density (e.g. by compaction) reduces water storage and decreases infiltration and drainage capabilities. The stone or coarse fragment content of the soil affects water storage, which decreases with increasing coarse fragment content. In addition, high soil bulk density, which generally increases with texture from clayey to sandy soil, can impede root growth physically, but its growth-limiting bulk densities occur at lower densities for fine-textured than coarse-textured soils (Mitchell *et al.* , 1982; Tuttle *et al*, 1988).

2.1.1.2. Drought

Availability of water to terrestrial ecosystems is a major determinant of ecosystem production and health because it supports plant growth directly and redistributes nutrients within landscapes (Aber and Mellilo, 1991; Schuur *et al.*, 2001). *Eucalyptus* is very important tree species in the tropical and subtropical zone. In order to introduce and plant successfully in arid and semi-arid lands, drought adaptation mechanisms of *Eucalyptus* and their adaptability to different drought conditions were studied by many authors, the results demonstrated that *Eucalyptus* genotypes adapted to drought-prone environment and plants growing under water deficit conditions adapt by maintaining tissue water content above values critical for cellular damage. High drought adaptation capacity of *Eucalyptus* populations with fixed xeric morphological and physiological adaptations, such as a small shoot/root ratio, thick leaves, high water-use efficiency, low growth rate, and/or high osmotic adjustment etc., would not be able to take advantage of humid conditions and mild environment, but they could be chosen for predictable severe drought conditions. In addition, climatic variable of natural habitats of *Eucalyptus* populations was main factor which contribute to the development of different drought adaptation mechanisms. But it doesn’t mean that it can grow in the absence of moisture.

Lack of water causes root damage and may lead to death if the plant is unable to take up water. Symptoms of drought include: Loss of turgor in needles or leaves, drooping, wilting, yellowing, premature leaf or needle drop, dieback, poor growth, stunting, plant death; predisposes plant to secondary problems and cultural injuries. Symptoms from drought are often not evident until the year after the drought, and may indicate permenant root damage.

2.1.1.3. Climate Change

Current knowledge on increased risk of damage to forests caused by pest or pathogen outbreaks arising from climate change is limited (Chakraborty, 2005). However, increased climatic variability with extremely wet and extremely dry periods may compromise the generally good health of Australia’s forests (Preston and Jones, 2006.) Tress stressed by water-logging or drought are more susceptible to attacks by pests or diseases (Sutherst and Maywald, 1999). The fungal pathogen phytophtora cinnamomi is of particular concern to forests in the south of Australia as it is very damaging and thrives in this conditions (Preston and Jones 2006)

Droughts can have negative impacts on plantation forests by reducing productivity, increasing mortality of saplings and seedlings and increasing vulnerability to pests and pathogens (Pittock, 2003). Forests could also face increasing competition from other users of water resources as the frequency of drought is projected to increase.

2.1.1.4. Topography

In terms of topography, extreme slopes and shallow depressions may present undesirable moisture conditions. Typically, as slope increases the soil becomes thinner and poorer, which is an inadequate planting medium. Shallow depressions may have standing water most of the year. As far as aspect is considered, erosion rates are relatively higher on the south-facing slopes of a land than on the north-facing one. This is also confirmed by the shallowness of soils on the south-facing slopes than on the north-facing ones. The south facing slopes are drier because of more radiation and higher evapotranspiration, which decrease weathering and retard soil development. But, a drier environment also has a scarcer vegetative cover which promotes erosion. Although the rock type is the main factor controlling the weathering rate, slope aspect effects not only weathering but also soil erosion (Shrestha, 1997).

2.1.2. Biotic Causes

Some pest groups are better known than others simply because they are easier to see. Insects are frequently found on trees although many are casual feeders and not serious pests, and some are beneficial (natural enemies). Fungi are frequently seen on dead and decayed organic matter, but they may not necessarily be the primary cause of the symptoms observed. Most fungi in nature are saprobic (living on dead or decaying tissue) and only a very small proportion are pathogenic. Insects and fungi are relatively easy to distinguish by direct observation, while the remaining pest groups are not. Several other living agents occur on trees, including mosses, lichens and epiphytes such as bromeliads, but these have only a superficial impact on tree health.

2.1.2.1. Insects

Eucalyptus are prone to intense insect herbivory (Ohmart and Edwards, 1991; Elliott *et al.*, 1998) which can cause significant decreases in growth in both plantations and naturally regenerating forests (Carne *et al.*, 1974; Elliot *et al.*, 1993; Stone *et al.*, 1998). Dieback in rural areas often involves repeated defoliation by a variety of native insects. Severely defoliated trees become susceptible to fungi, which cause lesions (cankers) in the branches, causing them to die back.

The insects involved include psyllids, scarab beetles, chrysomelids (leaf beetles), leaf hoppers, sawfly larvae, scale, gall-forming insects and skeletonizing caterpillars (Landsberg and Cork, 1997). In addition, outbreaks of phasmatids (stick insects) can occur in forests. The relative importance of a particular species of insect can vary over time, and since different insects prefer different species of *Eucalyptus*, the relative susceptibility of *Eucalyptus species* changes (Landsberg and Cork,1997).

In recent years, psyllids have been the most prominent defoliating insect in Blakely's red gum (*Eucalyptus blakelyi*) woodlands on the Central and Southern Tablelands of Australia. Psyllid outbreaks have also been observed on yellow box (*Eucalyptus melliodora*) in the Hunter Valley and river red gums on the Western Plains of Australia. Defoliation by scarab and chrysomelid beetles was a major contributor to dieback on the New England Tablelands in the late 1970s, but their populations collapsed during the 1980–83 drought, and since then infestations have not been as severe (Landsberg and Cork,1997). Several factors appear to contribute to the occurrence of insect outbreaks.

Favourable Weather Conditions

Insect outbreaks generally occur when the weather favours the insect's breeding and survival.Many species of insects are susceptible to extremes of heat or cold or prolonged wet or dry spells (Landsberg and Cork,1997).

Effects of Clearing and Pasture Improvement on Scarab Beetles

Scarab beetles that feed on eucalypt foliage (e.g. Christmas beetles, *Anoplognathus* spp. or smaller *Sericestis* spp.) have larvae that feed on the roots of pasture plants and on soil organic matter. These beetles have become a greater problem on rural eucalypts, probably because the number of scarab beetles per tree increases as the ratio of trees to pasture declines. Populations of scarab larvae can build up to greater densities in improved pastures than in native pastures. However, soils beneath improved pastures usually dry out faster than those beneath native pastures so that populations of scarab larvae in improved pastures may collapse to a greater extent during dry spells. This means the relative abundance of scarabs in improved versus native pastures depends on weather patterns (Landsberg and Cork, 1997).

Reduced Effectiveness of Control By Natural Enemies

In healthy bushland, parasites and predators may kill a large proportion of insects and thereby reduce the rate at which their populations increase. For example, parasitic wasps locate hosts and at least some species breed more successfully if the density of their host is high. Birds tend to feed more intensely on localised concentrations of insects, which may reduce the likelihood that an insect outbreak will develop (Davidson, 1992).

Many insect-feeding animals that may have once controlled insects have disappeared from or become rare in rural areas, chiefly as a result of the loss of farm bushland. Bandicoots, which eat scarab larvae, and gliders, which often eat insects on trees, have disappeared from much of the Tablelands. Densities of birds in areas affected by dieback are about 10% of those in healthy woodland. In addition, the number of bird species is dramatically reduced in small patches of bushland that have been taken over by aggressive birds such as Noisy Miners. The activities of some parasitic wasps and flies depend on nearby sources of food, such as nectar from tea trees (*Leptospermum*) or blackthorn (*Bursaria spinosa*). Some species of wasp and fly seldom fly more than 200 metres from such sources of food, so these parasites can not control insects in areas where nectar-bearing plants are absent (Davidson, 1992).

More Nutritious Foliage

Foliage with enhanced nutritional value (particularly available nitrogen) can increase the number of young each female insect produces (fecundity) and may increase the growth rates and survival of the young insects (Landsberg and Cork,1997).

2.1.2.2. Diseases

Phytophthora root rot

Phytophthora cinnamomi (cinnamon fungus) is a major cause of dieback of eucalypts and many other native plants in Western Australia, Victoria and Tasmania. Both chronic lack of water and prolonged inundation due to river regulation appear to contribute to dieback of river red gums (*Eucalyptus camaldulensis*); and fungal diseases, such as Phytophthora root rot, can be spread by earth-moving equipment and vehicles (Nadolny, 1995).

Other Diseases

Several other fungal diseases affect leaves, stems or roots of *Eucalyptus*. The mushroom forming fungus, *Armillaria luteobubalina*, causes a severe root rot. It can become established in old stumps and spread vegetatively from tree to tree via root contacts, resulting in roughly circular patches of dieback-affected trees (Nadolny, C., 1995).

2.1.3. Natural Deaths of Aging Trees

The symptoms of natural aging can be difficult to separate from those of dieback. Aging trees (often called over-mature trees) usually have thinner, more irregular crowns, many dead branches and hollows. Larger, older trees are less vigorous; the ratio of leaves (which produce food) to supportive tissue (which needs food) is smaller; wood decay accumulates; and the risk of wind-throw increases (Nadolny, C., 1995).

2.1.4. Self-thinning of Dense Regrowth Stands

Regrowth forests are often denser than the original forests. As a stand develops, competition for resources intensifies. Smaller trees tend to be crowded out, lose condition and eventually die. During episodes of dieback when all trees are under stress, trees within regrowth stands are often in especially poor condition, because they tend to be crowded by larger surrounding trees, and are less capable of competing for resources (Nadolny, 1995).

3. MATERIALS AND METHODS

3.1. Description of the Study Area

3.1.1. Criteria of Selection of the Study (Case) Areas

A reconnisance survey was made to find *Eucalyptus* plantations consisting of a significant amount of dried-up populations or where the dry-up is prevelent that is believed to help to find out the possible cause. The areas that were surveyed: Shashemene, Lode Hetosa Woreda, Addis Ababa, Adama, and Kombolcha. Of these Lode Hetosa Woreda, Arsi Zone and Kombolcha Woreda, South Wollo Zone were selected as case areas since the extent of dry-up were relatively severe and the size and the spatial distribution of the population of the plantation was convinient for making appropriate sampling design. Consequently the study was conducted in two selected case areas of the highlands namely: Kombolcha, South Wollo Zone of Amhara Region & Lode Hetosa, Arsi Zone of Oromia Region.

3.1.2. Case Area I: (Gallessa, Kombolcha Woreda)

One of the case area called Gallessa that is found on the way from Kombolcha to Dessie of South Wollo Administrative zone of Amhara Regional State is located between latitude 1225200 - 1225600 and longitude 575100 - 575500, where the problem had relatively high prevalence. It is about 380km from Addis Ababa in the north direction and 20 km from the zonal capital Dessie. The Woreda town is Kombolcha. The map of both case study areas is shown in fig.1.

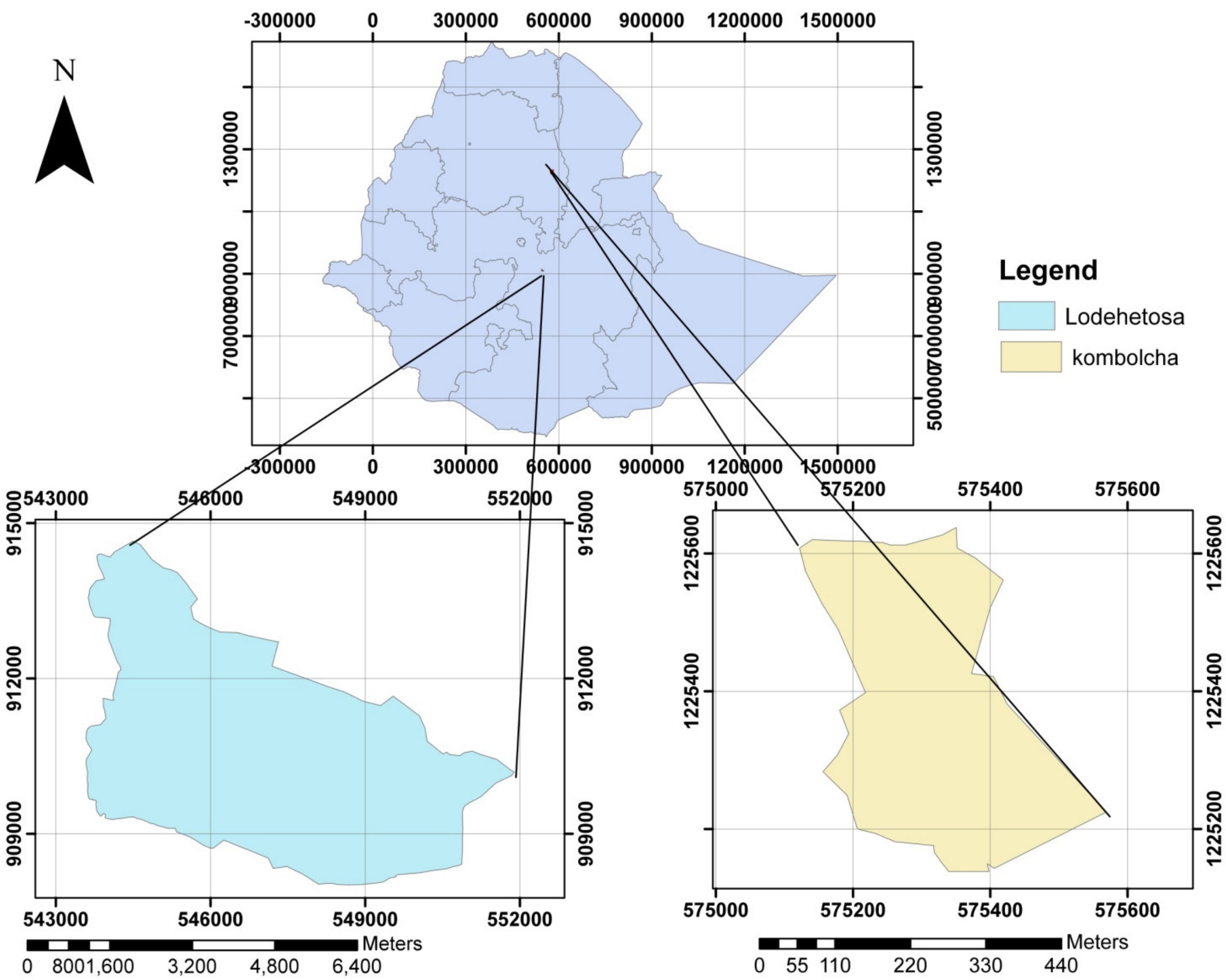


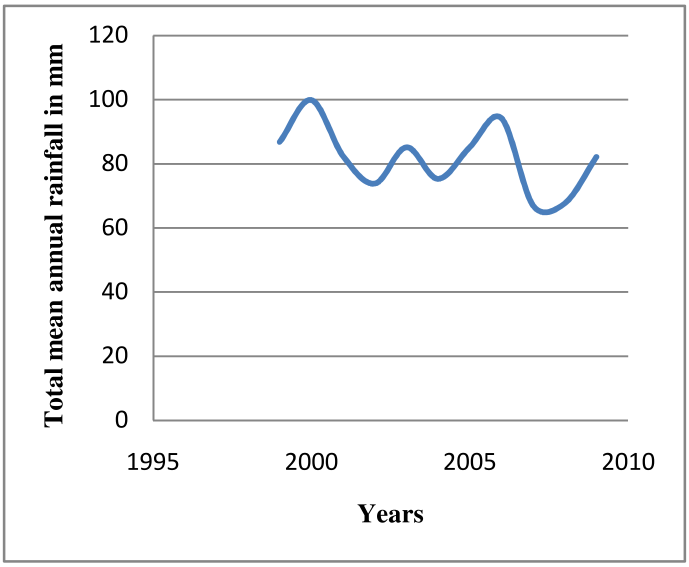
Figure 1: The map of the study areas

3.1.1.1. Soil

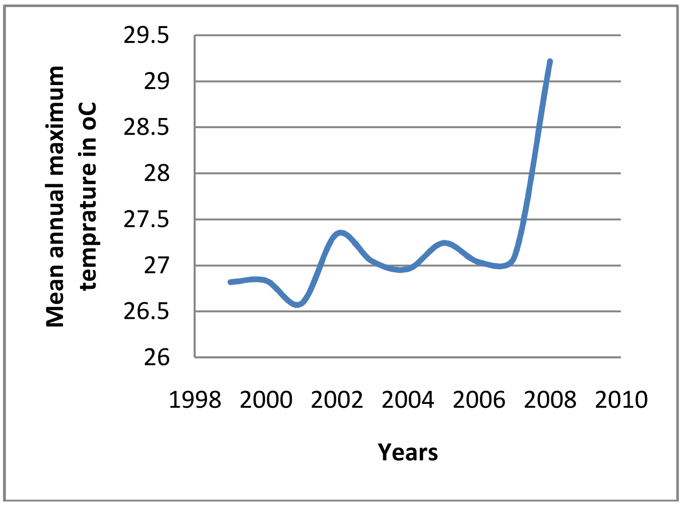
The major soil type in the study area is loam (Boda), sandy loam. The soil is fertile and is highly suitable for ceareal. However, as the area is highly populated there is a severe erosion in the area. Since the land scape has lost its natural vegetation the soil of the surrounding hills are degraded with frequent rock outcrops.

3.1.1.2. Climate

The rainfall in the study area is bimodal. The longer rainy season extends from June to September, which supports the major crop production. The shorter rainy season comes in March and April and allows minor crop production. The physiographic characterstics of the study area include: altitude 1425-2820m a.s.l., mean annual rainfall 900-1000mm , mean annual temprature 19˚C, mean maximum annual temprature 27˚C, mean minimum annual temprature 20˚C, and the crop growing period 60-180days. The trend of the mean maximum annual temprature and the mean total annual rainfall was shown in fig. 2 A & B respectively.



A



B

Figure 2. Case area I of A) Rainfall map , B) Temprature map

3.1.1.3.Topograpphy

Topography of the study area is comprised of plain (3%), Mountainous 23.5%, Rugged and undulating 73.5%.

3.1.1.4. Vegetation

Major vegetation types are *Eucalyptus camaldulensis*, *Eucalyptus globulus* , and Endigenous and exotic *Acacia* species.

3.1.2. Case Area II (Lode Hetosa Woreda)

The study was also replicated to Lode Hetosa Woreda, Arsi zone, Oromia Regional State between latitude 909000-912000˚E and longitude 543000-552000˚N. It is about 175 km from Addis Ababa in the Southeast direction and 50km from the zonal capital Assela. The Woreda town is Huruta. Arsi zone is one of the 12 zones of Oromia Regional State. It is highly populated area in which the average family size is eight (Lodehetosa Woreda office of Agriculture and Rural Development, 2005). Where both study sites are located in the country is shown in the map (fig.1) of section 3.1.2.

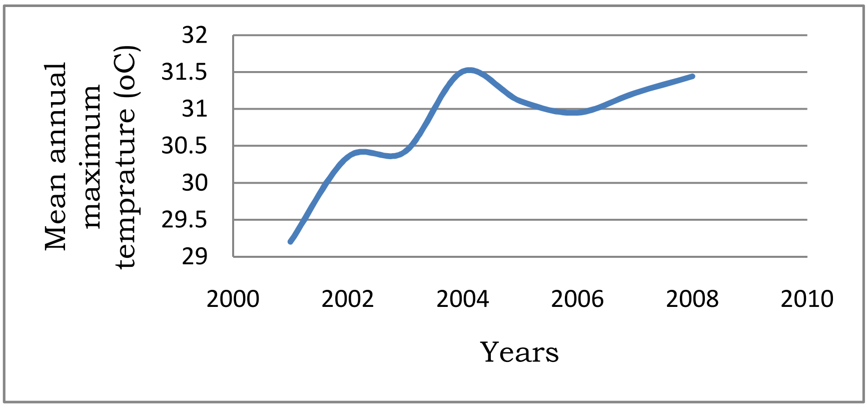
3.1.2.1. Soils

The soil in the study area is light brown with loamy-clay texture.the soil is fertile and is highly suitable for ceareal and vegetable production such as onion. However, as the area is highly populated there is a severe erosion in the area. Since the land scape has lost its natural vegetation the soil of the surrounding hills are degraded with frequent rock outcrops.

3.1.2.2. Climate

The rainfall in the study area is bimodal. The longer rainy season extends from June to September, which supports the major crop production. The shorter rainy season comes in March and April and allows minor crop production. The physiographic characterstics of the study area include: altitude 1800-2500m a.s.l., mean annual rainfall 800-1000mm , mean annual temprature 19˚c, mean maximum annual temprature 27˚c, mean minimum annual temprature 10˚c, and the crop growing period 60-180days (Lodehetosa Woreda office of Agriculture and Rural Development, 2005). The trend of the mean maximum annual temprature and the mean total annual rainfall was shown in fig. 3 A & B respectively.

A



B

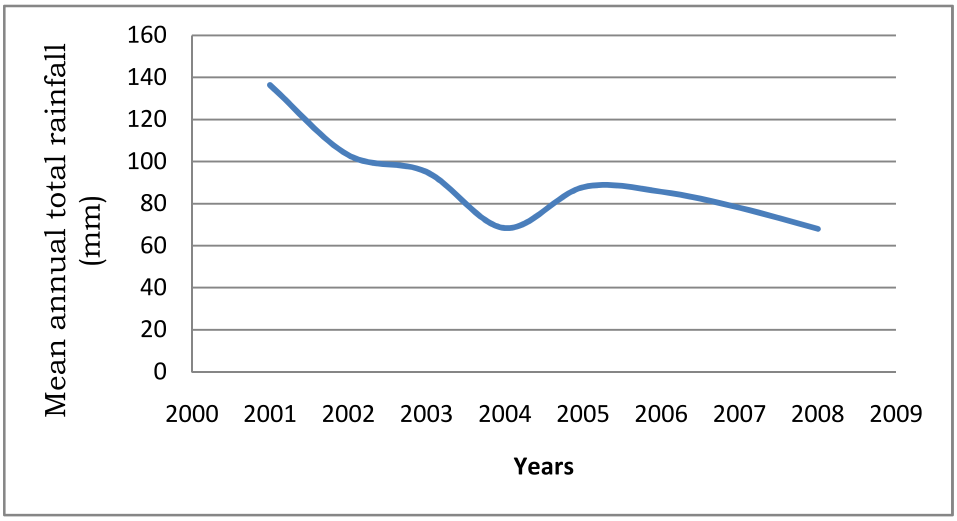


Figure 3. Case area II of A) Temprature map, B) Rainfall map

3.1.2.3. vegetation

Apart from few trees arround homesteads and farm borders , native trees are rarely seen in the landscape of the study area. There are only some *Accacia* species, *Croton macrostachyus, Cordia africana, Ficus* species, *Calpurnia aurea, Rhus species* and other shrubs that are sparsely seen in the farmlands and on adjacent hills. As a result, wood for construction and firewood is hardly available. The scarcity of firewood in the area is so severe that cow dung is widely used as firewood. Had it not been for the adoption of eucalyptus in the area, the community would have been in a severe problem of wood shortage for construction and firewood (Lodehetosa Woreda office of Agriculture and Rural Development, 2005).

3.1.2.4. Agriculture and natural resources

The farming system is a mixed crop and livestock production including intensive cultivation of onion for income generation. The farmers use oxen to cultivate their farmlands. Only few farmers use tractors for cultivation and combine harvesters for harvesting and threshing through renting from investers working in the area. The main crops cultivated in the area are wheat, barley and maize. The main livestock to be reared are cattle and donkeys followed by goats and sheep. Grazing lands, however, are shrinking. According to information from the Lodehetosa Woreda Agriculture Office (2005), much of the land in the woreda is used for crop production (70.89%). Rangelands, forestlands and others, including settlements, account for 16.87%, 4.54%,7.7%, respectively. About 84.93% of the forest area is natural woodlands with the main species of *acacias* and the remaining part is plantation forest with *Eucalyptus* contributing more than 85% of it. According to the same source the woredas agro ecological set up is divided in to lowland (7%), middle altitude (58%) and highland (35%)(Lodehetosa Woreda office of Agriculture and Rural Development, 2005).

Overcutting of the existing trees without replacement and improper land use methods had resulted in loss of land productivity and shortage of wood for subsistence requirements. The problem, especially the short of wood has forced the people to plant some fast growing tree species like *Eucalyptus* to balance the demand and supply of wood requirements .

3.2. Study Design

In each case/study area a systematic sampling was employed. However, before sampling the plantation areas were blocked and stratified based on height and diameter to homogenize the the population to be studied. A random starting point were selected and sampling was repeated at 100m interval. In general, since the spatial distribution of the dried-up populations of the plantation is scattered and cover the entire population 20m×20m quadrats at 100meters interval were made along a transect lines (Michelsen, *et al,* 1996) that covered the entire population. To demarcate the plot boundaries strong wooden pegs were used. To avoid the edge effect the plots were laid out 20m far from the edge of the plantation; the distance is modified according to the plantation structure from the recommended value of 50m for natural forest inventory. In each quadrats three different data sets namely: **soil**, **vegetation** and **landscape** feature were collected. The two major data acqusition methods in this study were **laboratory analysis** and **field measurement** of the soil and vegetation properties that possibly cause or lead to drying-up of the trees.

3.3.1. Vegetation Sampling

As far as vegetation is concerned height and diameter of each tree in each quadrat was measured to determine the height and diameter distribution class of the affected trees. Rooting depth of sample trees (i.e., 15 from healthy and 15 from dried-up trees) was also measured to compare whether there was a significant difference or not. In the mean time rooting condition of both dried-up and healthy trees were also observed. The total number of trees and the number of trees dried-up were taken on a total count basis to determine the stand density and the intensity of drying-up respectively per each plot.

Root Pathology

From the trees observed for rooting depth number of primary roots (roots originating directly from the root collar or from the tap root) were counted up on observation and they were registered on a pre-prepared record sheet. From the trees observed for rooting depth, samples having a length of 15-20cm were taken from a part of the tree root that show a symptom of disease by using techniques modified from (Jung *et al.*, 1996, 2000). The samples were taken in such a way that it includes the part of the tree in which the disease symptom advances, i.e., the sample consisting of both the dried and healthy part then after the excess soil was knocked off and the sample was placed in a bag and the bag was coded/tagged and they were taken to Ethiopian National Soil Laboratory for analysis of presence of phytophtora, a pathogen that causes root rot disease of trees which inturn inhibits moisture absorption and nutrient uptake.

Plant tissue was washed with hand soap to gently remove all of the soil associated with the plants then rinsed thoroughly with tap water. The plant tissue was then rinsed for 10 sec in 0.5% sodium hypochlorite solution, rinsed with sterile distilled water, and blotted dry on sterile paper towels. The sections from the edge of the lesion are placed on growing medium agar. The grown cultures were examined for the presence of *Phytophthora* sporangia, gametangia and morphology in general using a light microscope.

3.3.2. Soil Sampling

In each quadrats the soil was sampled for analysis of both for soil physical characterstics (i.e., soil texture, water holding capacity, bulk density, and soil depth and rooting depth) and for detection of presence of possible soil pathogen and all the samples were analysed in Ethiopian National Soil Laboratory.

Soil Physical Characterstics

According to Sumner and Stewart(1992) a composite soil samples from every corner of the plots were taken to a depth of 20cm with the help of augers and then the samples were kept in plastic bags and the bags were tagged from which plot and transect it was taken. Finally all the soil samples were collected and taken to Ethiopian National Soil Laboratory for both soil texture and water holding capacity analysis.

For bulk density determination undisturbed soil samples were taken from the center of each plot with coarse sampler by pushing it in to the undisturbed soil to a depth equal to the height of the coarse sampler with the help of a wooden hammer. Then the soil in excess was knocked off from the coarse samplers and the coarse samplers from the same plot are kept in plastic bag and tagged from which plot and transect it was taken and finally they were collected and taken to the the Since rooting depth observation is destructive, in each plot one from the healthy trees and one from the dried ones were observed for root depth. In addition to soil depth rooting depth was measured for both healthy and dried trees assuming that those trees that extend their roots into the rock layers have an advantage of resisting drought by accessing moistures found in the rock layers. To measure the rooting depth pits having a size proportional to the roots each tree sampled were dug down the profile along the roots in such a way to see where the roots end. Trees having relatively of the same diameter size were taken for rooting depth measurement and root condition observation.

Soil Pathology

A composite soil samples were taken from the top and to a depth of 20cm and from around the root zones of both the healthy and dried ones by using techniques modified from (Jung *et al.*,1996, 2000). The soil samples were taken from those trees that were observed for rooting depth with attention paid to sampling along main lateral and tap roots. The soil was taken with a sterile material to avoid contamination and mixed and kept in a medium that is favorable for a pathogen to survive. At the end the soil samples were taken to plant disease laboratory for analysis of any evidence of disease causing pathogen that may be attributed to the cause to the drying-up of the trees upon comparison for the healthy and dried ones.

3.3.3. Laboratory Analysis

3.3.3.1. Soil Texture

All the soil samples were crushed and passed through a 2 mm sieve before analysis to sort out rocks, twigs, and roots. Soil particle size distribution was determined using the Bouyoucos method in which hydrometer reading was taken at 40 secs and 2hrs, and the proportion of sand, silt and clay calculated (Bouyoucos, 1962).

3.3.3.2. Water Holding Capacity

It was determined on undisturbed, non-sieved samples, as the weight difference between water saturated and oven-dried (105^{o}C) soil. With the same soil samples the water holding capacity of the soil was also analysed by determining the the permanent wilting point and field capacty of the soil in the laboratory and taking the difference value.

3.3.3.3. Bulk Density

Bulk density was determined on undisturbed soil samples using a steel cylinder of 100 cm^3 volume (5 cm in diameter, and 5.1 cm in height) (Blake and Hartge, 1986). The smples taken with a core-sampler were oven dried and bulk density was determined by weighing, drying at 70^{0}C to constant weight and re-weighing known soil volumes and dividing the mass obtained by the volume of the core samplers.

3.3.4. Topographic Features

Since **altitude**, **slope**, and **aspect** may have a relationship with the drying-up of the trees through their effect generally on the temperature and moisture, they were measured per each plot using GPS, clinometer, and compass respectively.

3.4. Data Analysis Method

Collected data were summarized, ranked and expressed using simple descriptive statistics such as percentages, graphs etc. The relationship of the data taken with the intensity of drying-up of the trees were assessed statistically by Pearson's Correlation Method.The strength of the existing relationship between the drying-up of the trees and soil depth, slope, bulk density, water holding capacity, stocking density, % sand, % clay, and % silt were compared using coefficient of the correlation. ANOVA was used to identify whether there is a significant difference between rooting depth of the dried trees and the healthy trees. The name of the statistical software used for data analyis was statistics 7 (www.statistics.com).

4. RESULT AND DISCUSSION

4.1. Soil Physical Properties and Eucalyptus Drying-up

4.1.1. Soil Depth and Rooting Depth

The measured soil depth plot mean values for both case study areas where the dry up occured were very low (≤1m) in almost all the plots where the data were taken. The values of the soil depth for each plot are shown in annex 5. The correlation analysis of mortality rate and soil depth showed that mortality rate of E*ucalyptus camaldulensis* is negatively correlated with soil depth with a correlation coefficient of r= -0.8507 and -0.9393 for both case area I and II respectively with a corresponding P value of 0.0001 for both case areas. The correlation coefficient and the corresponding p-values of all the parameters is shown in Table 1.

Table 1: Pearson correlation coefficients (r) for soil physical characterstics with mortality rate for stands sampled in 2009 in Kombolcha, South Wollo & Lode Hetosa, Arsi zone, Ethiopia.

Variables	Pearson correlation (r) of mortality rate of CA_1[1]	P- value	Pearson correlation (r) of mortality rate of CA_2[2]	P- value
Bulk density (g/cc)	0.0521	0.8536	-0.0064	0.9859
Water holding capacity (%)	-0.2529	0.3632	-0.0322	0.9297
Sand (%)	-0.0749	0.7908	0.0380	0.9170
Silt (%)	0.2440	0.3808	0.3258	0.3583
Clay (%)	-0.0520	0.8539	-0.3178	0.3708
Slope (%)	0.3288	0.2314	0.2466	0.4922
Soil depth (cm)	-0.8507**	0.0001	-0.9393**	0.0001
Population density (No. Of trees/plot)	0.3643	0.1819	0.2205	0.5405

**pearson correlation coefficient was significant at p<0.001

[1] Case area 1: Kombolcha, South Wollo, Ethiopia
[2] Case area 2: Lode Hetosa Woreda, Arsi zone, Ethiopia

The scater plots how mortality rate and soil depth are related together with the regression line for both case study areas I & II are shown in the figures 4 & 5 respectively.

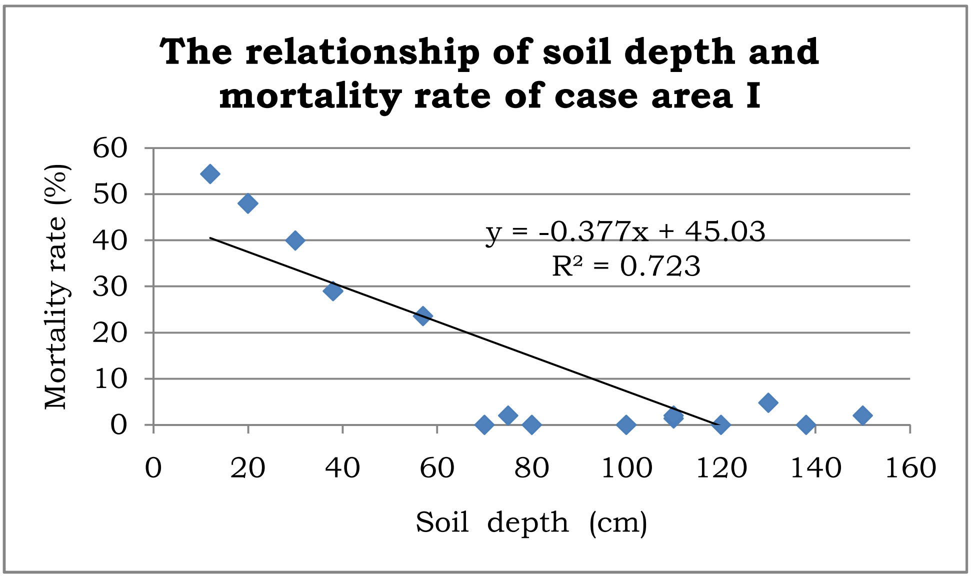


Figure 4: A scater plot graph showing the relationship of mortality rate and soil depth in case area I (Kombolcha, South Wollo) in 2009.

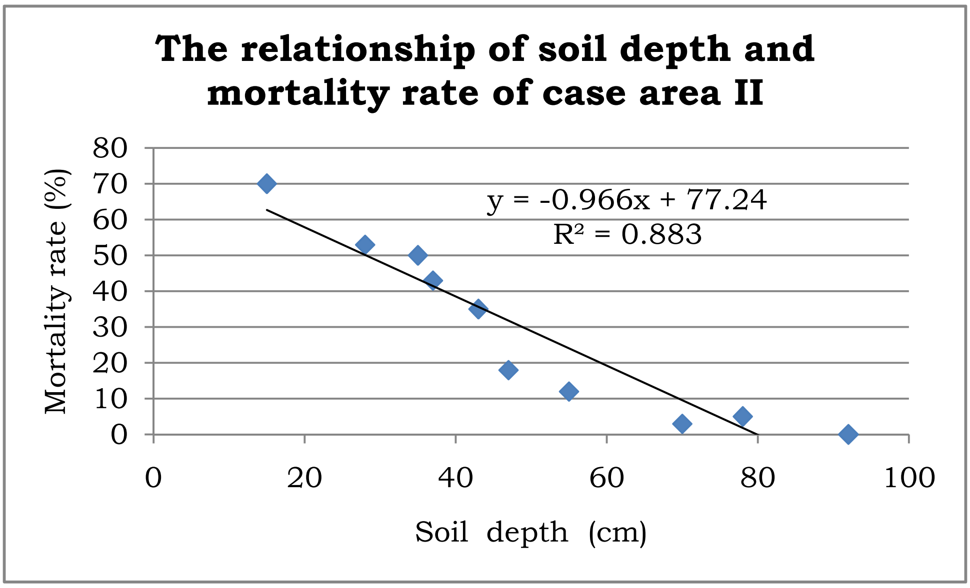


Figure 5: A scator plot graph showing the relationship of mortality rate and soil depth in case area II (Lode Hetosa, Arsi Zone) in 2009.

From the analysis of all the data of the different parameters taken only soil depth found to be the likely cause of *Eucalyptus* drying-up. Despite the deep soil requirement of *Eucalyptus* spp. the measured soil depth mean values for both case study areas where the dry up occured were very low (≤100cm) in almost all the plots where the data were taken.This shallow soil depth reduces the available soil moisture that can be accssed by the deep tap root and the lateral or feeder roots of *Eucalyptus* spp. In addition to the low soil moisture reserve, the possibility of shallow soils losing their moisture reserve through evaporation is very high.

According to personal communication with some of the local peoples, the site where the plantation established was under intensive cultivation of crops before the establishment of the *Eucalyptus* plantation. Such life history of the area together with the rugged and undulating topography makes the area shallow soil or leptosol.

Shallow soil depth was uniform for all trees but one might ask why some trees survived and the others dried-up. Up on root depth observation and ANOVA of rooting depth (table 2) of roots of all those sampled trees that dried up were found to encounter continuous & impervious rocks layers (Fig. 6, A) that prevents the tap root from going down and accssesing the moisture reserve of the deep rock and soil layers (Fig. 7, E,F,G) & annex 7.

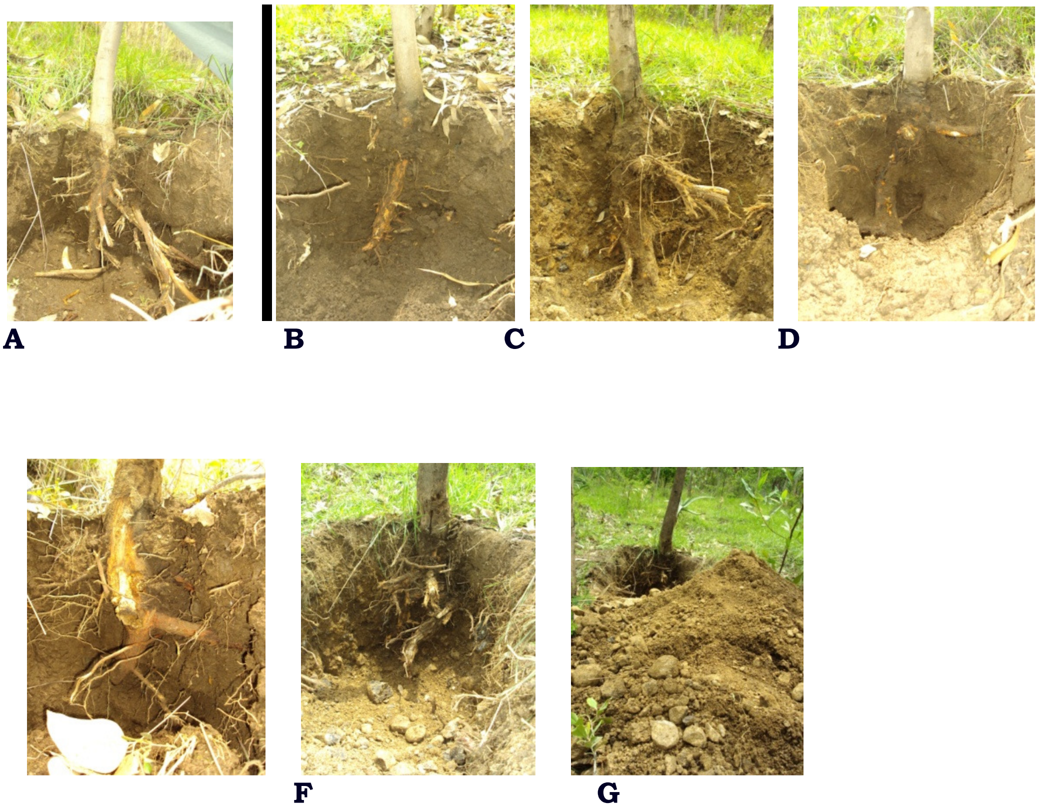
Table 2: The one way ANOVA for rooting depth of 30 trees (15 dead & 15 live trees) sampled from Kombolcha, South Wollo, Ethiopia

SOURCE	**DF**	**SS**	**MS**	**F**	P
BETWEEN	1	7332.03	7332.03	5.01	0.0334
WITHIN	28	41014.3	1464.80		
TOTAL	29	48346.3			

A **B**

Figure 6. A) shows an impervious rock layer B) shows a relatively weathered and fractured rock layer

However, all the roots of the healthy trees were relatively found to be found deep because of deep soil accumulation as a result of some physical barriers such as soil and water conservation structures and availability of rocks that underwent fracturing to start weathering (Fig. 6, B). This spatial variability of the area in terms of soil depth gave the opportunity to the live trees to resist the extended drought in that particular year. This result is in consistent with a study on the occurrences of tree deaths in young, 3-6 year old *Eucalyptus globulus* plantations established on farmland in south-western Australia was found to be strongly related to factors indicative of poor soil water storage capacity. In the same study seven years after planting tree survival was significantly less on soils < 2m deep compared to >2m deep (22% versus 70%) (Harperâ ,et al., 2009).



E

Figure 7: A piture showing root status of trees of A, B, C, D) healthy E, F, G) dried-up and encountered a rock layer from which masses of rock fragments were collected and piled (F& G) and a big mass of stone(E) when a pit was dug around the root of dried trees.

The other possible evidence that supports soil depth caused to the dry-up is that in most cases the dry-up occurred on those trees planted on the edge of a dissected land or on far end of a land whose soil was taken up by erosion or landslide such that one side of its profil is exposed to the outside environment (Fig. 8).

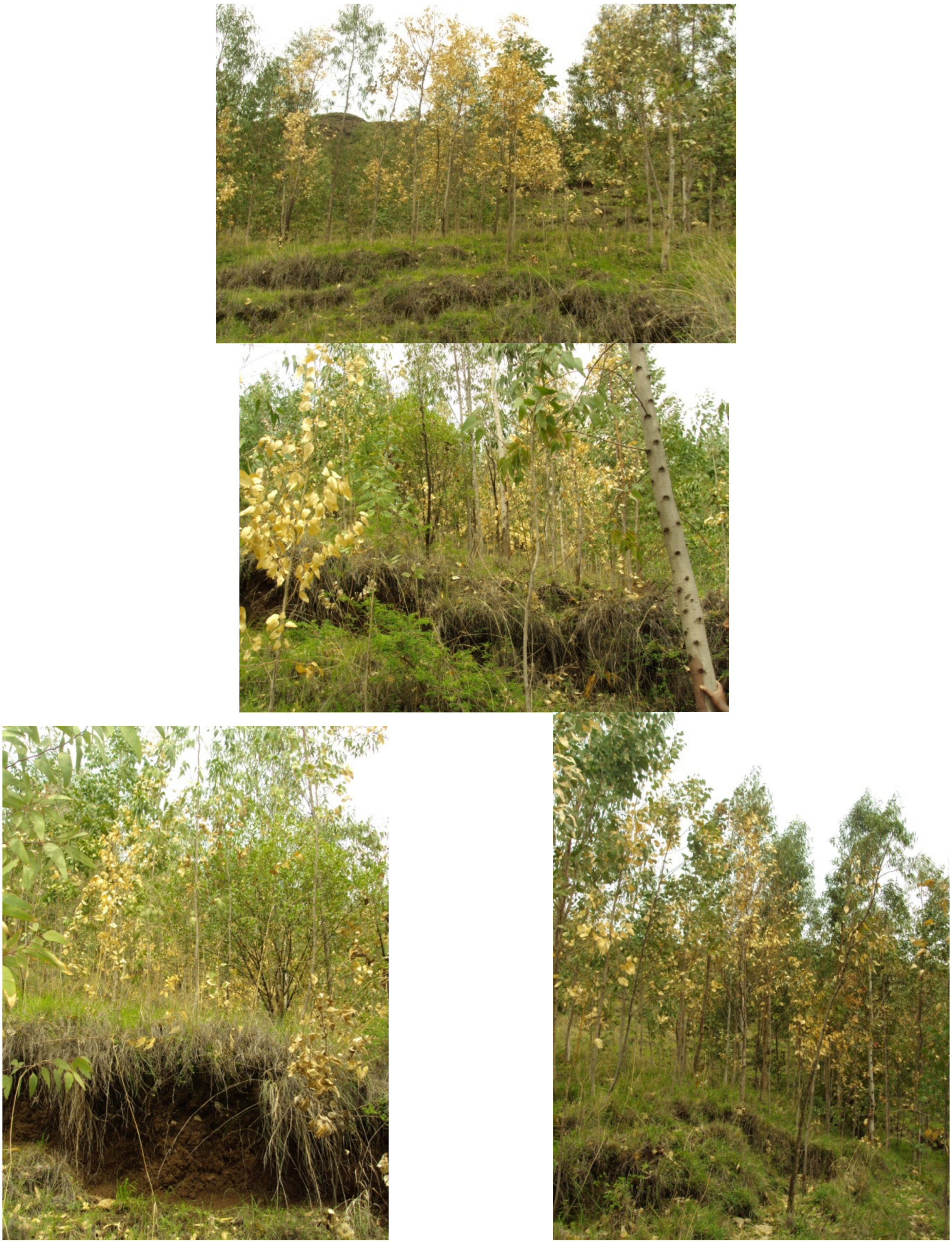


Figure 8 :A picture showing the incidence of dry-up of trees of *Eucalyptus species* in the landscape.

On such dissected lands that their vertical soil profile is dissected and exposed to the external atmosphere such as wind and high temprature, the rate of evaporation would be high and the potential of the soil to hold water for extended period of time would be very low because of low soil volume. In addition to this the one way ANOVA (d.f.=1, *P*=0.0334) of rooting depth of a total of 30 trees 15 trees from the dead and 15 trees from the live ones showed that there is significant difference between rooting depths of the live and dead trees which inturn show the rooting depth of the live trees is significantly higher than the rooting depth of the dead trees. The results of the analysis of varience is shown in Table 2.

4.1.2. Soil Texture

According to the textural analysis of % clay, sand & silt of all plots both case study areas are categorized under loam and sandy loam. However, the correlation analysis showed that mortality rate was not significantly correlated with sand, silt, and clay content in both case area I & II, respectively (Table 1) of section 4.1.1.

4.1.3. Water holding capacity

Though it is insignificant statistically water holding capacity (the difference between permanent wilting point and field capacity) and mortality rate had a correlation coefficient of -0.2529 and -0.0322 for both case area I and case area II. The soil texture class of both case areas were loam and sandy loam. These soil texture classes have relatively good soil water holding cappacity. Therefore from the result water holding capacity did not have any causal relationship with the dry-up.

4.1.4. Soil bulk density

The relationship of soil bulk density and mortality rate of trees of each plot for both case study areas is shown in figures 9 and 10. From the graph soil bulk density was more or less similar for all plots and according to lireatures all values of the bulk density were ideal. Thus it had very weak correlation with the dry-up.

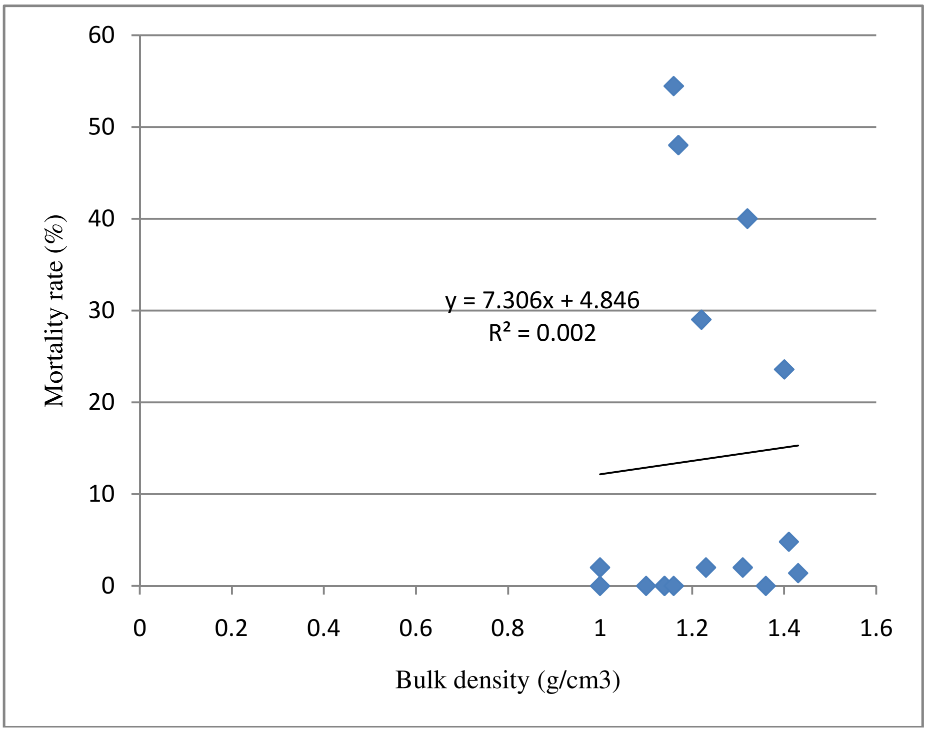


Figure 9: A scater plot graph showing the relationship of mortality rate and bulk density in case area I (Kombolcha, South Wollo) in 2009.

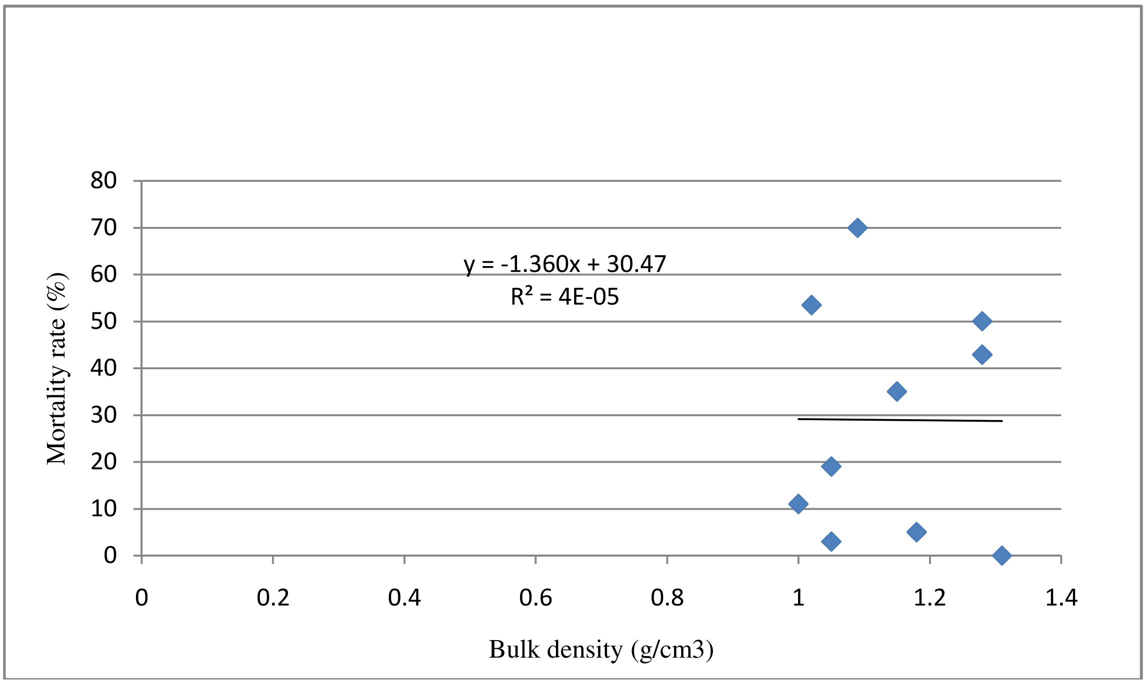


Figure 10: A scator plot graph showing the relationship of mortality rate and bulk density of the plot in case area II (Lode Hotesa Woreda , Arsi zone, Ethiopia) in 2009

4.2. Topographic Factors and Eucalyptus drying-up

4.2.1. Slope

The result of the correlation analysis for slope and mortality rate of both case study areas is shown in the Table 1. The scator plot for slope and mortality rate is also presented in fig. 11 & 12. From the graph and correlation coefficient of both case area I & II slope contributed some to the dry-up of the trees though it is insignificant statistically.

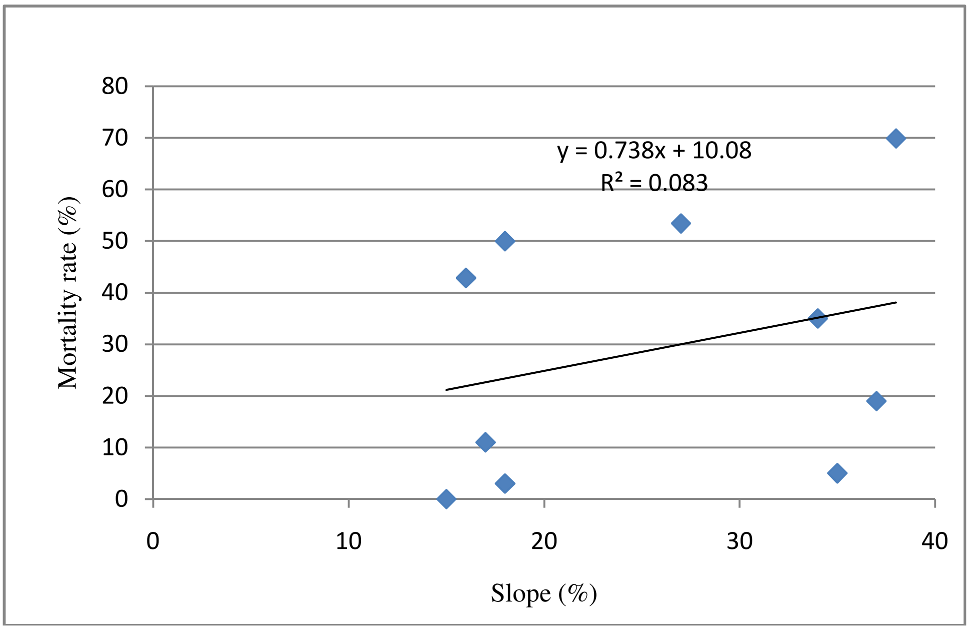


Figure 11. A scator plot graph showing the relationship of mortality rate and percent slope of the plot in case area II (Lode Hotesa Woreda , Arsi zone, Ethiopia)

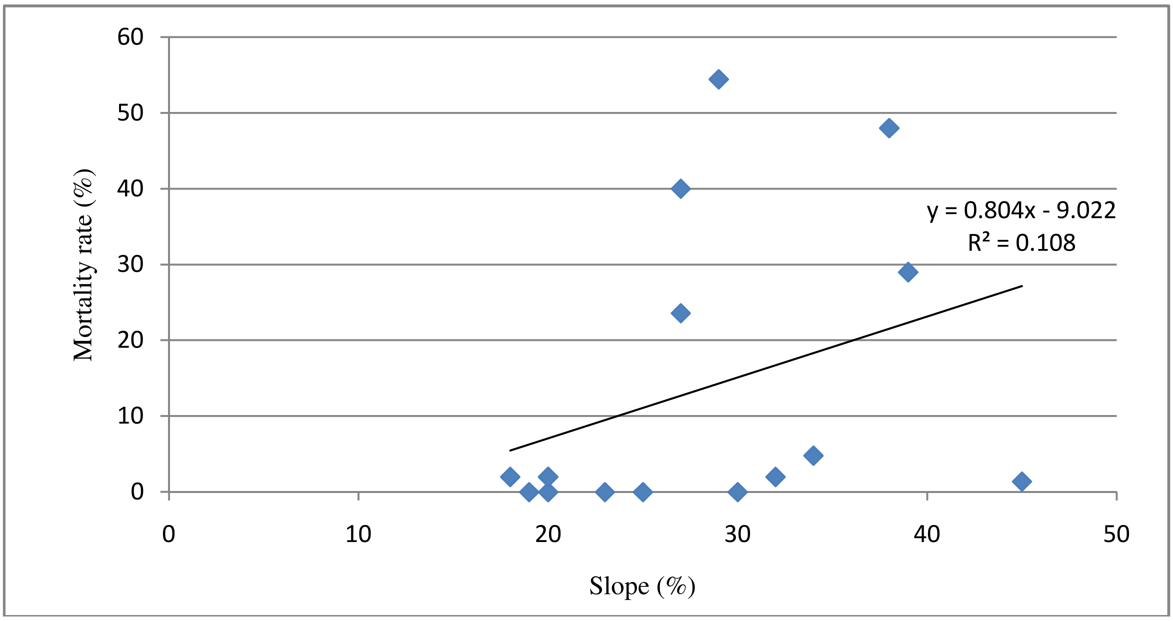


Figure 12: A scater plot graph showing the relationship of mortality rate and bulk density in case area I (Kombolcha, South Wollo) in 2009.

4.2.2. Aspect

A relatively high mortality rate was observed on plots facing N10W and followed by N20E & N20W in decreasing order (Fig.13) for case area I.

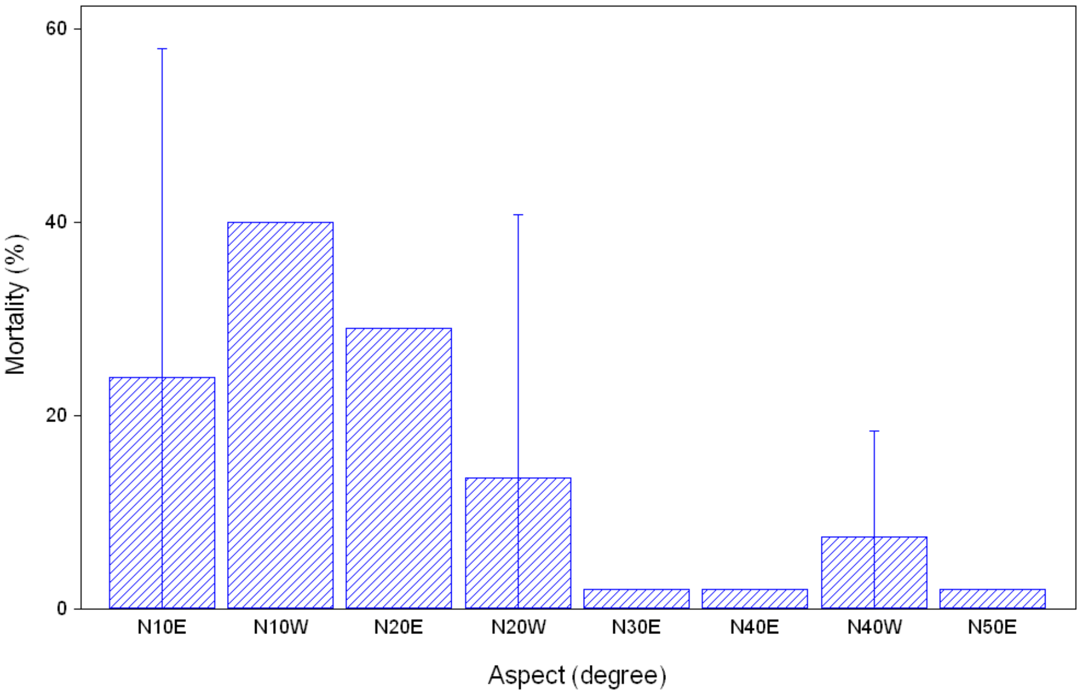


Figure 13: Aspect & mortality rate

4.3. Climatic Factors

The total amount of rainfall of case area I from 1999 to 2009 was obtained and analysed graphically and is presented in (Fig. 14).

Monthly total rainfall analysis of the year 1999 to 2009 (fig. 14) showed that there was a rainfall distribution and amount problem; for instance in the year 2008 there was a complete failure of Belg rain (i.e., 0 mm in the month of February & March) and in April even if there was rain it was very less (18.1mm) unlike that of other years. In general for the year 2008 the monthly total rainfall amount was very much below the average from January to May. In the mean time the temprature went above the average, i.e, 27^{0}C (annex fig.2B & 3A) for 6 consecutive months (i.e., from January to June). Although there was a year in which some of the months had a rainfall amount very much less than the average, what was especial in 2008 there was rain whose amount was very much less than the average for 6 consecutive months from January to June. In the mean time the average maximum temprature of those consecutive months were exceptionally above the average. According to Range Office of Bhutan (2009), this phenomenon of climatic/rainfall pattern i.e., leads to the die-back in the following year. According to National Metrologial Agency (2009) report moisture status of May, 2009 was characterized as very dry with a rainfall amount of 10% of the normal. On top of this *Eucalyptus* spp. depletes the soil moisture reserve in the long term because their high moisture uptake and for their survival they need a continuous supply of water due to this fact if there is a failure like February & March and a decline in monthly total rainfall like the year 2008, the trees would be severely stressed and then this ultimately results in the dry-up of the trees.

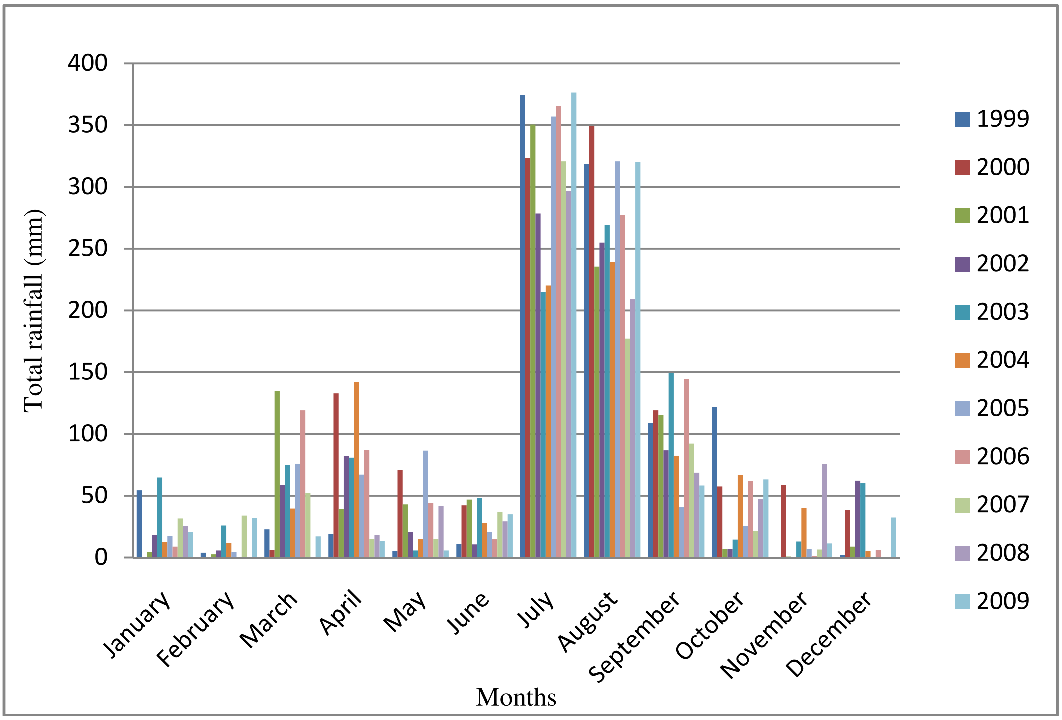


Figure 14: A graph showing the total monthly rainfall of Kombolcha (case area I) for the year 1999 to 2009

4.4. Soil and Root Pathogen and Eucalyptus Drying-up

Root and soil samples test for *Phytophtora,* which is known to cause root rot were found negative for both the healthy and dried sample trees. On the other hand a comparative disease symptom (such as discoloration on the under bark side of the stem) assessment of the stems of the live and dried trees were made and the result showed that there was no indication of disease and no difference was obtained except one is live and the other is dried(Fig. 15).

A B C D

Figure 15: Pictures showing evidences of absence of disease with comparative symptom assessment of trees of dried (A & B) and healthy (C&D)

The other evidence for the root to be free from a pathogen was that those trees that completely dried when their above ground stem cut late in the rainy season (i.e., when the soil moisture content reaches complete saturation) start to coppice or resprout from the root (Annex 8). Even if their above ground dried stem left as they are (i.e., without removing) the dried trees started coppicing and gave rise to a new plant. According to personal communication with the local peoples, unless the moisture shortage (i.e., drought) is severe and extreme, those trees that were grown from coppice were relatively resistant to extended drought because of the well established root system that can easily provide the essential growth requirements of the above ground part of the tree. Again according to personal communication with the local peoples those dried trees that felled or cut early in the rainy season were found to be incapable of coppicing and regenerating. On top of this, according to personal observation and personal communication with the local peoples those mature trees of *Eucalyptus* grown through coppice were found alive and relatively in good health in both case study areas and and in areas where reconnisance survey was made for site selection. This shows that those trees grown from coppice can resist the extended drought as compared to their counterparts in a given area.

4.5. Stand Characterstics and Eucalyptus Drying-up

4.5.1. Population density

Though it is insignificant population density was positively correlated with mortality rate with a correlation coefficient of 0.3643 & 0.2205 for both case area1 & case area 2. The relationship of population density and mortality rate of both case study areas is shown in the figures 16 & 17 below. Thus from the result they had some contribution to the dry-up but statistically insignificant.

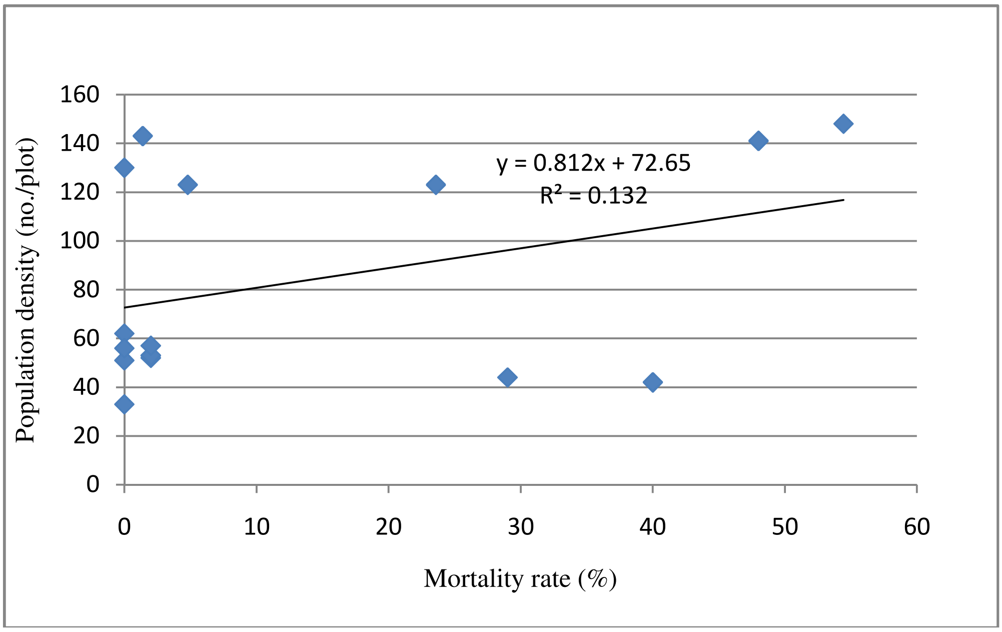


Figure 16: A scater plot graph showing the relationship of mortality rate and population density in case area I (Kombolcha, South Wollo) in 2009.

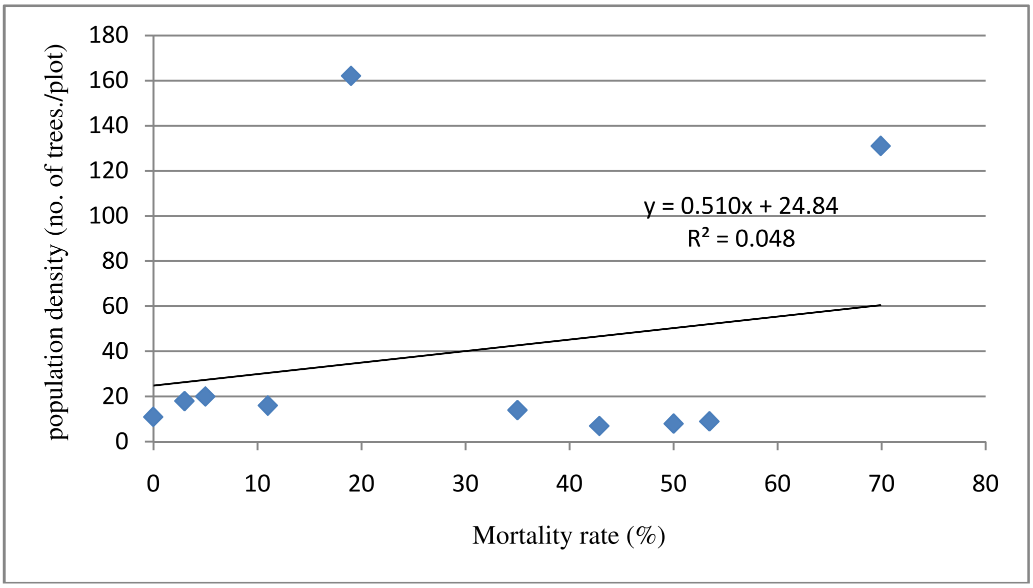


Figure 17: A scator plot graph showing the relationship of mortality rate and population density of the plot in case area II (Lode Hetosa Woreda, Arsi zone, Ethiopia) in 2009.

4.5.2. Root Condition

Live trees had greater lateral root cross-sectional areas than partially or totally dried or dead trees. Even the live trees had root system that is relatively uniformly distributed along the soil profile and they had also relatively bigger diameter tap root system and feeder roots too (Fig. 7, A, B, C, D) ; and a greater proportion of this cross sectional area for *the live trees* was further down the soil profile (Fig.7, A, B, C, D) & annex 7. Live trees appeared to maintain relatively high water potentials during dry periods because of its access to deeper water supplies and thus it largely avoided drought effects.

4.5.3. Incidence of *Eucalyptus* Drying-up by size class and Recovery of Dried-up Trees

Incidence of *Eucalyptus* Drying-up by size class

According to personal communication with the local peoples of the study areas, frequent die-backs/dry-up of trees were observed in the plantation of both case study areas particularly in the month of March to June during 2008 and 2009. From July onwards of the same year the severity of drying-up decreased and eventually those trees that didn't reach total death were revived/recovered. What the incidence of the drying-up in the plantation in the landscape looked like is shown in annex 6.

The affected trees had an average DBH of 3.702293cm with a standard deviation of 2.1540cm and 3.79cm for both case area I & case area II respectively. In most cases the incidence occurred in trees having relatively of smaller diameter i.e., 2.5cm & 3cm for both case area I & II and the dry-up showed in general a more or less progressive decline in frequency of occurrence of the dry-up with an increase in diameter (Fig.18 & 19).

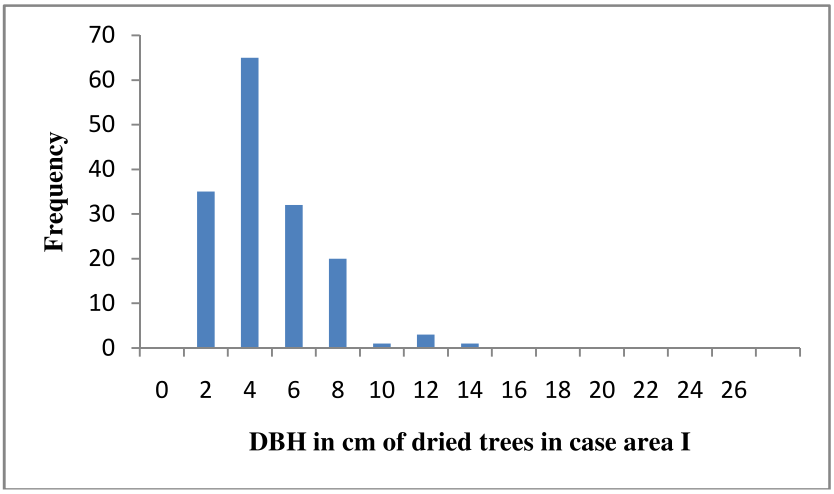


Figure 18: A histogram showing the frequency distribution of DBH of dried trees for case area I

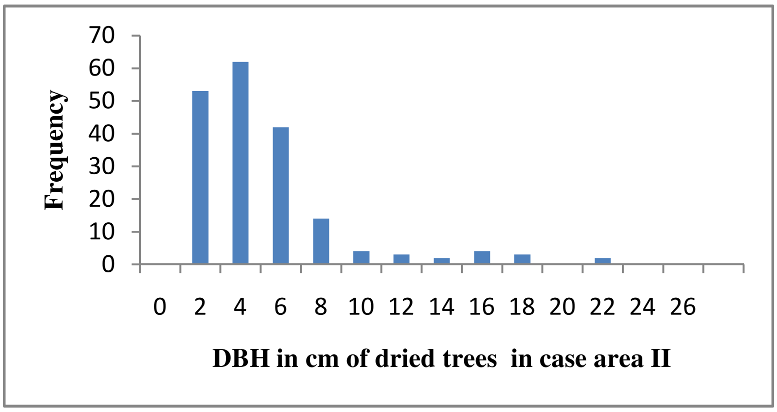


Figure 19: A histogram showing the frequency distribution of DBH of dried trees in case area II

The occurrence of the dry-up with height is shown in figures 20 & 21. For case area I the affected trees had a height having a normal distribution with a mean of 480.3822 cm & a standard deviation of 173.63cm (Annex 9). There is a general increase in frequency of height of dried trees from 100cm – 480.3822cm and there is also a general decrease in the frequency of height of dried trees from 480.3822 to the maximum height, i.e., 950cm (Annex 9). But in case area II, though the distribution of the values of height is not normal, it has a mean of 641.64cm with a standard deviation of 240.5cm (Annex 9). Like DBH there was a general decrease in the frequency of dry-up with an increase in height.

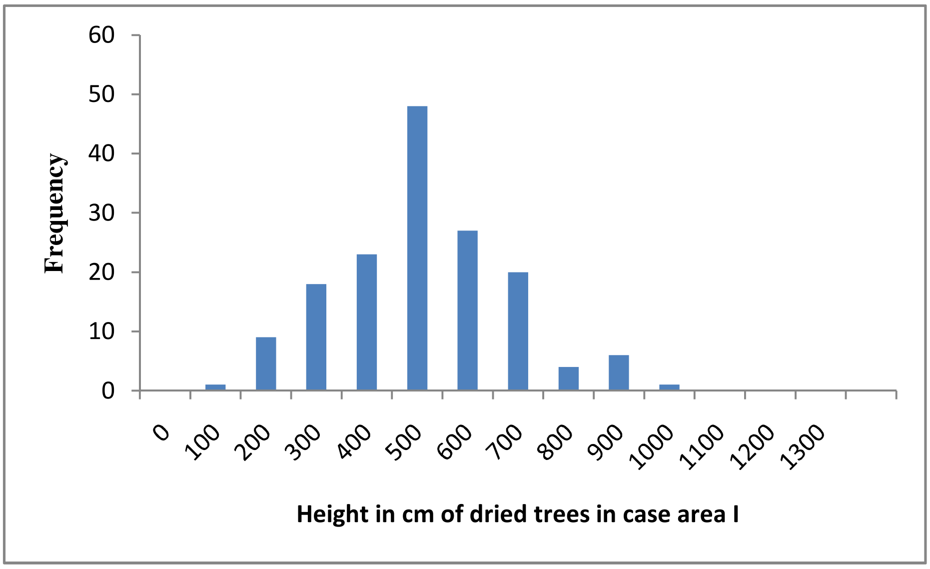


Figure 20: A histogram showing the frequency distribution of height of dried trees in case area I.

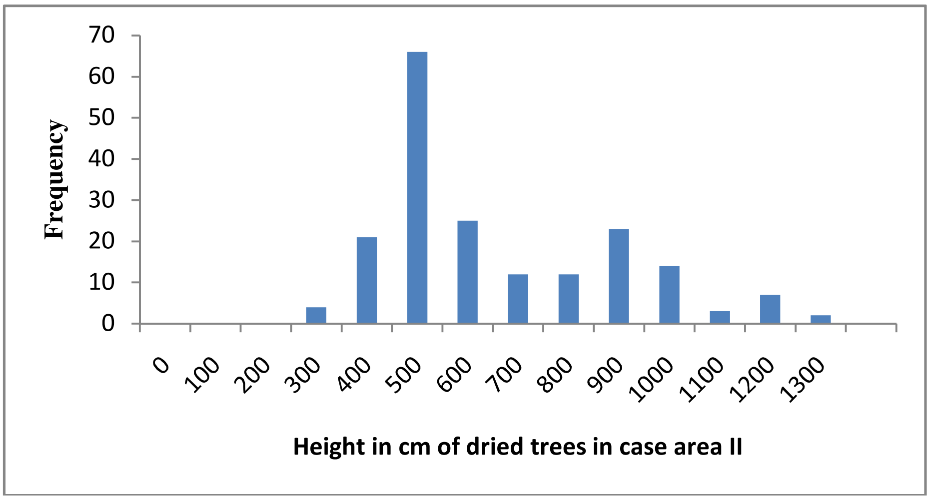


Figure 21: A histogram showing the frequency distribution of height of dried trees in case area II

Recovery of Dried- up Trees

A follow up observation of the same study sites in 2010 showed that dried-up trees were found to be recovered and alive. In case area I those trees that dried-up in 2008 unless they reach a stage of total death start to recover right from July onwards where the soil becomes saturated with moisture. For instance, in the year mid 2009 & 2010 no dry-up (Annex 10, 2010 0) was observed which could be attributed to the fact that in those years the rainfall amount and distribution was favourable for the healthy growth of the trees.

5. CONCLUSION

The objectives of this study were to identify which, if any, of seven major factors (Soil depth, soil texture, bulk density, water holding capacity of the soil, slope, aspect, soil and root pathology and stand density) caused the dry-up of the exotic trees of *Eucalyptus* speciess and to estimate their relative importance.

It was found that it is only soil depth and mortality rate that had a higher correlation coefficient and therefore they had a significant causal relationship for both case study areas. However, the other factors (such as stand density & slope) also had contribution but their strength of relationship with mortality rate is weak and stastically insignificant.

Live trees had greater lateral root cross-sectional areas than partially or totally dried or dead trees and a greater proportion of this sectional area for *the live trees* was further down the soil profile. This supports causal relationship between soil depth and mortality rate.

Exceptionally higher temprature above the average and exceptionally lower rainfall below the average for consecutive months like the year 2008 could lead to dieback in the following year.

It was also found that there was no indication of disease and no difference was obtained except one is live and the other is dried.

6. RECOMMENDATIONS

- *Eucalyptus* spp. should be planted in areas having a soil depth greater than 2m deep.

- In case *Eucalyptus* spp. should be planted on mountainous and rugged areas, soil and water conservation structures should be integrated; construction of bench or level terrces across the slope so that most of the sediments brought from upslope are trapped and increase the available soil volume that improves the available moisture .

- The planting holes should be deep and well prepared so that they allow the root system to develope well which in turn determines the survival of the whole live plant in the future.

- Appropriate spacing should be followed based on the site potential to support growth.

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APPENDIX

Annex 1. Correlation matrix of case area1 (South Wollo, Kombolcha)

Statistix 7.1 Correlations (Pearson)

	Mortality (%)	Bulk density (g/cm^3)	Population density (No. Of Trees/plot)	Slope (%)	Clay (%)	Sand (%)	Silt (%)
Soil depth(cm)	**r=-0.8507** *P-value* 0.0001	**-0.0250** 0.9296	**-0.1696** 0.5456	**-0.0752** 0.7898	**0.1486** 0.5971	**-0.0049** 0.9862	**-0.2799** 0.3123
Water holding capacity (%)	**-0.2529** 0.3632	**0.1140** 0.6858	**0.1140** 0.6858	**0.0468** 0.8684	**0.3859** 0.1554	**-0.2078** 0.4574	**-0.3552** 0.1938
Population density (No.of trees /plot)	**0.3643** 0.1819	**0.1571** 0.5762		**0.4948** 0.0608	**-0.3288** 0.2314	**0.2336** 0.4021	**0.1949** 0.4864
Bulk density (g/cm^3)	**0.0521** 0.8536						
Slope(%)	**0.3288** 0.2314	**0.4931** 0.0618					
Clay(%)	**-0.0520** 0.8539	**-0.6398** 0.0102					
Sand(%)	**-0.0749** 0.7908	**0.5895** 0.0207					
Silt(%)	**0.2440** 0.3808	**0.1220** 0.6649					

r = correlation coefficient written in bold

p = p-value is the second one written in non-bol

Annex 2. Correlation matrix of case area II (Arsi zone, Lode Hetosa Woreda)

Statistix 7.1 Correlations (Pearson)

	Mortality (%)	Bulk density (g/cm^3)	Population density (No. Of Trees/plot)	Slope (%)	Clay (%)	Sand (%)	Silt (%)
Soil depth(cm)	**r=-0.9393** *P-value* 0.0001	**0.2640** 0.4611	**-0.3291** 0.3531	**-0.2843** 0.4259	**0.1486** 0.5971	**-0.0049** 0.9862	**-0.2799** 0.3123
Water holding capacity (%)	**-0.0322** 0.9297	**-0.7588** 0.0109	**0.6417** 0.0455	**0.5028** 0.1385	**0.3859** 0.1554	**-0.1708** 0.6371	**0.6371** 0.0476
Population density (No.of trees /plot)	**0.2205** 0.5405	**-0.3603** 0.3064		**0.6328** 0.0496	**-0.3349** 0.3442	**0.0384** 0.9162	**0.3454** 0.3283
Bulk density (g/cm^3)	**-0.0064** 0.9859						
Slope(%)	**0.2466** 0.4922	**-0.3382** 0.3392					
Clay(%)	**-0.3178** 0.3708	**-0.1765** 0.6258					
Sand(%)	**0.0380** 0.9170	**0.6766** 0.0317					
Silt(%)	**0.3258** 0.3583	**-0.6328** 0.0496					

r = correlation coefficient written in bold

p = p-value is the second one written in non bold

Annex 3.Table showing the mean values for DBH & height of live, partially dried & completely dried trees of both case study areas.

Transect No.	Plot No.	Tree status					
		Live		Partially Dried		Completely Dried	
		Mean Dbh (cm)	Mean Height (cm)	Mean Dbh (cm)	Mean Height (cm)	Mean Dbh (cm)	Mean Height (cm)
[3]GT1	1	3.4808	332.56	4.14	288	-	-
	2	3.325	418.823	2.95	424.58	2.26	385
	3	3.06	396.23	3.05	409.14	2.34	298.33
	4	4.35	430.48	3.35	412.47	2.9	440.69
	5	9.98	927.29	0	0	0	0
	6	6.34	773.89	4.33	623.88	3.13	524.81
GT2	1	4.86	534	6.56	725	5.53	552.4
	2	5.52	571.21	3.1	390	3.82	523.33
	3	4.09	579.6	1.91	450	1.69	316
	4	5.44	601.63	4.69	540	3.91	457.14
	5	5.01	511.52	2.55	150	3.29	412
	6	3.5	412.4	2.44	323.33	0	0
GT3	1	4.31	508.95	3.5	496.27	3.58	454.24
	2	6.81	650.95	4.525	544.23	4.86	588.89
	3	5.69	619.72	3.69	534.67	5.04	566.67
[4]KT1	1	7.83	894.19	5.56	766.67	5.69	821.43
	2	15.72	1050	0	0	0	0
	3	17.88	1093.75	0	0	0	0
	4	21.37	1175	0	0	17.83	1133.33
	5	16.83	1125	15.5	900	0	0
KT2	1	4.11	555.26	2	450	2.6	475.44
	2	17	1393.75	0	0	0	0
	3	14	977.78	0	0	0	0
	4	15.44	1100	22	1300	11.1	1005
	5	16.1	990.9	0	0	0	0

[3] G-stands for Gallessa, Kombolcha Woreda, South Wollo
[4] K-stands for Korbu, Lode Hetosa Woreda, Arsi Zone

Annex 4. Laboratory analysis results of soil physical characterstics for each plot for both case study area I & II.

Study Area: South Wollo Kombolcha & Arsi Zone, Lode Hetosa	Location: Korbu and Gallessa							
Field No.	Bulk Density in (g/cc)	Field Capacity (FC) in (%)	Permanent Wilting Point (PWP) in (%)	Water Holding Capacity (WHC)= (FC-PWP) in (%)	Sand (%)	Silt (%)	Clay (%)	Textural Class
T1P1K	1.09	30.58	19.09	11.49	50	40	10	Loam
T1P2K	1.02	30.06	18.70	11.36	50	40	10	Loam
T1P3K	1.28	28.75	19.05	9.7	52	34	14	Sandy Loam
T1P4K	1.28	26.32	15.37	10.57	56	38	6	Sandy Loam
T1P5K	1.15	32.4	21.00	11.4	54	34	12	Sandy Loam
T2P1K	1.05	30.40	17.44	12.96	54	38	8	Sandy Loam
T2P2K	1.00	31.86	20.93	10.93	44	36	20	Loam
T2P3K	1.05	30.01	17.77	12.24	50	40	10	Loam
T2P4K	1.18	33.48	22.83	10.65	48	38	14	Loam
T2P5K	1.31	30.60	20.87	9.73	58	30	12	Sandy Loam
T1P1G	1.36	19.47	10.89	8.58	60	36	4	Sandy Loam
T1P2G	1.43	19.95	11.88	8.07	68	28	4	Sandy Loam
T1P3G	1.41	23.71	14.35	9.36	50	40	10	Loam
T1P4G	1.40	19.80	11.89	7.91	60	36	4	Sandy Loam
T1P5G	1.14	19.63	12.36	7.27	60	34	6	Sandy Loam
T1P6G	1.16	24.02	16.32	7.7	54	34	12	Sandy Loam
T2P1G	1.32	28.50	19.21	9.29	48	34	18	Loam
T2P2G	1.22	24.73	16.77	7.96	50	26	24	Sandy Loam
T2P3G	1.17	30.74	22.24	8.5	40	40	20	Loam
T2P4G	1.10	31.86	22.84	9.02	46	30	24	Loam
T2P5G	1.00	32.59	23.08	9.51	38	36	26	Loam
T2P6G	1.31	32.19	12.73	19.46	50	26	24	Sandy Loam
T3P1G	1.00	29.58	20.66	8.92	48	28	24	Loam
T3P2G	1.16	31.45	21.66	9.79	42	32	26	Loam
T3P3G	1.23	32.81	22.95	9.96	40	36	24	Loam

Annex 5. Field measurement results

Field No.	Slope (%)	Aspect (degree)	Soil Depth (cm)	Rooting Depth (cm)		Proportion of Partially dried tress (%)	Proportion of completely dried trees (%)	population density (No. of trees/plot)
				Live	Completely dried			
T1P1 K	38	N90E	15	50	18	13.74	53.44	131
T1P2 K	27	N90W	28	53.44	-	0	0	9
T1P3 K	18	N90W	35	50	-	0	0	8
T1P4 K	16	N90W	37	42.86	-	0	42.86	7
T1P5 K	34	N90W	43	35	-	0	14.29	14
T2P1 K	37	N20W	47	90	40	0.62	69.98	162
T2P2 K	17	S90W	55	11	-	0	0	16
T2P3 K	18	S90W	70	3	-	0	0	18
T2P4 K	38	S90W	78	5	-	5	50	20
T2P5 K	15	S90W	92	0	-	0	0	11
T1P1 G	23	N40W	70	100	70	1.96	0	51
T1P2 G	45	N40W	110	110	76	74.8	1.39	143
T1P3 G	23	N40W	130	230	130	46.4	4.8	123
T1P4 G	27	N40W	57	53	27	59.35	23.58	123
T1P5 G	19	N20W	100	120	80	0	0	33
T1P6 G	29	N20W	12	80	47	18.24	54.43	148
T2P1 G	27	N10W	30	22	12	4.76	40	42
T2P2 G	39	N20E	38	100	50	18.8	29	44
T2P3 G	38	N10E	20	90	65	0.71	48	141

T2P4 G	20	N10E	80	85	62	19.35	0	62
T2P5 G	18	N40E	110	88	70	1.92	2	52
T2P6 G	32	N50E	150	82	63	5.66	2	53
T3P1 G	25	N20W	120	78	71	45.38	0	130
T3P2 G	30	N20W	138	92	57	46.43	0	56
T3P3 G	20	N30E	75	40	21	26.32	2	57

Annex 6. Pictures showing the incidence of dry-up in case area I.

Pictures showing the incidence of dry-up in case area I.

Pictures showing the incidence of dry-up in case area I.

Pictures showing the incidence of dry-up in case area I.

Annex 7: Pictures showing comparative difference of root status of the healthy and dried trees

Live(A) Live(B) Live(C)

A root with deep soil

The fractured rock layer
Undergoing weathering

pile of soil dominated
by rock fragments

Dried & Live (D) Dried (E) Dried (F)

abnormal and deformed root
structure

A=live because of deep soil with out impervious rock or stone layer

B & C=live with a soil depth having a rock layer of relatively weathered and penetrable by the root

D= dried & live: they are close to each other but soil profile of the dead tree was relatively full of stone fragments and builders in addition to the shallowness of the soil

E=dried because of heavy mass of stone on the rooting way even though the soil is relatively deep

F= dried because of very thin shallow soil layer(depth)

Annex 8: A picture depicting coppicing potential of *Eucalyptus camaldulensis* from the root after the above ground dried or dead stem was removed

A dried coppice from dried trees felled before or early in the rainy season

Annex 9: Summary stastics of DBH & height of dried trees of both case study areas

	Case area I		Case area II	
Descriptive stastics	DBH of completely dried trees	Height of completely dried trees	DBH of completely dried trees	Height of copmpletely dried trees
Mean	3.702293	480.3822	4.603175	641.6402
Standard Error	0.171366	13.81361	0.274749	17.44801
Median	3.18	480	3.25	575
Mode	2.23	500	3	450
Standard Deviation	2.154043	173.6344	3.787153	240.5042
Sample Variance	4.639899	30148.9	14.34253	57842.28
Kurtosis	3.15847	0.149416	5.952793	-0.24799
Skewness	1.501489	0.218407	2.273978	0.851716
Range	12.73	850	21	1000
Minimum	0.96	100	1	300
Maximum	13.69	950	22	1300
Sum	584.9623	75900.38	874.6032	121911.6
Count	158	158	190	190
Largest(1)	13.69	950	22	1300
Smallest(1)	0.96	100	1	300
Confidence Level(95.0%)	0.338481	27.28449	0.541968	34.41786

Annex 10: A picture showing the regeneration and recovery of partially and completely dried *Eucalyptus* trees by comparing *Eucalyptus* trees of the same area in 2009 &2010.

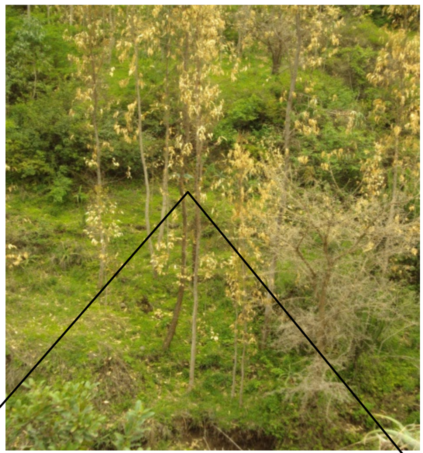
July, 2009

July, 2010

Recovery of the same trees from the dried status to live status after a year

A picture showing the regeneration and recovery of partially and completely dried *Eucalyptus* trees by comparing *Eucalyptus* trees of the same area in 2009 &2010.

July, 2009



July, 2010

Recovery from dried status to live status after a year

Annex 11. Survey and inventory field formats, some intervied questioners and laboratory analysis results

a): Format one of vegetation data set

The Recent drying-up of *Eucalyptus species* in major exotic plantations

Region………………… Zone……………………..Woreda……………………..

Tabia / Kebele……………….Altitude (m)…………………. Mean Annual Rainfall

(mm)…………….Temperature (^{0}C)…………Agroclimatic Zone……………….

UTM………………………….

Transect No……………….Plot No………………………Date……………….

Slope…………………..Aspect…………………Forest Type…………………Age……. Season or Month drying-up appear………………….

Frequency (seasonally, during drought period, etc)……………………………………..

Above ground/ tree attribute						
No.	List of Local /scientific name of each tree	Tree Status(dead, live, partially dried)	DBH	Height	Revival status	Remark
1						
2						

<table>
<tr><td colspan="5">Below ground/Root attribute</td></tr>
<tr><td rowspan="3">No.</td><td colspan="4">Root Status</td></tr>
<tr><td colspan="4">Roots From Live Trees</td></tr>
<tr><td>No. of primary roots per stump</td><td>Rooting Depth</td><td>Root distribution with respect to the tap root(uniformly, skewed to the left, right, etc)</td><td>Remark</td></tr>
<tr><td>1</td><td></td><td></td><td></td><td></td></tr>
<tr><td>2</td><td></td><td></td><td></td><td></td></tr>
<tr><td>3</td><td></td><td></td><td></td><td></td></tr>
<tr><td colspan="5">Roots From Dried Trees</td></tr>
<tr><td>No.</td><td>No. of primary roots per stump</td><td>Rooting Depth</td><td>Rooting distribution with respect to the tap root(uniformly, skewed to the left, right, etc</td><td>Remark</td></tr>
<tr><td>1</td><td></td><td></td><td></td><td></td></tr>
<tr><td>2</td><td></td><td></td><td></td><td></td></tr>
</table>

b) Format of Soil data

The Recent Drying-Up of Eucalyptus Species in Major Exotic Plantations

Region………………… Zone…………………….Woreda…………………….

Tabia / Kebele………………..Altitude (m)…………………. Mean Annual Rainfall (mm)…………….Temperature (^{0}C)…………Agroclimatic Zone……………….

UTM………………………….Transect No………………..Plot No……………………..Date………………..Slope…………………..Aspect…………..

Forest Type…………………Age…….. Season or Month drying-up appear………………….

Frequency (seasonally, during drought period, etc)…………………………………….

<table>
<tr><td colspan="2">physical properties</td><td>Unit</td><td>Remark</td></tr>
<tr><td colspan="2">Sample</td><td>Sample ID, character</td><td></td></tr>
<tr><td colspan="2">Water holding capacity</td><td rowspan="2">bar</td><td rowspan="2"></td></tr>
<tr><td>Permanent wilting point</td><td>Field capacity</td></tr>
<tr><td colspan="2">Bulk density</td><td>gm/cm^3</td><td></td></tr>
<tr><td colspan="2">Sand</td><td>%</td><td></td></tr>
<tr><td colspan="2">Silt</td><td>%</td><td></td></tr>
<tr><td colspan="2">Clay</td><td>%</td><td></td></tr>
<tr><td colspan="2">texture</td><td>Character description</td><td></td></tr>
</table>

c) Format of pathologic data set

The recent drying-up of *Eucalyptus species* in major exotic plantations

Region……….. Zone………..Woreda………..Tabia / Kebele……………….

Altitude (m)………..Mean Annual Rainfall (mm)……Temperature (^{0}C)…………

Format of pathologic data set

Agroclimatic Zone........... UTM...........Transect No...........Plot

No.........Date..............Slope........... Aspect..............Forest

Type....................Age........ Season or Month drying-up appear.....................

Frequency (seasonally, during drought period, etc)...

<table>
<tr><td colspan="5">Symptom identification and sampling from Root and Stem of the dead/dried ones and the respective surrounding soil and comparing with samples of the healthier ones up on lab. analysis</td></tr>
<tr><td>No.</td><td>Sample to be taken</td><td>Unit</td><td>Scientific Name of Possible Pathogen identified up on analysis</td><td>Remark</td></tr>
<tr><td rowspan="5">1</td><td rowspan="5">Dried Stem and Root</td><td rowspan="5">Sample ID and Character</td><td></td><td rowspan="5"></td></tr>
<tr><td></td></tr>
<tr><td></td></tr>
<tr><td></td></tr>
<tr><td></td></tr>
<tr><td rowspan="8">2</td><td rowspan="8">Soil</td><td rowspan="8">Sample ID and Character</td><td></td><td rowspan="8"></td></tr>
<tr><td></td></tr>
<tr><td></td></tr>
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<tr><td></td></tr>
<tr><td></td></tr>
<tr><td></td></tr>
</table>

In all the tables of this document T stands for transect and P stands for plot

Declaration

I, Demelash Bekele, here by declare to AAU that this thesis is my origional research work and all the necessary sources of materials used are accordingly acknowledged. It hasn't already been submitted for any degree in any other university.

Submitted by

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Name of the student	Signature	Date

Approved by

1.-------------------------------------	------------------	--------------------
Name of advisor	Signature	Date
2.-------------------------------------	-------------------	--------------------
Name of co-ordinator	Signature	Date
3.------------------------------------	---------------------	---------------------
Name of Chairperson, Department's gratuate commission	Signature	Date
4.------------------------------------	----------------------	--------------------
Name of chairperson, Faculty's gratuate commission	Signature	Date
5.------------------------------------	----------------------	-------------------
Name of the dean, School of gratuate studies	Signature	Date