THE EFFECT OF *EUCALYPTUS* ON CROP PRODUCTIVITY, AND SOIL PROPERTIES IN THE KOGA WATERSHED, WESTERN AMHARA REGION, ETHIOPIA

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by

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ABSTRACT

This study was conducted at the Koga Watershed in the Western Amhara region of Ethiopia. The main objective of the study was to observe if the *Eucalyptus* plantation is harmful for the ecosystem. The study through key informants' interview proved that almost all local farmers perceive that *Eucalyptus* trees are exhausting the once productive land because of its fast growth. Water points dried up, too. Despite this, the growers insist on planting *Eucalyptus* because of its fast biomass production to sell it after relative short time for cash income and use in construction. A triplicate experiment was established to understand the effect of *Eucalyptus* on soil properties, crop production and water bodies. Its effect was compared to other land uses such as *Croton macrostachyus* border plantation along maize farm (regarding soil bulk density, moisture content and maize plant count and height) and coffee garden (concerning undergrowth density). There were no pronounced changes in soil bulk density, organic matter, texture, pH, exchangeable potassium and available water capacity due to *Eucalyptus* hedgerows along maize farmland. *Eucalyptus* trees significantly affect available phosphorus (avail. P), exchangeable calcium (exch. Ca), total nitrogen (TN), moisture content (MC), soil hydrophobicity, light intensity and the density of the undergrowth. At 5 m distance from *Eucalyptus* stand, there were the greatest reductions of values of avail. P (3.5 mg kg^{-1}), TN (0.1 %) and MC at maize maturity stage (8.7 %) compared to the not affected soil at 40 m away from the *Eucalyptus* trees. In addition, the exch. Ca value at 1 m distance was most reduced and was decreased by 4.1 (cmol (+) kg $soil^{-1}$) compared to the control. The top dried field soils at 0 to 220 cm distances were water repellent since the water drop penetration time values were greater than 5 seconds. Moreover, *Eucalyptus* canopy intercepted 64.5 to 1579 lux of the light intensity resulting in poor performance of maize plants

under its shade. Plant height, yield, biomass and count decreased with distance to *Eucalyptus* trees. This was not the case for *Croton macrostachyus*. The yield reduction was in the range of 4.9 to 13.5 $ton.ha^{-1}$. Furthermore, the undergrowth density of *Eucalyptus* was almost nil (24787 $No.ha^{-1}$) as compared to that of coffee garden shade (171102 $No.ha^{-1}$). Altogether, our findings lead to a conclusion that *Eucalyptus* plantation has a negative effect on sustainable cropping, soil, and water conservation systems by decreasing TN, avail. P and exch. Ca through plant uptake, lowering the soil moisture content both by its dense root system and by making the soil hydrophobic and taking light away from the crop due to its dense and long canopy. It has also been reported by local farmers that the dense *Eucalyptus* root network lowers water tables and dries up springs.

BIOGRAPHICAL SKETCH

Tilashwork C. Alemie was born and raised in Western Amhara region, Ethiopia. She received her Diploma in General Agriculture in 1999 from Ambo College of Agriculture, located at 125km distance from Addis. From 2000 to 2002, she taught chemistry at Gambella High School in Southern Ethiopia. Then, she joined Debub University as an advance standing student and received a B.Sc. degree in Plant Production and Dry land Farming in July 2005. Soon after she was employed as a researcher in Amhara Regional Agricultural Research Institute (ARARI) and worked for two years. Even though she had experience in plant breeding research, she wanted to know much more about the details of the basic natural resources (soil and water), which are key if they are managed well to reduce poverty in Ethiopia effectively. Therefore, she joined the Integrated Watershed Management and Hydrology Masters Program opened by Cornell University in collaboration with Bahir Dar University. Now, she has been assessing the environmental impact of *Eucalyptus* plantation in the Koga Watershed, which is a known watershed in the Amhara Region of Ethiopia. Her further interest area of research is conducting poverty alleviating research activities by giving due attention to Integrated Watershed Management: Developing suitable model(s) to assess soil loss and the impact of hydrological dynamics on crop production in a given watershed, and developing high yielding crop varieties there.

This work is dedicated to my father, Chanie Alemie and my mother, Dilulanch Aemiro. Without their decision that allowed me to pass through modern education, in a situation where modern education was not significantly encouraged, I would have never been in my present position. Especially, my mother was spice for my success until she passed away in February 2009. Mam, my hope is buried with you! But I never forget you forever.

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CHAPTER ONE

1. INTRODUCTION

The livelihood of 85% of the Ethiopian population depends on agriculture. There are more than seven million predominantly subsistence farm families who produce about 90% of the agricultural output such as food crops (cereals, pulses, vegetables and oil seeds), livestock and coffee. In the past, Ethiopia was rich in natural resources. As population pressure increased, resources have been exploited excessively. The need to expand cultivated land and shortages of fuel biomass have led to the removal of well-adapted, nutrient additive indigenous trees. Cropping areas have expanded into marginal lands, such as steep slopes and mountainous areas, and fallow periods have been shortened or abandoned (Jouquet et al., 2007). Despite this expansion, food insecurity remains because agricultural productivity has been seriously eroded by resource depletion.

To alleviate this problem, the past emphasis was on introducing early maturing tree species rather than environmentally friendly species, such as nutrient-replenishing, leguminous trees into agricultural systems in areas where trees can be combined with the production of crops (Garay et al., 2004). *Eucalyptus* has been a common species introduced during past agroforestry efforts (Kidanu et al., 2005). Traditional agro-forestry practices in Ethiopia involve tree planting in various spatial patterns to meet the demand for fuel wood and construction. In recent years, single rows of *Eucalyptus* species planted along field borders have become a dominant feature of the central highlands of Ethiopia including the Koga Watershed, located at the head of the Blue Nile basin. Although quantitative evidence is scanty, there has been a perception that this practice adversely affects crop productivity (Kidanu et al., 2005). However, in order to satisfy the biomass energy demand of the country by

2014, 6 percent of the total utilizable land area would have to be put under *Eucalyptus* plantations (Kidanu et al., 2005) entailing a major shift in land use. Increasing plantations would create competition between agricultural food crops and *Eucalyptus* trees for land area, major resources (water and soil nutrients) and light.

In general, ecological implications of exotic trees like those that *Eucalyptus* species, which have been used for industrial purpose as well as for agro-forestry are often questioned since their ecology has not been appropriately studied (Bernhard-Reversat, 1999). Lane et al. (2004) found in China described that the expansion of Eucalyptus plantation on lands previously used for crops and occupied by indigenous trees and grass lowers water tables and reduces water availability for irrigation due to soil hydrophobicity (water repellancy) and its deep and dense root network. Eucalyptus seedlings are vulnerable to severe water stress unlike the seedlings of indigenous deciduous tree species in Ethiopia (Gindaba et al., 2004). This shows that Eucalyptus trees need more water and compete with neighboring plants for the available water in the soil. EI-Amin et al. (2001) in Sudan reported that Eucalyptus caused crop yield reduction due to nutrient depletion and production of toxic exudates (allelochemicals). Finally, nutrients are exported out from the plantation's soil system by removing trees for timber sales and fuel wood (zerfu, 2002).

Even though there has been concern among scientists and farmers that *Eucalyptus* trees are affecting ecosystem negatively in watersheds, environmental impacts of *Eucalyptus* trees have been studied only to limited extents in Ethiopia and eastern Africa. Therefore, this study (1) examines the effects of two common plantation types (*Eucalyptus* stand and coffee garden shade) on the density of undergrowth; (2) determines the effect of *Eucalyptus* trees on the soil physical and chemical properties; (3) investigates the influence of *Eucalyptus* stand on light intensity at different times within the day and at different distances from woodlots; (4)

evaluates the soil hydrophobicity under a *Eucalyptus* stand; (5) assesses *Eucalyptus* root distribution at different distances and depths; and (6) compares crop performances at different distances from tree stands.

Results from this study can effectively create awareness for the community concerning specific effects of *Eucalyptus* on nearby crops and the surrounding environment. Furthermore, land management planners can use this information in their decisions on land use in the study area and to understand the particular choices made by farmers concerning *Eucalyptus*.

CHAPTER TWO

2. MATERIALS AND METHODS

2.1. Study area

The study was conducted in the 28,000-hectare (ha) Koga Irrigation and Watershed Management project, an agriculturally potential area at the head of the Blue Nile within the Lake Tana Watershed. This project supported by the African Development Bank (ADB) and the Ethiopian government, has a 7000 ha command area intended for the cultivation of profitable and environmentally friendly crops. The catchment area, defined by its hydrological boundaries, is located at 11^{o} 10’ N to 11^{o} 25’ N latitude and 37^{o} 02’ E to 37^{o} 17’ E longitude and ranges from 1800 to 3200 meters above sea level (masl) with a mean annual rainfall of 1560 mm and a mean daily temperature between 16 and 20 ^{o}C.

The dominant soil type in the watershed is nitisol. As reported by FAO (2001), nitisols are deep, well-drained, red, tropical soils. They are generally considered fertile soils. Besides, they are stable soils with favourable physical properties .The deep porous and stable soil structure permits deep rooting and make the soil quite resistant to erosion. Thus, they are the most productive soils to produce the commonly grown food and plantation crops. Coffee, *Zea mays L.,* finger millet*, Eragrostis teff, Guizotia abyssinica* and others, such as lupine, beans and vegetables are cultivated throughout the study area. Despite the future opportunity to diversify crop production, farmers have widely planted *Eucalyptus* because it grows fast and requires low upkeep (**Figure 1**). The *Eucalyptus* trees are mostly planted along cropland borders and the main road to fulfil the need for fuel wood, construction and to generate income (Jagger and Pender, 2003). Its purpose is not to protect land against erosion.

Figure 1: The Irrigation scheme in partial view of the Koga Watershed (Photo, in August 2008)

However, indigenous, environmentally, friendly trees are nearly absent due to intensive deforestation. Maize is the major crop to perform well on nitisols including in the study area (FAO, 2001). The variety, BH540, which was utilized for the study is late maturing, has good grain filling ability, and is characterized by reddish tassel. Spacing between plants and between rows was 30 cm. 100 kg. DAP and 50 kg urea per hectare were applied at sowing and vegetative stages, respectively. As described by development agents and local farmers, growers could harvest greater than 50 quintals (5 tons) per hectare with a sale price of about 600 Ethiopian birr per quintal (1 quintal is equivalent to 100kg) in 2008.

2.2 Data collection and analysis

The general impact of *Eucalyptus* trees on crop production, soil property and moisture storage was assessed through interviews with key informants. Twenty-five interested, active farmers were interviewed in two representative *kebeles* (Ambomesk and Enguty), which are dominated by *Eucalyptus* plantations. The primary purpose of these interviews was to gather information concerning the history and background of *Eucalyptus* and to provide direction concerning the fundamental issues and questions to be answered experimentally. The answers from respondents were expressed in percentages for comparison. Since the interviewed farmers were very familiar with their environment, accurate indigenous knowledge concerning *Eucalyptus* trees with their environment was definitely collected.

For field and laboratory experiments, three farmers' maize croplands with adjacent *Eucalyptus* and *C. macrostachyus* plantations were selected since sampling was possible with out causing excessive damage to crop plants unlike in other croplands in the area. To check the effects of trees on maize cropland, soil physical properties, such as texture, bulk density, moisture content, available water capacity (AWC), and hydrophobicity were determined. In addition, the soil pH (KCl and H_2O), percentages of organic matter (OM) and total nitrogen (TN), available phosphorus (avail. P), exchangeable calcium (exch. Ca) and potassium (exch. K) were determined to test whether the *Eucalyptus* hedgerows affect soil chemical properties. For the analyses of the above parameters, soil samples were taken at 0.5, 1, 2, 5, 10, 15, 20 and 40 m distances from *Eucalyptus* hedgerows except for soil hydrophobicity taken at 0 to 300 cm at 20 cm intervals, and for pH, moisture in July-August and all the soil nutrients taken at 1, 5, 10, 15, 20 and 40 m.

Soil texture was determined using the textural triangle after the percentages of sand, silt and clay were determined from laboratory analysis using particle-size or mechanical analysis for air-dried soil samples, which were collected at different distances from *Eucalyptus* trees in the maize farm fields as described by Rowell (1994). According to Blake (1965), bulk density was determined to compare the values at the given sampling distances from both *Eucalyptus* and *C. macrostachyus* woodlots and in different depths (0-20, 20-40 and 40-60 cm) using tube core method.

To examine at what distance(s), stage(s) and depth(s), *Eucalyptus* trees caused moisture scarcity upon the adjacent maize plant, soil samples for gravimetric and volumetric soil moisture determination were collected at different distances from tree stands every month between July and October 2008 (at vegetative, flowering, tasseling and grain filling stages) in 0-20, 20-40 and 40-60 cm depths. The soil samples were taken using an auger and sealed in plastic bags to control moisture loss until the wet soil weight was recorded. Soil moisture contents were determined after the soil was oven-dried for 24 hours at 105 ◦C. At tasseling, the moisture contents at similar distances from *C. macrostachyus* stand were determined in three depths as described for *Eucalyptus* to compare the effects of the two tree species. In addition, the AWC was evaluated at field capacity (FC) and permanent wilting point (PWP), which were determined at suctions of 0.33 and 15 bars, respectively (Klute, 1965).

Hydrophobicity was determined in both the field and laboratory for dry and wet soils using a water drop penetration time (WDPT) test used by Dekker and Ritsema (1995). The water drop penetration time (WDPT) test was used to determine how long water repellency persists on a soil surface, and this measure is highly relevant to the hydrological effects of water repellency in soils caused by *Eucalyptus* trees as it relates to the time required for raindrops to infiltrate. For the laboratory analysis, five-gram samples of air-dried soil samples were placed in Petri dishes. A wetting phase was imposed through adding two grams of distilled water on the surface of each sample and allowing it to penetrate for three days. The samples were mixed gently to obtain constant moisture content (40%) in the whole volume of soil. For the field case, the test was done during the rainy month (July) to impose wetting phase, and the drier month (October) for the dried soils. Then three drops of distilled water released from approximately 10 mm above the soil surface, a standard droplet release height to minimize the cratering effect were dripped on to the soil. The actual time required for the complete penetration of the drops was recorded with a stopwatch for both laboratory and field tests. Moreover, the WDPT test was done for the dried and wetted *Eucalyptus* tree parts (leaf, bark and root) after they were ground to check which part and at which moisture condition causes soil water repellency.

Regarding the major soil chemical properties, pH was measured potentiometrically using a digital pH meter in the supernatant suspension of 1:2.5 soil to liquid ratio where the liquids were water and 1 M KCl whereas the percentages of OM and TN were determined by titration method. Exchangeable bases such as calcium and potassium were extracted from the soil colloids with 1M-ammonium acetate at pH 7 (Sahlemeden and Taye, 2000). Then, exchangeable Ca was measured from the extracts with atomic absorption spectrophotometer while exchangeable K was determined from the same extracts with flame photometer as described by Rowell (1994). Finally, available P was determined by Olsen extraction method (Olsen et al., 1954).

Since light is one of the most important plant growth factors, the impact of *Eucalyptus* shade on light intensity at the stand edge and on the undergrowth within the plantations was examined using a light meter. The measurements were taken above the canopy of neighbouring plants. The data were collected inside the shade and at 0.5, 1, 2, 5, 10, 15, 20 and 40 m distances from the *Eucalyptus* stands in the maize fields at different times during a day (9:00 am, noon, 12:30 pm, 3:00 pm and 4:00 pm).

In addition, the *Eucalyptus* root distribution was examined at 1, 5 and 10 meter distances from the trunk and in 0-20, 20-40 and 40-60 cm depths in profile pits. Roots were counted per 0.2 m^2 (1 m length x 0.2 m width) area. Then, comparisons were done along distance and depth.

To check the overall effects of *Eucalyptus* trees on maize plant performance for the factors described previously, maize plant population, plant height, biomass and yield data collected per 4 m^2 (2 m x 2 m) area at 1, 5, 10, 15, 20 and 40 m distances in to the maize fields from the tree stands were compared. In this case, the effects of *C. macrostachyus* and *Eucalyptus* spp. on maize plant height and count were compared. Moreover, to evaluate the effect of habitat modification on the growth of ecologically important understory assemblages in the study area, *Eucalyptus* stands and coffee garden shades were compared in terms of undergrowth density expressed as number of individual stands of shrubs, herbs, climbers and others in sum per ha. The plants considered as undergrowth were less than 3 m in height. By observing the canopy closure of the plantation stands, a count of understory growth was conducted under very sparse, sparse, dense and very dense shades of each plantation. Plot area for counting was 3 m x 3 m. A similar procedure was carried out for a coffee plantation with *Croton macrostachyus* as shade trees. Photographs of coffee gardens with the *Croton macrostachyus and Eucalyptus* stands are shown in **Figure 2**.

The experiment was carried out in triplicate using three different fields. For each parameter, the data collected at the 40 m distance from the tree stand edge was used as the control value. Statistical differences were determined by one-way ANOVA employing a 95% level of confidence. Descriptive statistical procedures were also applied.

Figure 2: *Croton macrostachyus* (A) and *Eucalyptus* (B) trees along maize farm borders, and the under growth density within a coffee garden (C) and a *Eucalyptus* stand (D).

CHAPTER THREE

3. RESULTS

3.1 Farmers' perception about the environmental impact of Eucalyptus plantation

The interviewed key informants were nearly all males ranging in age from 36 to 45 years old with an education level that varies from non formal education to grade eight or higher (**Table 1**). Females were less familiar with the day-to-day agricultural activities and there was little exchange of information from males to females. Tree planting in the area was most commonly for fuel wood (100%), income generation (96%) and construction (84%). No respondents replied that trees were planted for environmental conservation. The most commonly planted tree species in the Koga Watershed was *Eucalyptus*, planting of which began during the reign of Emperor Haile Selassie (1915-1974) with a very fast expansion rate since 1991 (**Table 2**).

Table 1: Demographic expression of well-informed farmers in the study area (N=25)

Demographic information	**% Farmers**			
Gender	Male (100)		Female (0)	
Age	25 - 35 (32)	36 - 45 (52)	46 - 55 (24)	56 -65 (4)
Farmers' educational status	Illiterate (28)	Grade 1-4 (60)	Grade 5-8 (8)	>8th grade (4)

Table 2: Farmers' perception concerning tree planting in the locality (N=25)

Issues regarding to trees planting	Percentage of respondents			
Source of energy in the area	Wood (100)	Manure (12)		Others (12)
Purpose of tree planting in study area	For fuel (100)	Income (96)	Construction (84)	Others (4)
Mostly planted tree	*Eucalyptus* (100)		Others (0)	
Start of *Eucalyptus* plantation	During emperor Mengistu (36)		HaileSelassie (64)	
Eucalyptus plantation expansion	Very fast (56)	Fast (24)	Average (12)	Slowly (8)

All farmers possessed land ranging from 0.25 to 3 hectares although most of them (48 %) owned farms of 0.25 to 1 ha size. All landowners utilized their land for a combination of crop production, tree plantation and grazing. Most farmers planted *Eucalyptus* trees on former cropland (40%) and along cropland borders (60%). The farm sizes covered with trees by individual farmers were 0.13-0.25 ha (44 %), 0.26-0.50 ha (32 %), 0.51-1 ha (16 %) and 1-2 ha (8 %) (**Figure 3**).

Table 3: Activities performed by a farmer on his land in the Koga watershed (N=25)

Farmer's land holding and uses	**% Respondents**			
Possession of land	Yes (100)			No (0)
Farmer's total area of land in hectare	0.25-1 (48)	1.25-2 (36)		2.25-3 (16)
Activities a farmer performs	Crop production (100)	Tree planting (100)		Grazing (100)
Tree sp. Planted by a farmer	*Eucalyptus* (100)		Others (28)	
Farmer's reason for *Eucalyptus* planting	Fast growth (84)	Cash (100)	Fuel wood (4)	Easy management (4)
Farmer's location to plant *Eucalyptus*	On crop land (40)	Along crop border (60)		On marginal land (64)
Land area covered by *Eucalyptus* (ha)	0.13-0.25 (44)	0.26-0.5 (32)	0.51-1 (16)	1-2 (8)

In the watershed, all farmers perceived that *Eucalyptus* plantations have a negative environmental impact (100 %). About 44 % of the local farmers professed that there is no difference between crops species in resisting the negative effect, i.e. all are susceptible (**Table 4**). From the common crops in the area, the highly affected crops in the farmers' opinions are finger millet (96%), maize (80%), teff (56%), *noug* (niger seed) (53%) and bean and other vegetables (44%) because of the shading effect, water and nutrient competition, thinning of seedlings and forcing poor grain filling. According to the farmers' opinions, the *Eucalyptus* trees affected soil property by drying out the soil (92%), making soil unfertile (8%) and reddish (4%). Most farmers (96%) in the watershed suggested that *Eucalyptus* trees affect soil moisture through excessive root suction. Soil moisture stores dried up due to the nearby *Eucalyptus* plantation (80 %) (**Table 5**). The responses from the interviewee showed that *Eucalyptus* trees adverse effects are more pronounced on reddish soil (96%), sloping land (84%), and dry land (96%) instead of on black soil, flat and wet lands. According to the view of the respondents, the most adverse effects of *Eucalyptus* can be seen if the trees are planted east (88%), south (32%), and west and north (20 %) of the cropland (**Table 6**).

Table 4: Farmers' perception about environmental impact of *Eucalyptus* plantation in the Koga Watershed (N=25)

Impact of *Eucalyptus*	**% of farmers**					
Effect on crop production, soil and water	Yes (100)			No (0)		
Resistance difference with crops	Yes (56)			No (44)		
Resistant crops	Maize (20)	f. millet (4)	Teff (28)	*noug* (12)	bean (4)	others (8)
Susceptible crops	Maize (80)	f. millet (96)	Teff (56)	*noug* (52)	bean (44)	others (44)

Table 5: Mechanisms and conditions by which *Eucalyptus* plantation affects the ecosystem (N=25)

Mechanisms	**% of farmers**				
Affect on crop production	Shading effect (4)	Nutrient competition (28)	Moisture competition (28)	Seedling thinning (56)	Affecting grain filling (8)
Causing alteration of soil property	Causing unfertility (8)		Changing soil color to red (4)		Drying out (92)
Water bodies	Sucking much water (96)		Have no idea (4)		
Presence of dried up water bodies	Yes (80)		No (20)		

Table 6: Conditions at which *Eucalyptus* plantation effect is more pronounced (N=25)

Conditions	% of farmers			
Soil	Unfertile soil (40)		Red soil (96)	Black soil (36)
Slope	Sloping land (84)		Flat land (48)	
Drainage systems	On dry land (96)		On wet land (12)	
Management system (direction of *Eucalyptus* trees to adjacent plantation)	East (88)	West (20)	North (20)	South (32)

Table 7: Farmers' recommendation for the future (N=25)

Type of recommendation	% of farmers	
Farmer's primary choice	Crops (88)	*Eucalyptus* (60)
Farmer's suggestion for food security and his priority	Crop production (100)	*Eucalyptus* plantation (12)
Proper *Eucalyptus* plantation allocation	On productive land (0)	On marginal land (100)

3.2 Experimental findings about the effect of Eucalyptus plantation on the ecosystem

3.2.1 Status of soil physical properties

In both texture and bulk density comparisons of soils at different distances and depths, non-significant differences were detected. The soil textural classes for all soil samples taken in 0-20 cm depth and all distances in the study area were clay loam (**Table 8** and **Appendix 2**). The average textural class of each field was also clay loam (**Table 9**).

Table 8: Means of percent soil fractions and textural classes at different sampling distances from *Eucalyptus* hedge rows

	Percent Soil Texture at Sampling Point Distances from Tree Stands							
	0.5m	1m	2m	5m	10m	15m	20m	40m
Sand	27.0	30.7	27.7	29.7	30.3	31.7	32.3	32.0
Silt	36.0	31.7	33.7	32.3	33.0	29.7	30.3	33.7
Clay	37.0	37.7	38.7	38.0	36.7	38.7	37.3	34.3
Class	Clay Loam	Clay Loam	Clay Loam	Clay Loam	Clay Loam	Clay Loam	Clay Loam	Clay Loam

Table 9: Average percent soil fractions and textural classes of each field soil

Plots (Fields)	Percent soil fraction Sand	Silt	Clay	Class
F1	27.4	34.0	38.6	Clay loam
F2	30.4	32.5	37.1	Clay loam
F3	32.8	31.3	36.3	Clay loam

All the bulk densities in all depths and distances from *Eucalyptus* and *C. macrostachyus* stands were grouped in the medium range (1-6 $g.cm^{-3}$); no samples were in low (< 1 $g.cm^{-3}$) or high (> 1.6 $g.cm^{-3}$) ranges (**Table 10**).

Table 10**:** Soil bulk density mean values ($g.cm^{-3}$) at different distances from wood lots

Tree species	**Sampling depth (cm)**	**Soil bulk density at sampling point distances (m) from trees stand**						
		0.5	1	2	5	15	20	40
Eucalyptus	20	1.1	1.0	1.1	1.0	1.1	1.1	1.1
	40	1.1	1.1	1.1	1.1	1.1	1.1	1.1
	60	1.0	1.1	1.0	1.0	1.1	1.1	1.1
Croton macrostachyus	20	1.1	1.1	1.2	1.1	1.1	1.0	1.1
	40	1.1	1.1	1.1	1.0	1.0	1.1	1.1
	60	1.1	1.1	1.1	1.1	1.1	1.1	1.1

In July and August when it rains almost contimuously, there was generally not a significant difference between moisture contents at the various distances from the *Eucalyptus* stand (**Figure 3**). Only in the 40-60 cm depth in July, the moisture content at 5 m from the tree was significantly lower thanvalues at 1 and 40 m. In the other depths and times the moisture content at 5 m was generally lower.

In September, at the end of the rainy monsoon period , the moisture contents near the *Eucalyptus* stand in all three depths were significantly less ($p < 0.001$) than the moisture contents farther away (**Figure 4**). This trend was not observed for *C. macrostachyus* where no signifcant difference in moisture content with distance to the tree was observed. It is interesting that at 15 m distance from the tree the moisture contents from *Eucalyptus* stand was statitically similar to that of *C. macrostachyus* stand as the sampling distance increased.

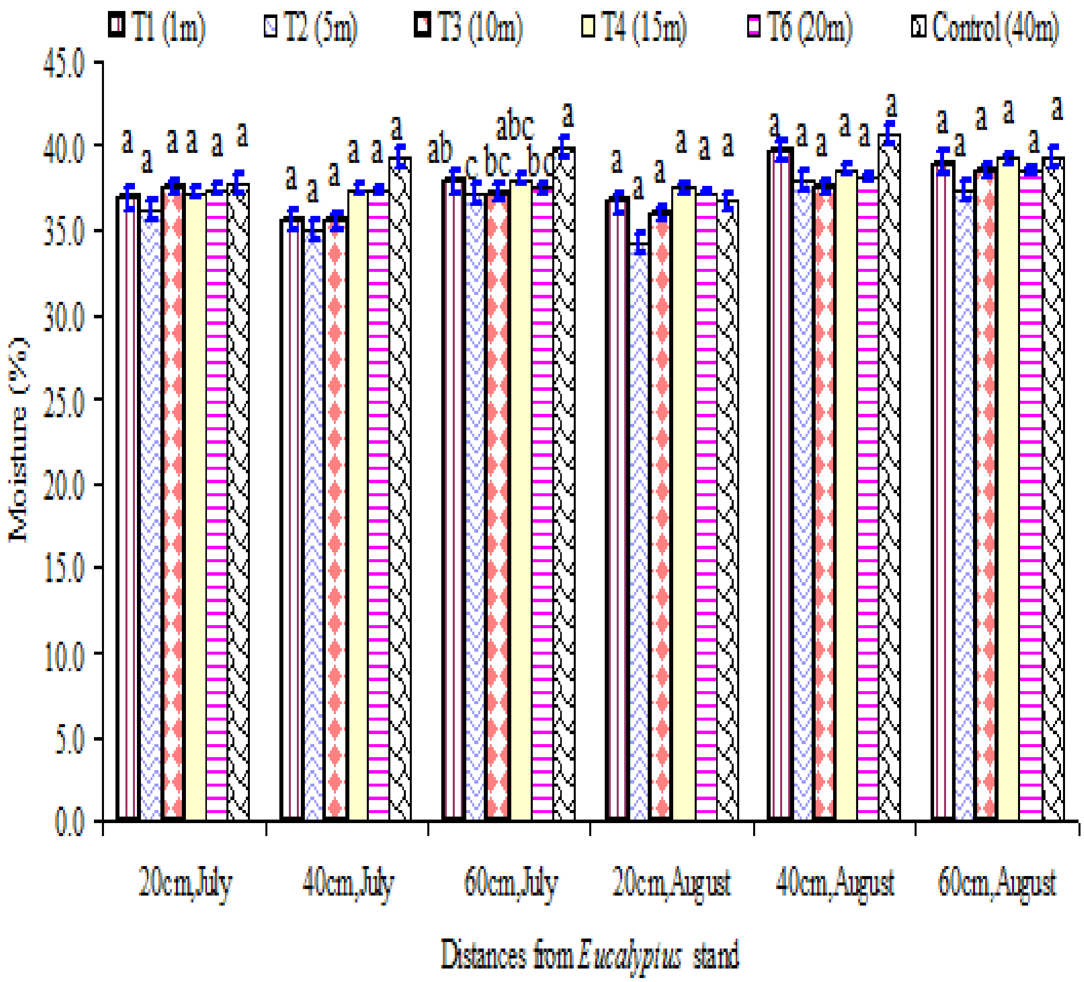

Figure 3: Gravimetric moisture content mean values comparison along distance from *Eucalyptus* stand at three different depths in July and August. Mean values followed by the same letters are not significantly different. Error bars represent the standard errors of the means (n=3).

In October, at maize grain filling stage, the trend in moisture content with distance along the *Eucalyptus* trees was similar to that of Sepember with moisture contents near *Eucalyptus* stand significantly ($p < 0.001$) less than father away moisture contents (**Figure 5**). In addition for this month, the moisture content in the 0-20 cm depth was significantly less than the moisture contents in 20-40 and 40-60 cm depths.

In other words, the AWC values of the maize farm soil at different distances from the trees at plow depth were notsignificantly difeerent ($p > 0.05$).

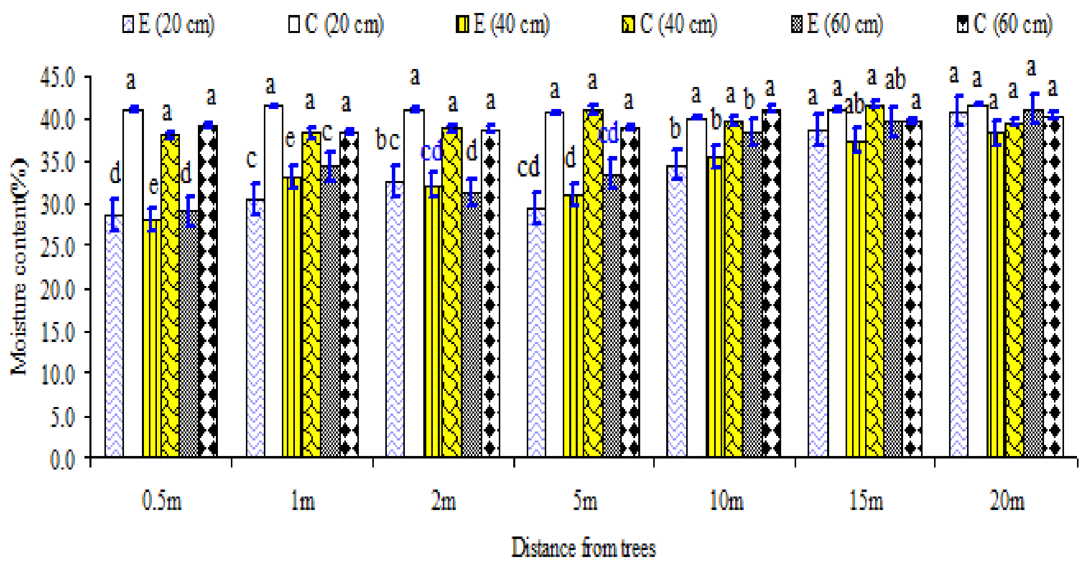

Figure 4: September gravimetric moisture content as a function of distance and depth of sampling to the *Eucalyptus* (E in the legend) and *C. macrostachyus* trees (C in the legend). Mean values followed by the same letters are not significantly different. Error bars represent the standard errors of the means (n=3).

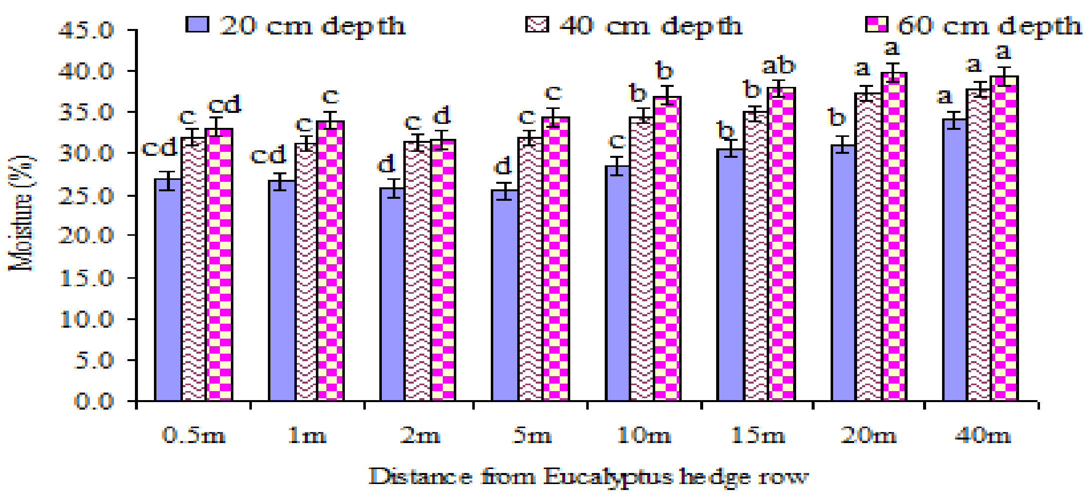

Figure 5: Gravimetric moisture content values comparison along distance from *Eucalyptus* stand at different depths in October. Mean values followed by the same letters are not significantly different. Error bars represent the standard errors of the means (n=3).

As expected, *Eucalyptus* trees did not affect organic matter content in the soil significantly. The organic matter varied from (2-4%) (**Figure 6**).

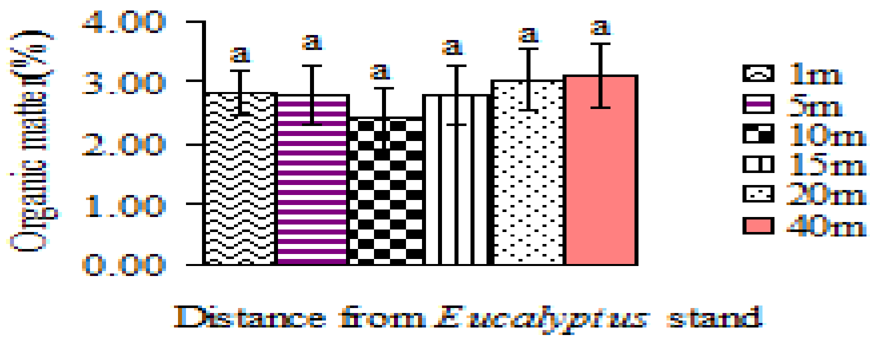

Figure 6: Organic matter values comparison along distance from *Eucalyptus* stand in the plough depth. Mean values followed by the same letter since they are not significantly different at 0.05 level LSD test. Error bars represent the standard errors of the means (n=3).

3.2.2 Status of soil chemical properties

In the study area, the surface soils (in 0-20 cm depth) were very acidic and did not significantly different ($p > 0.05$) with distance to the *Eucalyptus* stand (**Figure 7**). As for moisture content observation, the pH value at 5 m from the tree was the lowest.

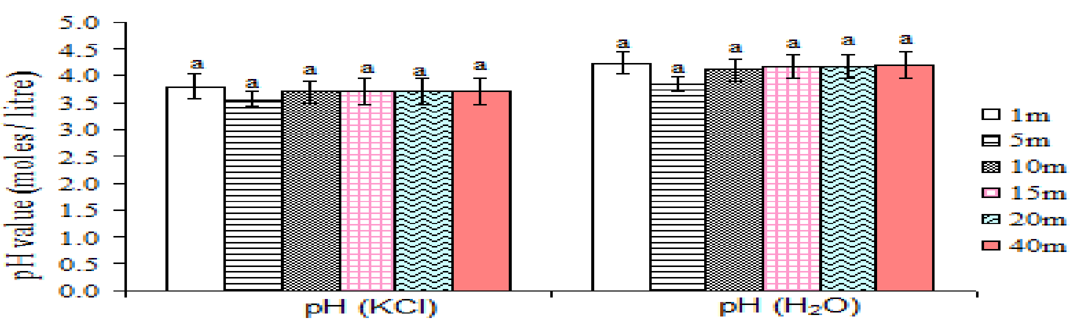

Figure 7: pH (moles/litre) values comparison along distance from *Eucalyptus* stand. Mean values marked with the same letter since they are not significantly different at 0.05 level LSD test. Error bars represent the standard errors of the means (n=3).

Unlike pH, there were significant differences in macronutrient concentration with distance from *Eucalyptus* tree. In general, the macronutrient status increased with distance from the *Eucalyptus* stand. Total N, nearest to the *Eucalyptus* stand however, was very significantly ($p < 0.001$) above the average. Next to it at 5 m TN was minimum (**Figure 8 A**). Farther from the trees, it increased up to the same value at 40 m as 1 m from the trees.

The available P content calculated was in the very low range (< 5 mg kg^{-1}). The one-way ANOVA showed that there was a highly significant difference ($P < 0.001$) in up ward trend with distance from the *Eucalyptus* stand (**Figure 8 B**). Exchangeable Ca concentrations, at 1 m distance was 7.8 (coml (+). kg $soil^{-1}$) and significantly ($P < 0.05$) less than the values at the other sampling points along the transect (**Figure 8 C**) which were in range that was considered in the high range 10-20 (coml (+). kg $soil^{-1}$) in Ethiopia. Finally, the exchangeable K concentrations at all distances were in high range, and independent of distance to the *Eucalyptus* stand at the 5% significant level (**Appendix 3**).

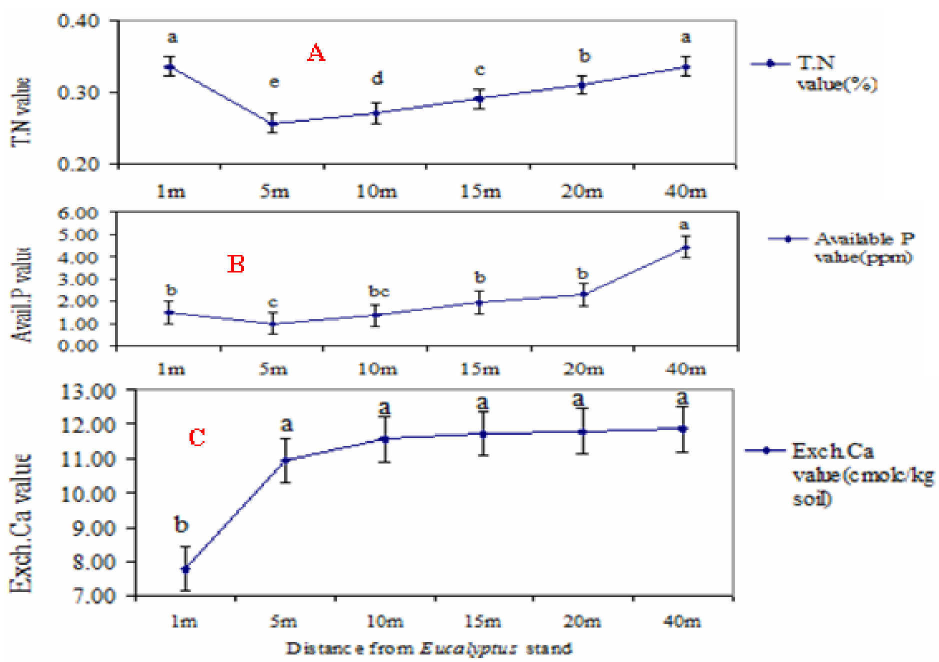

Figure 8: Percentage of total nitrogen (A) available phosphorus in mg kg^{-1} (B) and exchangeable calcium in centimol of cations per kg of soil, and (C) mean values comparison along distance from Eucalyptus stand in plough depth. Mean values followed by the same letters are not significantly different at 0.05 level LSD test. Error bars represent the standard errors of the means (n=3).

3.2.3 Status of soil hydrophobicity

Hydrophobicity has been often associated with *Eucalyptus* trees. We tested during July the soils for hydrophobicity in transect when they were wet. Samples were also taken at 20 cm intervals up to 3 m from the *Eucalyptus* stand and wet in the laboratory. Under these wet conditions, the soils were wettable with WDPT value < 4s (**Table 11**). However, when the soils were air or oven dried, they became highly hydrophobic especially close to the *Eucalyptus* stand as shown by the WDPT test with highly significant difference ($P < 0.001$). The WDPT test showed that for the field dried soils at 0 to 80 cm from the trees, the soils were severely water repellent, from 100 to 160 cm strongly water repellent, from 180 to 220 cm slightly water repellent and over 240 cm, non- water repellent. For the air-dried soil, the same trend was observed but water repellency was less severe. The dried *Eucalyptus* plant parts (leaf, bark and root) were found to be slightly water repellent. The WDPT value of the leaf was significantly ($P < 0.001$) greater than the values of bark and root (**Figure 9**).

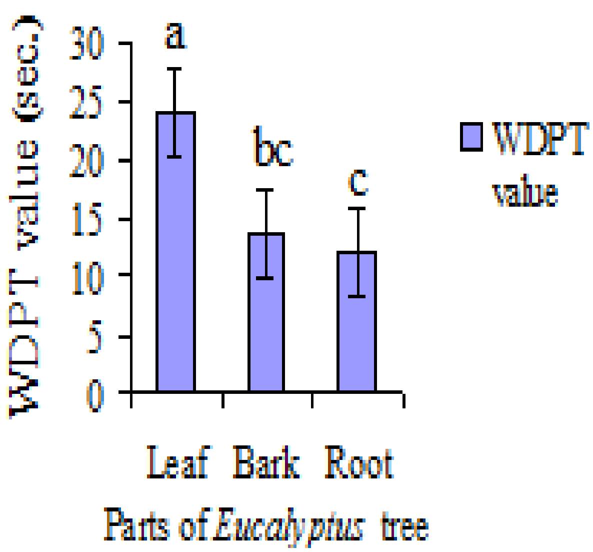

Figure 9: Water repellence comparison of parts of *Eucalyptus* plant.

Table 11: Soils hydrophobicity classification at different distances from *Eucalyptus* stand for soils in the field and sampled soils in the lab. in July and October

Sampling Distance (cm)	WDPT values (sec)		
	Field dry soils	Air-dried soils samples	Wetted soils samples
T1 (0 cm)	2740 a ***	110.7 a **	3.0 a *-
T2 (20 cm)	2640 b ***	106.3 b **	2.4 b *-
T3 (40 cm)	2220 c ***	44.7 c *	1.5 c *-
T4 (60 cm)	1980 d ***	1.3 d *-	0 d *-
T5 (80 cm)	1680 e ***	0 e *-	0 d *-
T6 (100 cm)	110 f **	0 e *-	0 d *-
T7 (120 cm)	80 fg **	0 e *-	0 d *-
T8 (140 cm)	74 fg **	0 e *-	0 d *-
T9 (160 cm)	70.8 fg **	0 e *-	0 d *-
T10 (180 cm)	22 g *	0 e *-	0 d *-
T11 (200 cm)	19.67 gh *	0 e *-	0 d *-
T12 (220 cm)	14.67 gh *	0 e *-	0 d *-
T13 (240 cm)	0.06 h *-	0 e *-	0 d *-
T14 (260 cm)	0.06 h *-	0 e *-	0 d *-
T15 (180 cm)	0.06 h *-r	0 e *-	0 d *-
T16 (300 cm)	0.05 h *-	0 e *-	0 d *-
C.V (%)	5.7	11.6	25.1
LSD at 0.05	68.71!!!	3.18!!!	0.18!!!

WDPT= water drop penetration time, *-= non-water repellent (WDPT< 5 sec), *= slightly water repellent (WDPT= 5-60 sec), **= strongly water repellent (WDPT= 60-600), ***= severely water repellent (WDPT= 600-3600 sec). Mean values followed by the same letters are not significantly different at 0.05 level LSD test,
!!!= Significant at the 0.001 level.

3.2.4 Effect of *Eucalyptus* trees on status of light intensity

Highly significant difference ($p < 0.001$) in light intensity at different distances from *Eucalyptus* stand was found for all measurement times. The trees caused serious light intensity reduction up to 5 and 10 m distances at 9:00 am and 12:00 am in the west direction, up to 10 m at 12:30 pm in the north and up to 15 m at 3:00 pm in the east direction (**Figure 10**). At 4:00 pm, *Eucalyptus* trees shade effect extended to 20 m in the east direction.

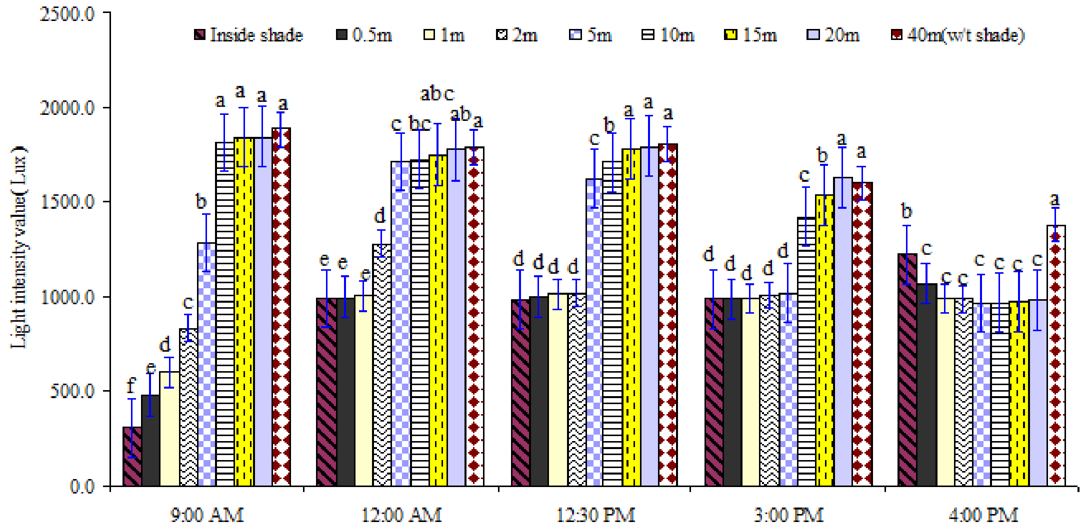

Figure 10: Light intensity values comparison along distance from *Eucalyptus* stand at different times within a day. Error bars represent the standard errors of the means (n=3). The measurements were taken in west direction at 9:00 and 12:00 am, north direction at 12:30 pm and east direction at 3:00 and 4:00 pm.

3.2.5 *Eucalyptus* root distribution

The *Eucalyptus* root was significantly ($p < 0.001$) more dense at 5 meter from the tree than at either 1 m or 10 m (**Table 12**). At 5 m distance, 600 roots per square meter were counted over the first 60 cm of the profile. That means that there is one root in every 1.8 cm^2. The variation of root density over the first 60 cm with depth was not significant.

Table 12: Mean *Eucalyptus* tree root distribution at different distances and depths (№/0.2 m^2)

Sampling depth (cm)	Root distribution (№/0.2 m^2) at different sampling distances from Eucalyptus stand (m)		
	1	5	10
20	22.7	135.0	13.3
40	26.3	144.0	14.7
60	37.7	177.0	16.3

3.2.6 Undergrowth status of shade trees

In the study area, a survey was performed to identify environmentally friendly tree species. The important overstory trees other than *Eucalyptus* spp. in the watershed were *Acacia albida, Acacia lahai, Croton macrostachyus, Grevilla robusta, Cordia Africana, Albizia spp., Maytenus obscura, Vernonia volkameriaefolia, Psidium guajava, Rhamnus prinoides, Ficus vasta, Olea africana* and some others. Most of these trees were used to provide shade for the coffee plants. Coffee is one of the most important exportable products. Moreover, some of them such as *P. guajava* and *R. prinoides* serve as food consumption. The average undergrowth density of the coffee garden shade was significantly ($P < 0.01$) greater than that of under *Eucalyptus* trees (**Figure 11**). The study proved that although the undergrowth density under both shades decreased as the canopy closure increased, the coffee shade trees undergrowth density is greater than that of the *Eucalyptus* stand at all densities of the overstory.

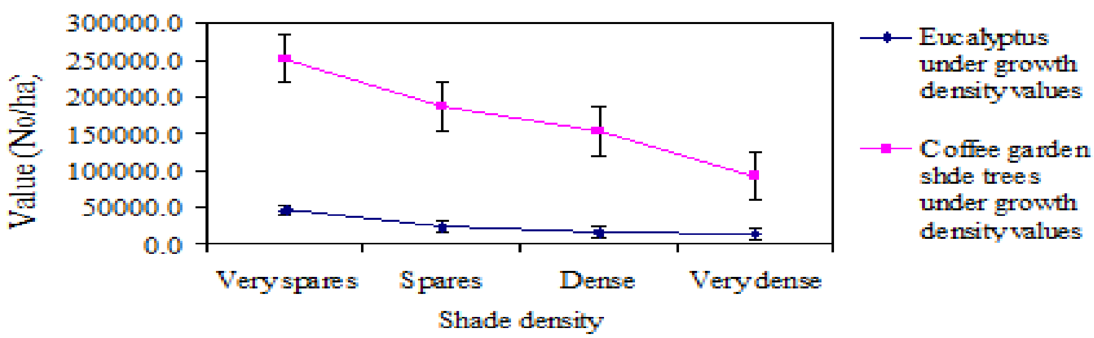

Figure 11: Undergrowth density ($no.ha^{-1}$) values comparison between *Eucalyptus* and coffee garden shade trees stands.

3.2.7 Effects of trees on crop performance

In **Figure 12 A and B**, the number of plants and plant height is given as function of distance from the tree for both the *Eucalyptus* and *C. macrostachyus* spp. Obviously the corn was not affected by the proximity of the *Croton spp.* while the effect on the corn near the *Eucalyptus* faired much worse than farther away. **Figure 12 C** shows a similar trend for both the corn yield and the biomass as a function of distance to the *Eucalyptus* stand. There was a 10 fold difference in biomass for the 1 and 20 m sampling points. The yield and biomass between 20 and 40 m was not significantly different.

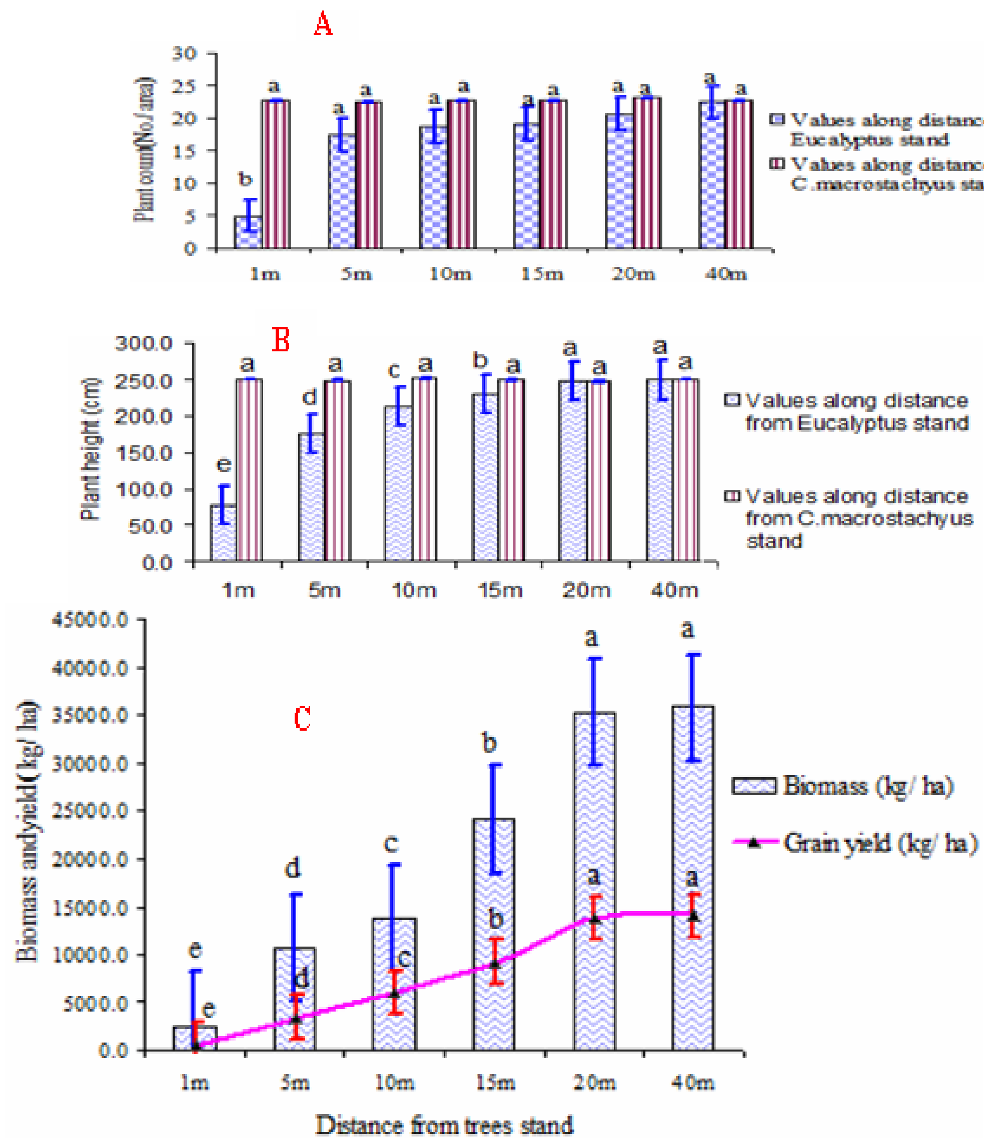

Figure 12: Maize plant count (A), Plant height (B) and biomass and grain yield (C) comparison along distance from *Eucalyptus* and *C. macrostachyus* trees. Error bars represent the standard errors of the means (n=3). The measurements were taken in west, east and north direction after half of November.

CHAPTER FOUR

4. DISCUSSION

In this study, there was a remarkable similarity between the three *Eucalyptus* stands tested. The soil in all three sites was a clay loam (**Table 9**) with medium organic matter (**Figure 6**) and low pH (**Figure 7**). The similarity was a result of that all sites were located on an old lakebed.

We found that for the three sites, the root density was greatest at 5 m from the tree (**Table 12**), and we found that the macronutrients (with exception of potassium) were most depleted at this point. Moisture content was also the lowest here, but not always statistically significant difference. Yield and biomass of maize were also most reduced near the *Eucalyptus* stand (**Figure 12**). Here not only the soil played a role but in addition, the light intensity was greatly reduced as well (**Figure 10**). However, soil pH (**Figure 7**), organic matter (**Figure 6**), exchangeable K (**Appendix 3**) and bulk density (**Table 10**) were not affected by the *Eucalyptus*.

At the maize maturity stage, moisture content was reduced even farther away 5m because of *Eucalyptus* border effect. Selamyihun and Stroonider (2004) reported that irrespective of crop species, less water remained in the soil in the tree-crop system than in the sole cropping. Since the growing medium is nitisol, both species can extend their roots deeper to take out water during the drier period. The nearest crop plants were wilted unlike the farther stands since E*ucalyptus* competes for moisture even deeper in the soil. However, the values were not significantly different because of *Croton* hedgerows due to their little lateral root extension and networking opposite to *Eucalyptus*. Yu et al. (2006) reported that the occurrence of most densely, maize plant rooted layers at or below 30 cm soil depth was very conducive to maintain plant water under the dry soil condition. In other words, Susiluoto and Berninger (2007) explained that the roots of *Eucalyptus* trees are usually well developed in the dry areas and enable them to use the water stored deep in the soil during the dry season. This opposes the maize plant to use the local water during the dry period by sending the roots deeply. As the respondents' opinion, *Eucalyptus* suctions excessive water from the soil and water stores. Therefore, the water in the plow depth and water points reduced and dried (**Table 5**). Thus, *Eucalyptus* trees unlike the other tree spp. such as *C. macrostachyus* compete with maize plants for soil moisture, and the plant available water is insufficient for the crop performance to get good yield.

Regarding the soil hydrophobicity, the soils at the field during the rainy season in the study area were non-water repellent even under the *Eucalyptus* trees similar to the wetted soil samples in the laboratory (**Appendix 4.1**). On the other hand, results of the WDPT test for the dry soils in the field revealed that the soils were severely, strongly, slightly and non-water repellent at 0 to 80, 100 to 160, 180 to 220 and ≥ 240 cm distances from *Eucalyptus* trees respectively. Moreover, the air-dried soils were only strongly water-repellent at 0-20 cm, and slightly and non- water repellent at 40 and ≥ 60 cm distances respectively (**Table 11**). Thus, the undisturbed top dry soil is more hydrophobic than the disturbed soil. Furthermore, from the *Eucalyptus* parts, leaf was much more water repellent than either the root or stem bark even though all are slightly water repellent (**Figure 9**). Therefore, *Eucalyptus* trees cause soil hydrophobicity up to 2.2 m distance from the woodlot during the dry season through leaf litter incorporation at surface soil. The situation happens particularly at the beginning and end of rainy seasons. Abelho and Graca (1996) found similarly that the *Eucalyptus* forest soils were highly hydrophobic and resulting in seasonal fluctuations in discharge. Hydrophobicity can affect soil microorganisms, plant growth, soil hydrology and soil erosion processes at centimetre to catchment scale as confirmed partly by Florenzano (1956) who found that the nitrifying bacteria were very low under *Eucalyptus* plantation litter.

Considering the soil chemical properties, all the soil samples taken at different distances from *Eucalyptus* stand in the maize farm were acidic (**Appendix 3**). One reason for that is leaching of cations deep in to the soil since the soil is red and rainfall is high (1560 mm). The other reason might be due to the incorporation of the maize stalk that increases humic and fulvic acids in the soil (Dou et al., 2008).

From the soil macronutrients, total nitrogen percentages in the plow zone from 0 to 20 cm depth at all distances were in the very high range (**Appendix 3**). Near the *Eucalyptus* stand, this might be due to its allelopathic effect, which opposes the mineral uptake by the plants and low mineralization. Bernhard-Reversat (1987) reported that mineralizable N, measured by 20 days averaged 11-14 mg N kg^{-1} soil under *Eucalyptus* and 40-50 mg N kg^{-1} soil under *Acacia* soils. Nevertheless, there was very highly significant difference between the TN values of sampling points. The value at 5 m was the least since the *Eucalyptus* root number was the highest. The TN values increased at the point where the competition of the *Eucalyptus* trees decreased. The available phosphorus content calculated in the first 20 cm depth at different distances from *Eucalyptus* stand was in the very low range (< 5 mg kg^{-1}) (**Appendix 3**) because the acidic soil fixed the phosphorus. Similar to other Ethiopian soils, we found that the exchangeable calcium and potassium were all in the high range (Ilaco, 1985). Dedecek et al. (2007) reported that *Eucalyptus* had a small effect on K level.

In the Koga Watershed, there were environmentally friendly trees like *Acacia* species. Under the important overstory tree types, the understory density was superior to *Eucalyptus* species (**Appendix 8**). Fabião et al. (2002) stated that *Eucalyptus* species were usually considered as having less understory vegetation than the other types of forest stands due to its competition and hydrophobic effects. These local tree species serve as shades of coffee plant including the other important undergrowth plant species like grasses, shrubs and ferns. As Mahmud et al. (2005) explained that there have been easily manageable, fast maturing and widely adaptable leguminous tree species (*Leucaena leucocephala, Prosopis juliflora* and *Albizia procera*), which improve the productivity of the adjacent plantation. The good performance of understory plants under these coffee shade trees is due to absence of competition for resources with the overstory plants as well as the advantage from the shade like nitrogen fixation. Hanil et al. (2008) stated that the undergrowth plants might show different patterns than the shade tree species because of different responses to light level, nutrient availability and temperature. Shaded crops such as coffee have shallower roots than the other fruit trees, and thus perform well (Lehmann, 2003). This is not true for *Eucalyptus* since local farmers tried and failed growing coffee under its shade. In addition, the different strata with in coffee garden shade facilitate infiltration, reduce erosion, increases water table and improve soil physical and chemical properties through the undergrowth biomass incorporation. Parker and Brown (1999) explained that multiple canopy or more specifically, the continuous distribution of foliar surfaces from the top of the crown to the ground created greater quantities and diversity of animal habitat, which enhances the decomposition of organic matter. However, allelopathy affects important soil organisms and other plant species under the *Eucalyptus* shade. Watson (2000) stated *Eucalyptus* leaf extracts have inhibited the germination of several plants. Therefore, *Eucalyptus* species caused drawbacks rather than improving the performance of the undergrowth vegetation unlike the mentioned multipurpose trees. One of the most important trees in the study area, *A. albida* shades and retains its tiny leaves during the rainy and dry seasons respectively (Dupuy and Dreyfus, 1992). Thus, it facilitates infiltration and reduces erosion due to mulches of the shaded leaves during rainy season, and reduces the sun radiation effect for vegetation and other microorganisms under the shade during the dry season.

As it was ensured experimentally, the maize plant performs poorly in its plant height and count up to 15 and 1 m distances respectively due to the impact of *Eucalyptus* species rather than *C. macrostachyus* border plantation. *Eucalyptus* hedgerow was also checked that it causes severe biomass and grain yield reductions up to 15 m from woodlots. The local farmers perceived that the common crop production is depressed by the adjacent *Eucalyptus* plantation although most farmers grew *Eucalyptus* species to be as similar as their neighbours did (**Table 4**). *Eucalyptus* reduces seedling emergence and other parameters of maize (EI-Khawas and Shehata, 2005). The reductions from the controls were 18.7-171 cm, 11.8-33.3 ton.ha^{-1} and 4.9-13.5 ton ha^{-1} in plant height, biomass and grain yield respectively. The most important parameter, the maize grain yield was greatly determined by light intensity that is important to get energy for whatever performances the crop does. Intercepted radiation by the crop plant relates to seed yield (R > 95) (Agele et al., 2007). Kotowskil et al. (2000) reported that light availability and/ or intensity had a large effect on most plant, species biomass production even than water level. Therefore, the plant species such as maize crop, planted to the *Eucalyptus* proximity in the west direction is more seriously affected due to light shortage (**Figure 10**). About 88, 32 and 20 percents of the farmers in the study area perceived that the *Eucalyptus* shading effect is more pronounced if the neighboring plants are in west, north, and south and east directions respectively (**Table 6**). In addition, *Eucalyptus* trees affected the maize plant performance by reducing available p even if the strength of belowground competition can be decreased with fertilization (James and Jr, 1999). Ayoola and Makinde (2008) explained that maize plant could give good yield if the growing medium has good amounts of N, P, K and Ca.

CHAPTER FIVE

5. CONCLUSIONS AND RECOMMENDATIONS

In the study area, the active farmers (males in the adult stage) perceived that *Eucalyptus* plantation depreciates the potential of the environment even though they keep on growing the trees because of the relative short time required to produce wood biomass for fuel, construction and cash. Experimentally, it was proven that the soils did not vary significantly in texture, bulk density, organic matter, pH, exchangeable K and AWC because of *Eucalyptus* impact. Therefore, the poor performances of the adjacent plants, particularly maize crop and undergrowth plants such as coffee and grasses were because of light, water and nutrients (total nitrogen, available phosphorus and exchangeable calcium) competition and soil hydrophobicity. Since *Eucalyptus* spp. are fast growing, and deep and dense rooted, the reducing and drying status of previously functional nearby water stores in the watershed is as a result of its greatest water sucking ability besides soil hydrophobicity and poor undergrowth that reduce infiltration and water table. Thus, there is a frustration that the potential ecosystem will be exhausted in the future because of the described worse environmental modification.

In the Koga Watershed, farmers suggested that priority should be given to crop production for food security point of view. That is crops and *Eucalyptus* trees should be cultivated on productive and marginal lands (consisting of wetlands and wastelands) respectively. Altogether, the results from the study leads to the recommendations those crops should be cultivated from at distance greater to about 15 m from *Eucalyptus* stand. Additional crops and undergrowth vegetation should be tested for its behaviour adjacent to the *Eucalyptus*. Furthermore, it is better to try to select the less resource seeking *Eucalyptus* species through additional studies. In addition, its allelopathic effect should be studied in detail. Economic analysis for *Eucalyptus* plantation should also be done to continue, reduce and potentially stop its use.

For the sustainability and efficiency of the Koga irrigation project, *Eucalyptus* should not be planted in close proximity to the water source (Koga River) since it reduces and dries up springs. Moreover, nitrogen fixing multipurpose tree species should be given preference to try to replace *Eucalyptus* species for successful plantation since *Eucalyptus* trees add nothing to the soil system except recycling some inputs unlike leguminous species, which fix nitrogen to the soil from the atmosphere. Therefore, *Acacia albida*, *Leucaena leucocephala*, *Prosopis juliflora* and *Albizia procera* due to special phenology, wide adaptability, drought resistance and timber quality respectively are promising species.

CHAPTER SIX

6. REFERENCES

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CHAPTER SEVEN

7. APPENDIX

Appendix 1: Status of soil moisture content

Appendix 1.1: Statistical summaries of gravimetric moisture content in July, August and September

Distance from Stand of trees (m)	Gravimetric moisture content (%) in three ranges of depths (cm)											
	July (*Eucalyptus*)											
	0-20				20-40				40-60			
	F1	F2	F3	Mean	F1	F2	F3	Mean	F1	F2	F3	Mean
T1 (1)	34.4	38.2	38.1	36.9	37.3	38.4	38.1	37.9	41.2	38.8	39.2	39.7
T2 (5)	33.9	37.2	37.7	36.3	36.2	37.2	38.0	37.1	37.4	37.9	38.5	37.9
T3 (10)	36.8	36.1	39.8	37.6	37.5	36.6	37.7	37.3	35.8	37.9	39.0	37.6
T4 (15)	35.0	37.3	39.6	37.3	36.3	37.3	40.4	38.0	37.9	37.5	40.4	38.6
T5 (20)	36.5	38.4	37.5	37.5	37.3	36.7	38.6	37.5	38.4	37.6	38.4	38.1
T6 (40)	38.8	37.3	37.5	37.9	42.7	37.0	39.9	39.9	39.8	41.0	41.0	40.6
C.V (%)	4.9				4.2				2.9			
LSD(0.05)	ns				ns				2.02*			
Distance	August (*Eucalyptus*)											
T1 (1)	38.7	35.4	32.7	35.6	37.8	36.7	35.4	36.6	42.4	37.4	37.4	39.1
T2 (5)	34.5	35.9	34.5	35.0	32.8	35.6	34.1	34.2	34.3	40.3	37.4	37.3
T3 (10)	34.7	36.8	35.1	35.5	35.4	38.1	34.2	35.9	36.9	38.0	40.7	38.5
T4 (15)	36.0	36.8	39.6	37.5	36.5	38.6	37.6	37.6	38.9	39.0	40.1	39.3
T5 (20)	35.4	41.4	35.4	37.4	36.7	37.3	37.8	37.3	37.1	37.3	41.3	38.6
T6 (40)	39.2	38.9	39.7	39.3	35.7	36.1	38.3	36.7	36.6	39.1	42.4	39.4
C.V (%)	5.7				3.7				6.3			
LSD(0.05)	ns				ns				ns			

C.V= Coefficient of variation
LSD= Least significant difference
***= Significant at the 0.001 level)
**= Significant at the 0.01 level
*= Significant at the 0.05 level
ns= Non significant
0-20, 20-40 and 40-60= Soil sampling depth ranges in centimetres
F1= Field one
F2= Field two
F3= Field three

Appendix 1.2: Statistical summaries of gravimetric moisture content in September

Distance from *Eucalyptus* (m)	September (*Eucalyptus*)											
	F1	F2	F3	Mean	F1	F2	F3	Mean	F1	F2	F3	Mean
T1 (0.5)	27.2	30.0	28.6	28.6	26.3	29.7	28.0	28.0	27.7	30.7	29.2	29.2
T2 (1)	30.1	30.5	30.9	30.5	32.7	33.1	33.5	33.1	34.3	33.4	35.1	34.3
T3 (2)	33.4	32.7	31.7	32.6	32.1	33.2	31.0	32.1	29.1	32.4	32.5	31.3
T4 (5)	27.8	30.5	29.8	29.4	28.0	32.5	32.3	30.9	31.5	35.2	33.4	33.4
T5 (10)	33.0	34.5	35.9	34.5	34.5	35.6	36.7	35.6	38.3	37.7	38.9	38.3
T6 (15)	38.2	41.1	37.0	38.8	35.9	38.0	38.3	37.4	39.6	38.1	41.1	39.6
T7 (20)	40.5	41.2	41.0	40.9	37.3	38.2	39.1	38.2	41.1	40.0	42.1	41.1
C.V (%)	3.8				4.3				4.0			
LSD(0.05)	2.2***				2.5***				2.5***			
Distance	September (*C. macrostachyus*)											
T1 (0.5)	40.2	42.0	41.0	41.1	39.0	37.1	38.1	38.1	39.8	40.0	37.7	39.2
T2 (1)	42.4	41.8	40.0	41.4	38.4	38.2	38.3	38.3	38.0	38.7	38.4	38.4
T3 (2)	39.4	42.2	41.8	41.1	38.0	39.5	39.0	38.8	38.0	38.9	39.0	38.6
T4 (5)	39.8	39.0	43.4	40.7	45.0	38.1	40.0	41.0	38.9	38.0	40.0	39.0
T5 (10)	39.8	38.8	41.5	40.0	39.8	40.4	39.0	39.7	39.8	41.0	42.2	41.0
T6 (15)	43.0	39.0	41.0	41.0	38.0	44.3	42.9	41.7	41.0	39.2	39.1	39.8
T7 (20)	44.2	40.0	41.0	41.7	39.0	40.0	39.5	39.5	41.7	40.0	39.2	40.3
C.V (%)	4.2				4.9				2.6			
LSD(0.05)	ns				ns				ns			

Appendix 1.3: Statistical summaries of gravimetric moisture content in October

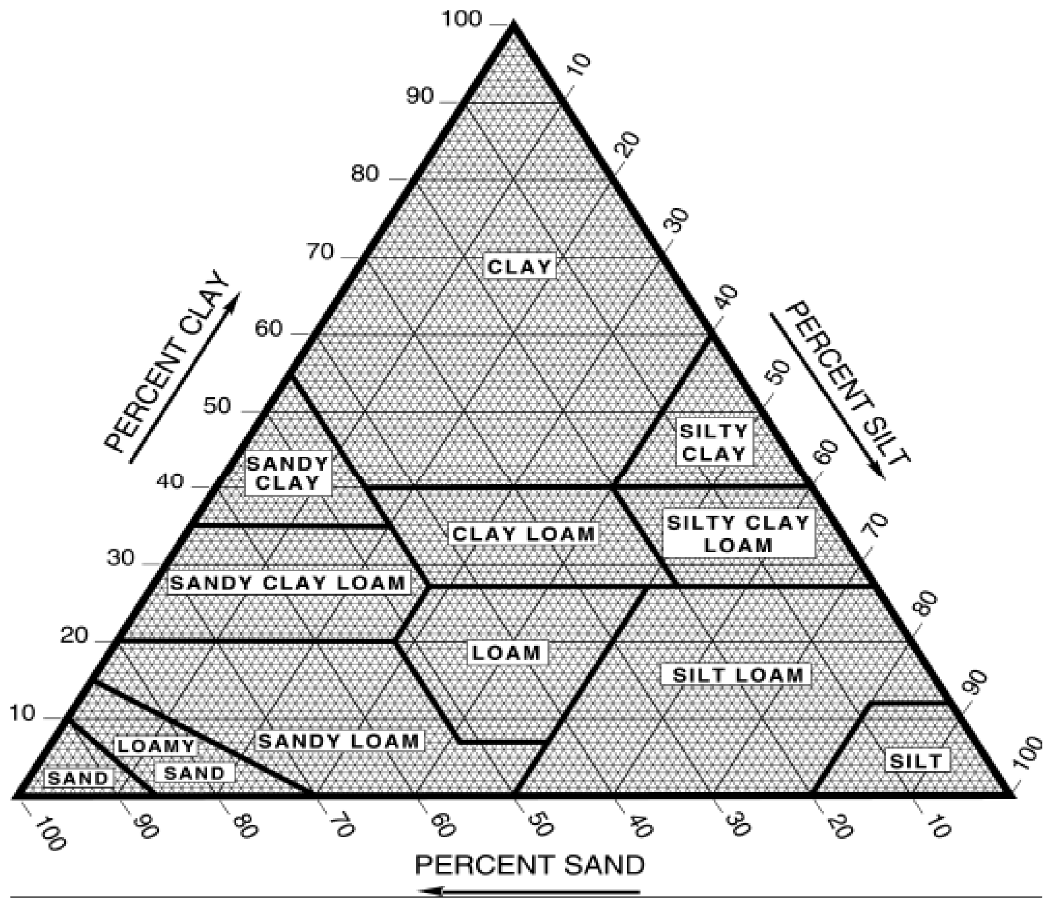
Distance from *Eucalyptus*	0-20				20-40				40-60			
	F1	F2	F3	Mean	F1	F2	F3	Mean	F1	F2	F3	Mean
T1 (0.5)	26.8	26.5	26.9	26.7	33.0	31.8	31.0	31.9	34.6	32.3	32.3	33.1
T2 (1)	25.9	26.2	27.7	26.6	31.6	29.3	32.4	31.1	34.4	33.4	34.1	34.0
T3 (2)	26.1	25.3	25.8	25.7	32.8	30.8	30.5	31.4	32.8	31.8	30.1	31.6
T4 (5)	23.4	24.9	27.8	25.4	33.6	30.6	31.3	31.8	36.3	33.5	33.1	34.3
T5 (10)	29.5	26.9	28.9	28.4	34.7	34.7	33.8	34.4	37.2	37.2	36.5	37.0
T6 (15)	30.7	30.5	30.4	30.5	34.1	36.0	34.3	34.8	36.7	40.0	37.0	37.9
T7 (20)	30.8	31.1	31.1	31.0	38.1	36.8	36.7	37.2	40.6	39.6	39.0	39.7
T8 (40)	33.9	34.2	33.9	34.0	37.5	37.5	38.0	37.7	41.2	38.2	38.6	39.3
C.V (%)	3.6				3.3				3.6			
LSD(0.05)	1.8***				1.9***				2.3***			

Appendix 1.4: Statistical summary of available water capacity in October

Distance from *Eucalyptus*	FC (%)				PWP (%)				AWC (%)			
	F1	F2	F3	Mean	F1	F2	F3	Mean	F1	F2	F3	Mean
T1 (0.5)	34.5	35.7	34.2	34.8	24.7	30.3	25.8	26.9	9.7	5.4	8.4	7.8
T2 (1)	33.6	35.7	34.5	34.6	28.2	26.8	26.5	27.2	5.4	8.9	8.0	7.4
T3 (2)	33.1	36.8	35.3	35.1	26.3	27.9	29.3	27.9	6.8	8.9	6.0	7.2
T4 (5)	32.8	34.2	35.7	34.2	20.7	27.4	29.8	25.9	12.2	6.8	5.9	7.7
T5 (10)	33.8	32.9	34.5	33.7	23.9	26.6	28.1	26.2	9.9	6.3	6.3	7.5
T6 (15)	39.5	35.1	37.5	37.4	31.8	28.3	30.9	30.3	7.8	6.8	6.6	7.1
T7 (20)	35.1	38.6	35.0	36.3	31.1	30.2	28.1	29.8	4.0	8.4	6.9	6.5
T8 (40)	35.7	35.2	39.7	36.9	29.2	28.7	32.6	30.2	6.5	6.5	7.0	6.7
C.V (%)									25.1			
LSD(0.05)									ns			

FC = field capacity; PWP = permanent wilting point; AWC = available water capacity

Appendix 2: The USDA soil texture triangle



Appendix 3: Statistical summaries of soil parameters

Distance from *Eucalyptus* (m)	pH(KCl) (mole/litre)				$pH(H_2O)$ (mole/litre)				O.M (%)			
	F1	F2	F3	Mean	F1	F2	F3	Mean	F1	F2	F3	Mean
T1 (1m)	3.7	3.8	3.9	3.8	3.9	4.8	4.0	4.2	2.1	3.1	3.3	2.8
T2 (5m)	3.6	3.6	3.5	3.6	3.7	3.9	4.0	3.9	3.3	2.3	2.8	2.8
T3 (10m)	3.7	3.7	3.7	3.7	3.9	4.5	3.9	4.1	2.2	2.6	2.3	2.4
T4 (15m)	3.7	3.8	3.6	3.7	3.8	4.9	3.8	4.2	2.6	2.7	3.0	2.8
T5 (20m)	3.6	3.9	3.6	3.7	3.8	4.9	3.8	4.2	3.0	3.0	3.1	3.0
C (40m)	3.6	3.8	3.7	3.7	4.3	4.5	3.8	4.2	3.1	3.1	3.1	3.1
C.V (%)	2.70				9.68				10.64			
LSD (0.05)	ns				ns				ns			
Distance	TN (%)				Available P (mg kg^{-1})				Exch. Ca (cmol (+) kg $soil^{-1}$)			
T1 (1m)	0.35	0.34	0.32	0.34	0.0	3.0	1.5	1.5	8.8	8.2	6.3	7.8
T2 (5m)	0.25	0.28	0.24	0.26	1.8	1.0	0.2	1.0	10.4	12.8	9.5	10.9
T3 (10m)	0.26	0.29	0.26	0.27	1.3	1.5	1.3	1.4	11.4	13.1	10.2	11.6
T4 (15m)	0.28	0.30	0.29	0.29	1.4	2.4	1.9	1.9	11.5	13.2	10.5	11.7
T5 (20m)	0.30	0.33	0.30	0.31	2.4	2.2	2.3	2.3	11.6	13.2	10.6	11.8
C (40m)	0.34	0.33	0.34	0.34	5.3	4.7	3.2	4.4	11.6	13.4	10.6	11.9
C.V (%)	0.00				33.55				12.79			
LSD(0.05)	0.00***				1.23***				2.47*			
Distance	Exch. K (cmol (+) kg $soil^{-1}$)				Cmol (+) kg $soil^{-1}$ = Cations in centimole per kilogram of soil							
T1 (1m)	1.59	1.07	0.95	1.20	Exch. Ca= Exchangeable calcium							
T2 (5m)	1.02	1.45	1.19	1.22	K= Potassium							
T3 (10m)	0.64	0.83	1.04	0.84								
T4 (15m)	0.64	1.69	0.81	1.05								
T5 (20m)	0.64	1.37	1.06	1.02								
C (40m)	0.64	1.42	0.68	0.91								
C.V (%)	39.34											
LSD(0.05)	ns											

Appendix 4: Hydrophobicity

Appendix 4.1: Statistical summary of soil hydrophobicity

Sampling distance from *Eucalyptus* (cm)	WDPT values (sec)											
	Field dry soils				Air-dried soils samples				Wetted soils samples			
	P1	P2	P3	Mean	P1	P2	P3	Mean	P1	P2	P3	Mean
T1 (0)	2760	2700	2760	2740	118	108	106	110.7	3	3	3	3.0
T2 (20)	2580	2640	2700	2640	103	106	110	106.3	2	2	3	2.4
T3 (40)	2100	2220	2340	2220	44	47	43	44.7	1	2	1	1.5
T4 (60)	1980	2040	1920	1980	1	2	1	1.3	0	0	0	0
T5 (80)	1740	1680	1620	1680	0	0	0	0	0	0	0	0
T6 (100)	120	90	120	110	0	0	0	0	0	0	0	0
T7 (120)	90	90	60	80	0	0	0	0	0	0	0	0
T8 (140)	78	84	60	74	0	0	0	0	0	0	0	0
T9 (160)	83.4	69.	60	70	0	0	0	0	0	0	0	0
T10(180)	23.0	22	21	22	0	0	0	0	0	0	0	0
T11 (200)	22.0	19	18	19.7	0	0	0	0	0	0	0	0
T12 (220)	16.0	15	13	14.7	0	0	0	0	0	0	0	0
T13 (240)	0.07	0.06	0.05	0.06	0	0	0	0	0	0	0	0
T14 (260)	0.06	0.06	0.06	0.06	0	0	0	0	0	0	0	0
T15 (180)	0.05	0.06	0.06	0.06	0	0	0	0	0	0	0	0
T16 (300)	0.05	0.05	0.05	0.05	0	0	0	0	0	0	0	0
C.V (%)	5.7				11.6				25.1			
LSD (0.05)	68.71***				3.18***				0.18***			

WDPT= Water drop penetration time
P1= Plot one
P2= Plot two
P3= Plot three
sec= Second

Appendix 4.2: Statistical summary of Eucalyptus parts

Treatments (Plant parts)	WDPT values (sec)			
	P1	P2	P3	Mean
T1 (leaf)	23	23	26	24
T2 (stem bark)	13	15	13	13.7
T3 (root)	11	12	13	12
C.V (%)	10.26			
LSD (0.05)	3.401***			

Appendix 5: Statistical summaries of light intensity

Appendix 5.1: Light intensity at 9:00 am, 12:00 am and 12:30 pm

Distance from trees (m)	Light intensity values (Lux)			
	9:00 am			
	P1	P2	P3	Mean
T1 (0)	392.4	267.0	256.5	305.3
T2 (0.5)	479.8	470.3	490.2	480.1
T3 (1)	570.0	617.5	617.5	601.7
T4 (2)	845.5	788.5	855.0	829.7
T5 (5)	1125.8	1425.0	1292.0	1280.9
T6 (10)	1805.0	1824.0	1813.6	1814.2
T7 (15)	1871.5	1843.0	1805.0	1839.8
T8 (20)	1795.5	1890.5	1843.0	1843.0
T9 (40)	1890.5	1881.0	1881.0	1884.2
C.V (%)	5.1			
LSD (0.05)	105.2***			
Distance	12:00 am			
T1 (0)	988.0	990.4	987.5	988.6
T2 (0.5)	996.6	993.2	996.1	995.3
T3 (1)	1008.4	1002.3	999.4	1003.4
T4 (2)	1251.6	1388.0	1188.5	1276.0
T5 (5)	1730.4	1698.1	1709.1	1712.5
T6 (10)	1720.5	1713.8	1731.9	1722.0
T7 (15)	1725.7	1757.5	1761.3	1748.2
T8 (20)	1765.1	1779.4	1786.0	1776.8
T9 (40)	1778.0	1790.0	1791.7	1786.6
C.V (%)	2.5			
LSD (0.05)	60.9***			
Distance	12:30 pm			
T1 (0)	988.0	978.5	977.6	981.4
T2 (0.5)	997.5	1001.3	1002.3	1000.4
T3 (1)	1019.4	1007.0	1002.3	1009.5
T4 (2)	1018.4	1014.6	1019.4	1017.5
T5 (5)	1502.0	1663.5	1702.4	1622.6
T6 (10)	1705.3	1708.1	1710.0	1707.8
T7 (15)	1772.7	1778.4	1780.3	1777.1
T8 (20)	1790.8	1791.7	1792.7	1791.7
T9 (40)	1793.6	1806.9	1810.7	1803.7
C.V (%)	2.5			
LSD (0.05)	61.4***			

Appendix 5.2: Light intensity 3:00 and 4:00 pm

Distance from trees (m)	Light intensity values (Lux)			
	3:00 pm			
	P1	P2	P3	Mean
T1 (0)	984.2	985.2	988.0	985.8
T2 (0.5)	985.2	987.1	986.1	986.1
T3 (1)	984.2	980.4	1006.1	990.2
T4 (2)	992.8	997.5	1026.0	1005.4
T5 (5)	995.6	1007.0	1058.3	1020.3
T6 (10)	1425.0	1414.6	1424.1	1421.2
T7 (15)	1589.4	1475.4	1541.9	1535.5
T8 (20)	1638.8	1635.9	1609.3	1628.0
T9 (40)	1589.4	1596.0	1618.8	1601.4
C.V (%)	2.0			
LSD (0.05)	42.2***			
Distance	4:00 pm			
T1 (0)	1324.3	1311.0	1035.5	1223.6
T2 (0.5)	1063.1	1161.9	980.4	1068.4
T3 (1)	988.0	978.5	997.5	988.0
T4 (2)	1007.0	969.0	978.5	984.8
T5 (5)	964.3	971.9	965.2	967.1
T6 (10)	970.0	968.1	970.0	969.3
T7 (15)	969.0	973.8	971.9	971.5
T8 (20)	980.4	984.2	978.5	981.0
T9 (40)	1383.2	1351.9	1392.7	1375.9
C.V (%)	6.0			
LSD (0.05)	108.2***			

Appendix 6: Statistical summaries of maize parameters

Treatment (Distances from trees)	Ph vs. Eu. Effect (cm)				Ph vs. Cr Effect (cm)			
	F1	F2	F3	Mean	F1	F2	F3	Mean
T1 (1m)	82.5	73.7	77.9	78	245	250	255	250
T2 (5m)	175.5	177	176.5	176.3	253	249	243	248.3
T3 (10m)	211.8	215.3	213.5	213.5	255	248	254	252.3
T4 (15m)	232.8	227.8	230.5	230.4	255	240	251	248.7
T5 (20m)	242	253	248.0	247.7	243	256	243	247.3
C (40m)	242	256	249.0	249	246	250	255	250.3
C.V (%)	2.1				2.3			
LSD (0.05)	7.6***				ns			
Distance	PC vs. Eu Effect (No./area)				PC vs. Cr Effect (No./area)			
T1 (1m)	5	6	4	5	24	21	23	22.7
T2 (5m)	17	13	22	17.3	21	24	22	22.3
T3 (10m)	13	19	24	18.7	21	24	23	22.7
T4 (15m)	13	20	24	19	22	23	23	22.7
T5 (20m)	13	23	26	20.7	22	23	24	23
C (40m)	14	20	33	22.3	20	20	28	22.7
C.V (%)	35.5				9.8			
LSD(0.05)	10.9*				ns			
Distance	Biomass vs. Eu Kg/ha				Yield vs. Eu (Kg/ha)			
T1 (1m)	1250	2500	3750	2500	750	250	625	541.7
T2 (5m)	10000	11250	10750	10666.7	3750	3000	3250	3333.3
T3 (10m)	12500	15000	13750	13750	6250	6000	5500	5916.7
T4 (15m)	23750	24000	24500	24083.3	8750	9000	9750	9166.7
T5 (20m)	35000	35000	35750	35250	12500	14500	14250	13750
C (40m)	35000	36250	36250	35833.3	12500	14750	15000	14083.3
C.V (%)	4.2				10.1			
LSD (0.05)	1519.2***				1399.7***			

Ph=plant height of maize
PC= plant count of maize
Eu= *Eucalyptus*
Cr= *Croton macrostachyus*
vs = Versus
C= Control

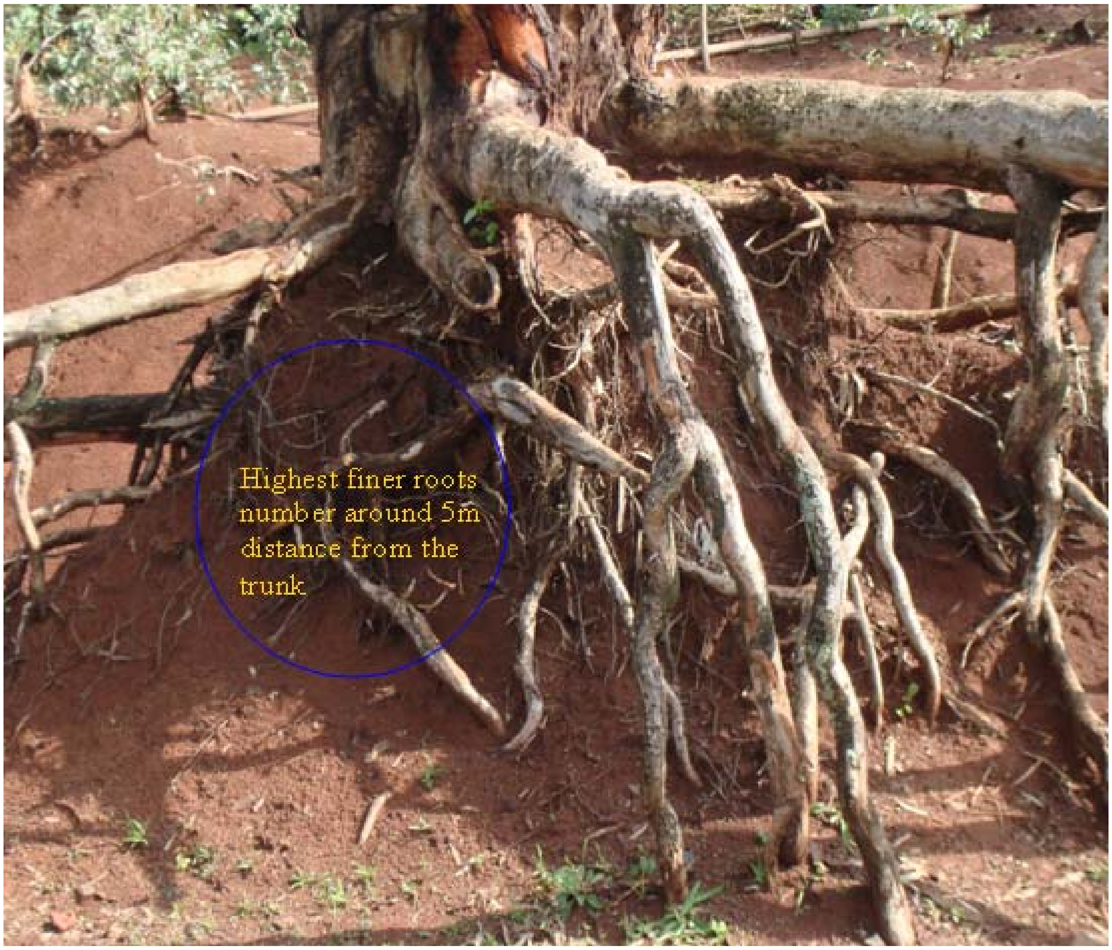
Appendix 7: Statistical summary of *Eucalyptus* root distribution

Distance from *Eucalyptus* stand (m)	Sampling depth (cm)											
	0-20				20-40				40-60			
	F1	F2	F3	Mean	F1	F2	F3	Mean	F1	F2	F3	Mean
T1 (1)	21	24	23	22.7	24	29	26	26.3	28	41	44	37.7
T2 (5)	104	134	167	135.0	131	102	199	144.0	263	143	125	177.0
T3 (10)	15	13	12	13.3	18	10	16	14.7	18	14	17	16.3
C.V (%)	32.0				46.8				56.6			
LSD(0.05)	36.4***				57.7**				87.1**			
Sampling depth (cm)	Distance from *Eucalyptus* trees (m)											
	1				5				10			
	F1	F2	F3	Mean	F1	F2	F3	Mean	F1	F2	F3	Mean
T1 (0-20)	21	24	23	22.7	104	134	167	135	15	13	12	13.3
T2 (20-40)	24	29	26	26.3	131	102	199	144	18	10	16	14.7
T3 (40-60)	28	41	44	37.7	263	143	125	177	18	14	17	16.3
C.V (%)	18.0				36.2				19.1			
LSD(0.05)	10.4*				ns				ns			

Appendix 8: Under growth density comparison of *Eucalyptus* and *C. macrostachyus*

Overstory Density	Undergrowth density (No.ha-1) of the two shades types								Statistical Significance
	Eucalyptus				Coffee shade trees				
	F1	F2	F3	Mean	F1	F2	F3	Mean	
Very sparse	56049.4	29753.1	54444.4	46749.0	280888.9	251888.9	222888.9	251888.9	***
Sparse	16049.4	26049.4	27777.8	23292.2	173222.2	244888.9	142333.3	186814.8	**
Dense	4567.9	17654.3	26777.8	16333.3	103666.7	210111.1	145888.9	153222.2	*
Very dense	3827.2	16049.4	18444.4	12773.7	57333.3	146333.3	73777.8	92481.5	*
Average	20123.5	22376.5	31861.1	24787.0	153777.8	213305.6	146222.2	171101.9	**

Appendix 9: Exposed deep and dense networked roots of *Eucalyptus* tree



Appendix 10: Questionnaire to Survey the environmental impact of *Eucalyptus* plantation in the Koga Watershed

Date: ------------ Time: --------------------
Key informants interview: Village/Location--------
Gender: M or F----- Name: ----------------------
Age: ------------------ Education: -----------------

Pertinent questions that was asked to study the effect of *Eucalyptus* on crop production, soil property and water bodies in Koga watershed:

1. How does the local community satisfy demand for wood biomass? ☐ by tree planting ☐ by animal manure ☐ by fuel gas ☐ other

➢Why do you think people plant trees? ---

2. Which tree species do most people plant in this watershed? ☐ *Eucalyptus* ☐ *Acacia* ☐ *Cordia* ☐ other

3. When do you think *Eucalyptus* trees planting was started in this locality? ☐ during emperor Menelik II ☐ during emperor Mengistu ☐ other

How *Eucalyptus* planting expanded in this area? ☐ Very slowly ☐ slowly ☐ average ☐ fast ☐ very fast

4. Do you have your own land? ☐ yes ☐ no

➢How many kada? ----------

5. For what purpose(s) do you use your land? ☐ crop production ☐ tree planting ☐ grazing ☐ other

➢What species of tree do you plant?
☐ *Eucalyptus* ☐ *Acacia* ☐ *Cordia* ☐ other

➢Why do you plant *Eucalyptus* rather than the other tree species? ---------------------

➢Where do you plant *Eucalyptus*? ☐ home stead ☐ on marginal land ☐ other

6. How much land do you plant in *Eucalyptus*? ----------------------------

7. Do you think that *Eucalyptus* trees have an effect on your crop production, soil property and water? ☐ yes ☐ no

8. Is their difference among crop species in resisting negative effects of *Eucalyptus*?
☐ yes ☐ no

If yes which are resistant? ---

Which are susceptible? --

➢How do *Eucalyptus* trees affect your crop production? --------------------------------

➢How do *Eucalyptus* trees affect soil property? ------------------------------------

➢How do *Eucalyptus* trees affect water? --

Are there dried streams, rivers and bore holes due to Eucalyptus trees plantation?
☐ yes ☐ no

9. Under which conditions of *Eucalyptus* are negative effects mostly pronounced? Please explain based on

Soil type---

Slope---

Drainage system---

Crop Management(direction)---
10. What measures could be taken to maximize crop productivity and the advantage of *Eucalyptus* in your locality? ---
11. Where do you think *Eucalyptus* should be planted? ----------------------------------
➢Please explain why--