Root production, soil organic matter, soil moisture, and sorghum yield in an alley-cropping system with *Acacia saligna* (Labill.) Wendl. and *Gliricidia sepium* (Jacq.) Walp. in the Hararghe Highlands, Eastern Ethiopia

by

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ABSTRACT

A major production constraint in alley-cropping is the below-ground competition of trees with the companion food crops for available water and nutrients in the soil. A knowledge of root production and distribution, soil water and nutrient availability in alley-cropping system, therefore, has considerable practical value for matching suitable trees and crops so that they complement one another and share the available resources effectively for maximum productivity. A field experiment was conducted to study root production, soil organic matter, soil moisture and sorghum yield in an alley-cropping system with *Acacia saligna* (Labill.) Wendl. and *Gliricidia sepium* (Jacq.) Walp. in the Hararghe highlands of Ethiopia. Tree hedgerows were planted on either side of a 4-m wide crop alley. Intra-row spacing between trees was 25, 50, and 100 cm. In October, 1994 and March, 1995 soil samples were taken at depths of 0-10 cm and 10-30 cm at a distance of 50 and 200 cm from the hedgerows using direct coring. A second method employed use of mesh bags to trap in-coming roots. Roots were separated from the soil by wet-sieving and root weight and root length density for each depth and distance were determined. Measurements of soil organic carbon and total nitrogen to a depth of 0-10, 10-30, and 30-60 cm were made. Field tensiometers were installed at 10, 30 and 60 cm depths to quantify soil moisture. Soil water content was periodically monitored at similar depths. Sorghum grain yield, above-ground dry matter production and height were also determined. *Acacia* fine-root ($\leq$ 2 mm) mass was significantly ($p \leq 0.05$) higher than for *Gliricidia* in the top 30 cm of the soil. *Acacia*

had over 45% of its fine roots in the top 10 cm of the soil while *Gliricidia* had only 30%. The presence of fine roots decreased by 55% and 40% for *Acacia* and *Gliricidia*, respectively, as the distance increased from 50 to 200 cm from hedgerows. Increase in tree root mass was accompanied by a proportional decrease in crop root mass. Results of the March samples showed that the long dry period is when trees allocate a higher proportion of carbon to the root system to stay competitive under the dry conditions. Leaf and twig dry matter of *Acacia* was significantly ($p \leq 0.05$) higher than for *Gliricidia*. Soil organic matter was 20% lower in control and 10% in *Gliricidia* plots compared to *Acacia* plots. Soil moisture content and water potential measurements indicated that soil moisture was lower in *Acacia* plots than in the control and *Gliricidia* plots. Sorghum biomass, grain yield and height were significantly ($p \leq 0.05$) higher with *Gliricidia* and control than with *Acacia*. The sorghum yield reduction with *Acacia* could be largely due to root competition for soil moisture.

CHAPTER 1: GENERAL INTRODUCTION

Traditional crop production systems that existed in Ethiopia and elsewhere in the tropics have destroyed the natural resource base of the land. Inefficient production systems compounded by rapid population growth have caused extensive forest clearance and overgrazing resulting in severe erosion, low soil fertility, lack of fuel wood and fodder for animals (Bishaw et al. 1993).

Ethiopia is a mountainous country with extensive plateaus dissected by deep valleys and steep slopes. Around 40% of the total land mass of the country lies above 1500 m. Due to the high population pressure marginal lands and steeps slopes are increasingly coming under cultivation with little or no soil conservation measures. In fact lack of appropriate soil and water conservation measures has been one of the major factors contributing to low levels of agricultural production in Ethiopia. Poschen (1987) reports that more than 50% of the Ethiopian highlands above 1500 m are currently under cultivation and that this is an extremely high percentage for a mountainous country like Ethiopia. As a result Hurni (1988) estimated soil loss under arable crops in Ethiopia to be 42 tons $ha^{-1}yr^{-1}$. This is much greater than the acceptable level of 2-11 ton $ha^{-1}yr^{-1}$ recommended by United States Department of Agriculture (USDA) for sustained agricultural production (Nair 1993).

Agriculture and forestry are in fierce competition for the scarce land resource in rural Ethiopia. Crops, trees, and animals compete for the same land. Since the importance of tree products is low compared to agricultural crops, forests are cleared to make way for agriculture. The encroachment on forested areas continues as more land for agriculture is required. Remnant forest lands, which are the subject of discussion later in chapter 2, now occupy less than 4 % of the land area of Ethiopia. This is a result of a steady decline in the land originally occupied by forests; which is believed to have been about 40 % of the country's land mass in 1890s. Fuel wood shortage is very acute in the eastern highlands of Ethiopia (Poschen and Eiche 1986). The difference in demand and supply of fuel-wood has to be made up from other sources, mainly from agricultural residues. As a result agricultural residues are increasingly overtaking fuelwood as a source of energy. Sorghum and maize stalks, roots, and leaves, for instance, are extensively used as source of energy. Use of plant and animal residues for energy indirectly reduces soil fertility by depriving the soil of recycled nutrients and conditioners.

Conventional large scale tree planting to aforest bare slopes is difficult under present land shortages. With the diminishing level of agricultural productivity it is also likely that farmers will continue to rely on land expansion and marginal lands will increasingly come under cultivation.

An integrated approach that satisfies all the needs of farmers for food, fodder, fuelwood, and cash income is required to improve and/or replace the present environmentally inefficient production systems. Sustainable agricultural production systems such as agroforestry systems can be used to satisfy the multiple needs and desires of farmers.

Alley-cropping, also known as hedgerow inter-cropping, is defined by Kang and Wilson (1987) as an agroforestry system in which agricultural crops are grown in alleys between hedgerows of trees and/or shrubs. The hedgerows are cut back at planting and periodically pruned during the cropping season to avoid shading and reduce competition with food crops. The system offers considerable potential for restoring soil fertility and supplying mulch, fodder, wood for fuel, and construction (Kang et al. 1985; Kang and Wilson 1987; Fernandes et al. 1993).

The benefits of the alley cropping in increasing crop productivity are well documented (Kang et al. 1981; Atta-krah and Kolawole 1987; Duguma et al. 1988; Kang 1988; Haile and Abdelkadir 1990). Recycling of nutrients, erosion control, production of mulching material, green manure, staking material, fuel wood, and fodder are among the benefits of alley-cropping cited (Yamoah et al. 1986a; Yamoah et al. 1986b; Lal 1989; Budelman 1990; Fernandes et al. 1993; Kang 1993).

Most of the success stories of alley-cropping reported so far measure only above-ground yields of crops and trees and do not report on the below-ground environment. The ecological conditions created by the root interaction of plant components of the system are rarely reported. Key issues of the below-ground environment and the level of competition that exists between different plant species grown together in an alley-cropping system, need to be addressed before arriving at any conclusion about the benefits of the system. The management option that optimizes efficient use of available resources should be evaluated and tested. Some basic questions on competition need to be addressed including how much do the roots of the hedgerow trees and the companion crop overlap? How competitive are the alley tree species and what is their effect on the companion food crop? Cadwell (1987) states that competition between two plants grown together occurs when either the soil resource is depleted more quickly by the stronger plant than is taken up by the weaker plant or the soil resource is depleted to levels below which the weaker plant is unable to extract the nutrients.

Competition for resources is severe especially in the semi-arid tropics. Singh et al. (1989) observed that there was severe reduction in crop yield in alley-cropping in the semi-arid tropics of India as a consequence of competition for water. Management options available must be identified. For instance, appropriate intra-row and inter-row spacing of hedgerows could alleviate domination of the below-ground spaces by the trees. This in turn improves the competitive ability of the companion crop and results in increased crop productivity.

This study reports results on the effects of intra-row spacing on root production, soil moisture changes and crop yield in an alley-cropping system in the Hararghe highlands of eastern Ethiopia. The study included two hedgerow tree species : *Acacia saligna* and *Gliricidia sepium* with three intra-row spaces of 25, 50 and 100 cm. Based on the hypotheses that selection of suitable tree species and intra-row spaces will mitigate the severity of competition between the components and improve the overall productivity of the alley-cropping system, the study had the following objectives:

Objective 1 - Compare the root biomass production of *Acacia saligna* and *Gliricidia sepium* grown at different intra-row spaces.

Hypothesis - differences in intra-row spaces will have an effect on the below-ground productivity of the tree species and will influence their competition with the food crops.

Objective 2 - Compare the soil nutrients and moisture under the different tree species and intra-row spaces.

Hypothesis - Changes in below-ground production as influenced by spacing will have an effect on the availability to plants of water and nutrient.

Objective 3 - Determine tree and crop productivity under alley-cropping systems for the two tree species using different intra-row spaces.

Hypothesis. Tree and crop productivity will be different in systems planted at different tree densities. Tree and crop productivity will be the basis for selection of the most suitable tree and crop combination for the Hararghe highlands of Ethiopia.

This research is a part of an ongoing study on agroforestry at Alemaya University of Agriculture (AUA) started in the 1980s by the then Forestry section. The present research project on alley-cropping was started in 1990 as a continuation of the agroforestry research tradition at AUA. The program was started as a joint research project of Alemaya University of Agriculture (AUA) and the Alley Farming Network for Tropical Africa (AFNETA), Ibadan, Nigeria. The research had two separate trials including intra-row spacing and alley-farming management with an extension activity to reach the farming community of the

Alemaya basin. Through the years the research not only helped obtain information on the biophysical potentials of alley cropping but also contributed to raising awareness of the importance of agroforestry among the rural communities surrounding the university through systematic extension and training programs conducted by the researchers. However, much remains to be done, especially in testing agroforestry technologies through on-farm and farmer participatory research and facilitation of the adoption of potential agroforestry practices by the farmers.

Dissertation Organization

The overall objective of the study seeks to find the relationship between the presence of tree roots, soil moisture conditions and productivity of sorghum grown in association with *Acacia saligna* and *Gliricidia sepium* in an alley-cropping system. The dissertation contains two manuscripts to be submitted to agroforestry systems and is organized as follows:

1. Chapter 1: General Introduction
2. Chapter 2: Background and Literature Review
3. Chapter 3: Root production and distribution of *Acacia saligna* (Labill.) Wendl. and *Gliricidia sepium* (Jacq.) Walp. in an alley-cropping system in the Hararghe Highlands, Eastern Ethiopia (Manuscript 1)
4. Chapter 4: Effect of *Acacia saligna* (Labill.) Wendl. and *Gliricidia sepium* (Jacq.) Walp. hedges on soil organic matter, moisture

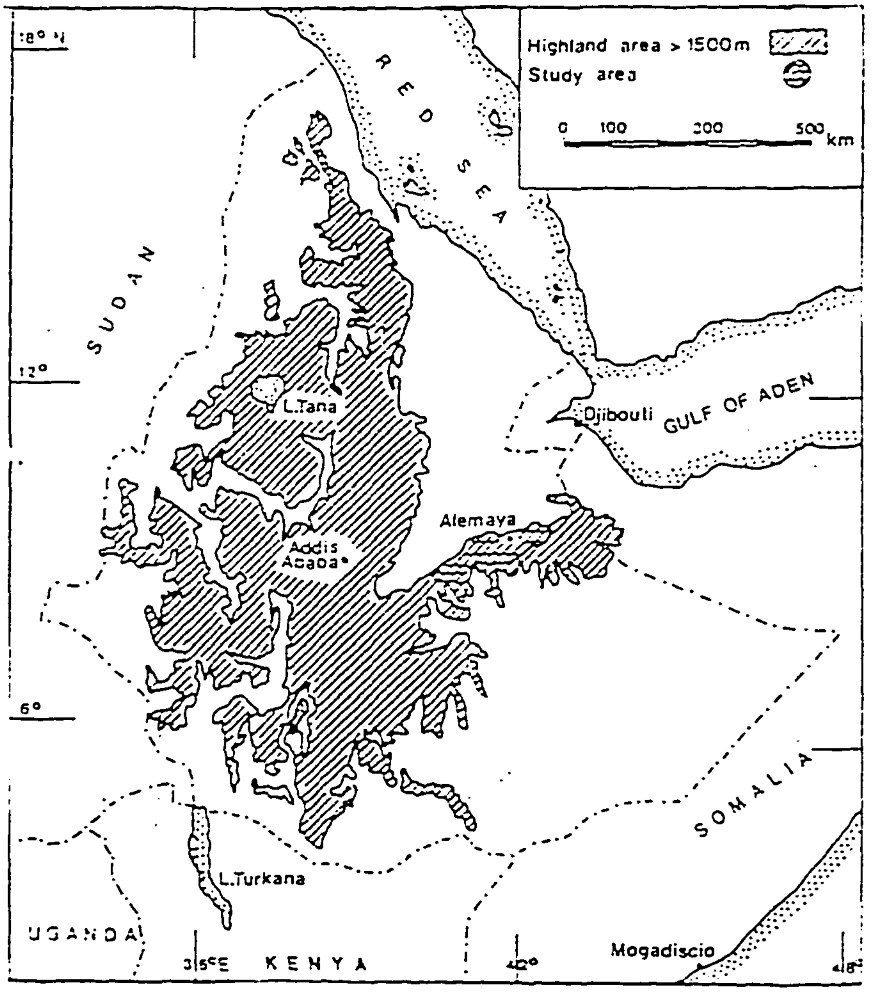
CHAPTER 2: BACKGROUND AND LITERATURE REVIEW

General -The Ethiopian Context

Ethiopia is located in eastern Africa commonly known as the "horn" of Africa. It has an area of approximately 1.2 million km^2. It is bordered by the Sudan in the west. Kenya in the south, Somalia in the south east, Eritrea in the north and Djibouti in the east (Figure 1). It has a population of 52 million with a population growth rate of 2-3%. Ethiopia is the third most populated country in Africa and the ninth largest in terms of land area (Ofcansky and Berry 1993).

The country's major physiographic features are the massive mountains and plateaus with characteristic deep valleys and steep slopes. More than 40% of the country's land area is considered highland area with elevations over 1500 m. Although the country is located in the tropics, the climate is greatly moderated by altitude. The county's climate follows the landscape varying from dry and hot lowlands of the rift valley to mild and cool climates in the mountains and plateaus. Because of their favorable climate and absence of many tropical diseases, the highlands are favored for settlement and more than two-thirds of the 52 million population lives there with the remaining living scattered over the lowlands. As a result some parts of the highlands are very densely populated.

Due to the high population pressure marginal lands and steep slopes are increasingly coming under cultivation with little or no soil conservation measures. Pocshen (1987) points



After Poschen (1987)

Figure 1: Map of Ethiopia showing the study site -Alemaya

out that more than 50% of the Ethiopian highlands are currently under cultivation and that this is an extremely high percentage for a mountainous country like Ethiopia. Continued deforestation, overgrazing and cultivation on marginal lands have eroded the soil and caused massive land degradation. Rugged topography and brief heavy rainfall are common features of the highlands causing accelerated erosion. Hurni (1988) estimated soil loss under arable crops in Ethiopia to be in the order of 42 tons $ha^{-1}yr^{-1}$. These figures are greater than the USDA acceptable level of 2-11 tons $ha^{-1}yr^{-1}$ for a sustained crop production (Nair 1993). Wide spread conservation measures were implemented during the late 1970's and 1980's aimed at expanding the forest resources base of the country and halting the severe erosion and land degradation. The program used large scale plantations and did not consider the farmer's production and the complex problems of the land tenure system. As a result, the program was ineffective and fell short of its objective. Large scale plantations compete with agriculture for the scarce land and labor resource. Increased population without agricultural intensification has forced farmers to adopt the strategy of land expansion to increase output. Forests are a low priority for farmers who depend on agriculture for their subsistence. At the same time farmers also need fuel wood. While large block plantations were not successful it is very possible that farmers would accept sustainable production systems like agroforestry which could be effective at achieving the desired conservation goals and providing the major source of fuel wood.

The Hararghe highlands, where this study was conducted, typically reflect the physical, ecological and social features that exist in the rest of the highlands in the country. Pressure on land and conflict between agriculture and forestry are major land-use problems in

Ethiopia as well as the Hararghe highlands. As a result, the experiment on which this dissertation is based may have similar implications to the whole of the country. To this end, the Hararghe highlands are a subject of detailed discussion in the following section.

The Hararghe Highlands, Ethiopia

The Hararghe highlands are located in the Hararghe region in the eastern part of Ethiopia. The Hararghe region comprises about 20 percent of the total land area of the country with 263,195 km^2. The physiographic features of Hararghe region vary from hot lowland plains in the northwest and southeast to highland and mountain areas in the south central and west. Most of the highland lies between 1800-2400 m with a few places above 3000 m. Alemaya district, the study site, is found in the eastern part of the Hararghe highlands and lies between elevations of 1850 and 2000 m. The site reflects most of the ecological and social features characterizing the Hararghe highlands.

Population

The population of Hararghe region, where Hararghe highlands are found, is about 4.5 million with an annual rate of growth of 2.9% (Haile and Abdelkadir 1990). The highland zone accounts for the majority of the population while the remaining few people live scattered over the lowlands. About 90% of the population of the Hararghe region live in rural areas and depend on subsistence agriculture for their livelyhood. The highlands are one of the most densely populated areas of Ethiopia. Poschen (1987) reports that population density increases from west to east of the highlands with Alemaya and Kerasa districts reporting the highest densities of 563 and 454 persons km^2, respectively.

Due to high population pressure, land scarcity is a limiting factor in agricultural production. As a result, there is increased cultivation of marginal lands better suited for forestry and grazing. Under pressure to produce more, marginal farmers continue to cultivate steeper and steeper slopes. When crop cultivation methods exceed the production capability of the landscape, land degradation becomes a serious problem.

Climate

Diverse rainfall and temperature patterns are the result of altitudinal changes in Hararghe highlands, in particular, and Ethiopia, in general. Traditionally, there are at least four environmental zones based on altitude and temperature (Table 1). Precipitation is the result of differences in altitude and seasonal changes in the atmospheric pressure systems that control the prevailing wind. Generally, rainfall increases with an increase in altitude. The highland areas, covering altitudes above 1500 m, have a rainfall reaching 900 mm/annum in dry and seasonal regions with up to 1250 mm/annum in the southwest humid areas of the highlands. The lowlands (below 1500 m altitude) are characterized by more arid conditions where rainfall is always meager with about 200-600 mm/annum.

Long term rainfall distribution in some selected sites of the Hararghe highlands is given in Table 2. Precipitation is seasonal and there are marked wet and dry seasons. The main rainy season is from June to September. This is usually preceded by a short rainy

Table 1: Climatic zones of Ethiopia (Franzel and Houten, 1992)

Zone	altitude (m)	temperature °C
Kola	500-1500	21-27
Woina dega	1500-2500	16-21
Dega	2500-3500	11-16
Wurch	>3500	<11

period in April and May, known locally as "belg". The Alemaya district, the study site, represents one of the major agroecological zones of the Hararghe highlands and has annual rainfall averaging about 840 mm.

Temperature is a function of altitude. Most of the Hararghe highlands experience a mild temperature between 10-20 °C. The cooler zone consists of the western parts of the Hararghe highlands and warms toward the eastern parts of the highlands. The warmest months include March, April and May. Seasonal variation is much smaller than daily variations. Temperatures warm during mid-day and diminish quickly and nights are usually

Table 2: Long term rainfall distribution in some selected sites of the Hararghe highlands of Eastern Ethiopia (Haile and Abdelkadir, 1990)

Name of site	altitude (m)	No. of years data was collected	average rainfall/year (mm)
Alemaya	1800-2000	28	840
Babile	1500-1700	10	680
Jijiga	1600-1800	10	570
Wacho	1700-1900	10	1307

cold sometimes below 0 °C. October. November and December are the coldest seasons. During these months frost often forms at night and can be strong enough to kill crops. The length of the growing period, defined as the number of days when available water exceeds 0.5 PET (potential evapotranspiration) is 180-270 days in most of the Hararghe highlands (Poschen 1987).

Soils

Precambrian quartz; calcareous sandstones. and calcareous limestones form the parent rock in the eastern and southwest parts of the Hararghe highlands. Towards the northwest the parent material is formed from tertiary basaltic rock (Tamirie 1984: Haile 1991). In response to variations in geological formations. climate. vegetation and relief different soils occur in Hararghe Highlands. According to Tamirie et al. (1981) soils vary considerably over short distances and dominant soil types vary with location. In the west. Alfisols. Ultisols. with some Vertisols prevail. In the east Inceptisols. Lithic Orthents. Orthents. and Fluvents are the dominant soil types (Table 3).

Overall the majority of the agricultural soils in the region are very shallow in depth. very low in fertility. In many places in the highland. the top soil. including the most recently formed rocks. has been eroded and the rock of the original continent is exposed once more. In general. soil fertility in the western half of the region is better than the eastern part (Tamirie 1984). According to Tamirie (1974) and Haile (1991) the soil where this

Table 3. Dominant soil types occurring on some selected sites in the Hararghe region. Data adapted from Haile (1991).

Area	Vertisols, Vertic fluvents Vertic Inceptisols	Alfisols, Ultisols	Inceptisols, Fluvents Lithic Orthents, Orthents,
Babile	4.0	19.00	76
Alemaya	0.7	0.08	99
Jijiga	1.0	0.06	98
Wacho	22.0	23.00	55

experiment was conducted is classified as a sandy loam, isothermic typic Usthorthent, locally known as the Alemaya series. It covers about 55-65% of the total land area of Hararghe highlands. The soil is low in organic matter (1.5 -2%), total nitrogen, available phosphorous and cation exchange capacity. The soil has a pH value near neutral. The soil is also very shallow and unproductive unless it is supplemented with very high amounts of commercial fertilizers.

Land Use in the Hararghe Highlands

Agriculture

Subsistence mixed farming dominates the Hararghe highlands. Crop and livestock farming are practiced simultaneously in the same management unit. Cereal and horticultural crops are the most important agricultural products in Hararghe highlands. Sorghum is the most important food crop grown in terms of area and production. Bishaw et al. (1993) reports that sorghum and maize accounted for about 72% of the annual cropland and represent the main staple food for the Alemayan basin. The leaves of these crops are removed for animal feed while the stalks are used as sources of fuel.

represent the main staple food for the Alemayan basin. The leaves of these crops are removed for animal feed while the stalks are used as sources of fuel.

Sweet potato, cabbage, lettuce, onion, potato, peaches and guava are some of the horticultural crops grown the Hararghe highlands. Most of these crops are almost exclusively grown as cash crops. They are grown with irrigation and are marketed both domestically and internationally mainly to Djibouti. The most important cash crop in Hararghe highlands is chat (*catha edulis*, (Vahl.) Endl.). This a stimulant that has a high demand in the domestic market as well as for export to Somalia and Djibouti. Initially, cultivation of the crop was confined to terraces on the well drained soils of the hillsides. Now, however, with increased demand the crop is grown in very fertile valleys mostly inter-cropped with sorghum and maize in an agroforestry system. It is estimated that about 23% of the agricultural land and 4% of the basin is used for chat cultivation (Poschen 1987; Bishaw et al. 1993)

The most important livestock in the Hararghe highlands are cattle, sheep, goats and donkey. Livestock is used for a variety of purposes including food, income sources, draft power, and transportation. Bishaw et al. (1993) reports that on the average, there are 2.68 head of cattle per household and 2.4 head of non-cattle livestock. The reason for the low level of livestock per household is lack of feed. The most important animal feeding method is tethering followed by open grazing on crop residues and stall feeding. Crop and livestock yields, in the area, are generally low and the recurrent drought aggravates the situation. The major constraints on crop production are an acute shortage of arable land, lack of fertilizer, shortage of rain, disease, and insects. Human pressure is very high. Poschen (1987) states that the present landuse system in the Hararghe highlands is generally associated with decreasing size of holdings both for arable land and pasture and there is a trend to convert forested and marginal lands into agricultural lands. As a result, steep rugged sites are now cultivated. When cultivation demands exceed the production capability of fragile landscapes, land degradation becomes a serious problem. Erosion threatens to undermine the usefulness of the land even for pasture and forestry.

Forestry

Before the turn of the century, most of the Hararghe highlands has a cover of climax forest vegetation (Breitenbach 1962). However, the forest resources of the Hararghe highlands were subjected to continued heavy exploitation. As a result only remnants of the original tropical highland forests are now evident. The two major species of these remnant forests are *Podocarpus gracilor* (Pigl.) Page and *Juniprus procera* Endl. Other minor species include: *Cordia africana* Lam., *Olea africana* Mill., *Croton macrostachys* Del., *Erythrina* L. species, *Hagenia abyssinica* (Bruce) Gmel., *Ficus* L. species, *Vernonia* Schreb. species and others.

Human created forests and plantations have recently been established through tree planting programs designed to meet local needs for fuel and construction wood. Bishaw et al. (1993) reports that plantations occupied about 5% of the Alemaya basin and were planted in the form of woodlots, roadside plantations and gully plantings. The common species in these programs included fast growing species such as *Eucalyptus camaldulensis* Dehnh., *Eucalyptus globulus* Labill., *Eucalyptus saligna* Smith, *Acacia saligna* (Labill.) Wedl. and others. The fast growth and the short time needed to reach the desirable size has made these species very popular among farmers.

Nearly 90% of the energy requirement of the Hararghe, in particular, and Ethiopia in general, comes from firewood and agricultural residues. Scarcity of fuelwood is very acute in most parts of the highland. According to study reports the region's fuelwood consumption rate is lower than the minimum required energy consumption (Poschen and Eiche 1986). A farmer in the region is forced to use one third of his farm labor to collect wood. Firewood supplies are brought in from a radius of 16-20 km. The average collector takes 3-4 days to collect one donkey load of wood (equivalent to 0.05 m^3). The price of wood is so high that the average consumer has to pay a substantial portion of his/her income to buy firewood (personal communication with farmers in Hararghe, 1994). As a result, farmers are more and more dependent on agricultural residue as a source of energy. Bishaw et al. (1993) reports that shortage of fuelwood is a major problem in the Alemaya basin and that most farmers (about 91%) identified crop residue as the main source of energy followed by cow dung. Building poles and sawn wood are also reported to be in acute shortage.

There is an interest among farmers to plant trees provided it meets their objectives and needs. Farmers may show preferences for species. Participation in tree planting can be strengthened by allowing farmer input in species selection, tree establishment and management, and allowing farmers the right to harvest and benefit from their efforts. If theses conditions are met future plantation efforts will be more successful.

Evolution of Alley-cropping as an Alternative Farming Technology in the Tropics

Kang and Wilson (1987) describe alley-cropping as an agroforestry system that involves the growing of agricultural crops in alleys formed by hedgerows of trees and/or shrubs. The hedgerows are cut back at planting and pruned periodically during the cropping season. The intention of pruning is to aid the companion food crops by avoiding excess shading and thereby reducing competition for resources from trees. When there are no food crops growing, however, the tree hedges are allowed to grow freely.

Alley-cropping offers considerable potential for restoring soil fertility and supplying food, mulch, fodder, wood for fire and construction, and medicinal products (Yamoah et al. 1986a; Lal 1989b; Fernandes et al. 1993; Atta krah and Kang 1993; Kang 1993). The system is also important in soil conservation and in combating soil erosion. Provided it is properly implemented alley-cropping has great potential for hilly terrain as an amendment against soil degradation (Lal 1989d; Pelleck 1993).

While alley-cropping is primarily for crop production, alley-farming (commonly used as synonym to alley-cropping) may combine crop production with livestock production. The idea, originally devised by the International Livestock Center for Africa (ILCA), is to extend alley-cropping to include livestock by using part of the foliage of trees and shrubs to feed animals in a crop and livestock mixed farming system (Kang and Wilson 1987).

In the tropics, trees have traditionally played an important role in the maintenance of soil fertility and protection of the land against erosion. One of the prominent tree based traditional farming systems of the tropics is shifting cultivation.

Shifting cultivation is a wide spread land use system in most of the humid tropics that involves temporary clearings which are cropped for short periods then left as fallow (Kwesiga 1994). Land is cleared and crops are planted for 2 or 3 years until yields are low and the land is abandoned to fallow vegetation. Under an abundance of land, which allows long periods of fallow, a stable and a fairly efficient crop production system can be developed. The long fallow periods allow enough time for soil fertility restoration. Kwesiga (1994) states that one of the salient characteristics of shifting cultivation is the state of equilibrium that exists depending on the quality of the land occupied and the population using it. Where the population is small enough to permit a lengthy fallow, returns per person are higher than can be obtained from continuous cultivation. However, the rapid rate of population growth and the correspondingly increased demand for food in the tropics has resulted in a shortening of the fallow periods that are essential for the restoration of soil fertility. As a result the practice has led to extensive forest clearance and subsquent soil erosion and land degradation in the tropics.

Alley-cropping was designed to overcome the inherent problems of shifting cultivation by direct incorporation of woody species as hedgerows into a continuous cultivation system. The trees function much as they do in shifting cultivation and bush fallow in restoring soil fertility. They fix nitrogen, recycle nutrients from deeper soils, suppress weeds, and increase the soil organic matter content (Nair 1993). Therefore, alley-cropping combines the regenerative ability of bush fallow and shifting cultivation in a continuous crop production system. Kang and Wilson (1987) state that the system actually has been practiced in the tropics for generations and its aim is to increase and sustain crop yields with or without external inputs such as fertilizers which may not be accessible to most farmers of the tropics.

Much of the research on alley-cropping has concentrated on improving and sustaining crop production and yield. Various trials have been conducted in the humid, sub humid and semi-arid tropics. Most of these studies report positive effects of alleys on their companion crops (Kang et al. 1985; Yoamha et al. 1986b; Duguma et al. 1989; Hairiah et al. 1992; Kang 1993). However, results of other researches also have shown alley-cropping to have serious negative effects on crop yields, especially those from the semi-arid tropics (Singh et al. 1989; Rao et al. 1991). Alley Farming Network for Tropical Africa (AFNETA) results, based on multiple locations have also arrived at similar conclusions for the dry tropics (AFNETA 1994).

In summary, over the years research in many parts of the tropics have, in most instances, confirmed the benefits of alley-cropping. Atta-krah et al. (1993), in a review of various research results, have concluded that alley-farming (alley-cropping) is a system with the potential for providing improved sustainability in crop productivity in the humid and sub-humid tropics. Through alley-farming soil productivity and crop production could be maintained at higher levels with no requirement for large inputs of inorganic fertilizer or long fallow periods.

Selection of tree and/or shrub species has been one major goal in alley-cropping research. Kang and Wilson (1987) say the success of alley-cropping depends on the choice of suitable woody species, successful establishment of the hedgerows, and appropriate management of the system. This realization has led to the selection and evaluation of local and exotic woody species to determine which best suit the prevailing conditions. A large amount of literature has been accumulated in this respect and national and international organizations have been screening species suitable for specific sites and conditions. ICRAF has compiled and reported a multipurpose data base which identified 1,600 woody species as potentially useful for agroforestry and the data base is being updated to include even more potential species (Owino 1989). Owino (1989) identifies the following characteristics for idiotypes for alley-cropping:

-Fast growth

-Good coppicing ability

-High biomass production

-Deep rooting habit

- Freedom from pests and diseases

- N_2 fixing legume

Woody species that have been extensively studied in alley cropping systems include: *Acacia auriculiformis* A. Cunn. ex Benth., *Cajanus cajan* (Linn.) Millsp., *Calliandra calothyrsus* Meissn., *Erythrina poeppigiana* (Walpers.) Cook, *Flemingia macrophylla, Inga edulis* Mart., *Gliricidia sepium* (Jacq.) Walp., *Leucaena leucocephala* (Lem.) De Wit., *Senna siamea, Alchornea cordifolia and Acioa barterii* (Atta-krah and Kang 1993).

The current stage of alley-cropping research is focused on the transfer of alley-cropping to farmers. On-farm research is an on-going process in many parts of the tropics. Ong (1994) observes that much of the reason for a lack of adoption of alley-cropping by farmers stems from the difficulty of reproducing the positive research results in farmers fields. Hairiah et al. (1992) state that the apparent reason why positive research results usually fail to be reproduced in farmers fields is that research results are obtained from highly controlled and high input experiments. Yield benefits from research may therefore be an insufficient basis to introduce the system to small farmers. Small farmers allocate all their limited resources to land, labor, and capital and are rarely able to manage new technology as prescribed by researchers. Rather they tend to make compromises in resource allocation and management (Franzel and Houten 1992). Therefore, the greater the farmers' participation in the design and testing of a new technology the greater the chances of adoption of that the technology by farmers; either as a full package or by incorporating individual components of the system.

On-farm research in alley-farming was started as far back as 1981 by the International Livestock Center for Africa (ILCA) in Southern Nigeria (Kang and Wilosn 1987). ILCA provided the seeds and technical advice and allowed farmers to modify the system to suit their objectives. Results of this and other on-farm tests have been successful and have shown the need for more research involving farmers. As a result, many institutions are conducting on- farm research.

Franzel and Houten (1992) suggest three areas of research that can include farmers and seek their participation: I) to develop an understanding of farmers priorities, management strategies, and criteria for evaluating the technology; II) draw upon farmers' indigenous knowledge for better understanding of their environment and their method for solving problems; and III) to use feedback from farmers to modify the new technology to make it more acceptable.

For example, Ong (1994) states that the response of mulching and organic matter addition may have long term effects which are not detectable to farmers over the short period. To get farmer adoption of a new technology he/she should be able to get benefits from the beginning. This dilemma provides a challenge in getting alley-cropping accepted by farmers.

Nutrient Cycling and Organic Matter Accumulation in Agroforestry Systems

Agroforestry mitigates land deterioration because of its potential for soil conservation and soil fertility maintenance. Incorporation of organic matter into the soil through litter fall and mulching, nutrient cycling from deep layers of the soil and nitrogen fixation are some of the venues of soil fertility maintenance in agroforestry systems. Nair (1993) states that agroforestry and other tree-based land-use systems are more efficient in nutrient cycling than traditional systems and thus have greater potential for soil fertility improvement than non-tree based systems. More extensive and deeper root systems enable trees to capture nutrients that might have been lost to deeper soil layers.

Plant production is dependent on the decomposition of organic matter and the release of its nutrients to the soil. Aber and Mellelo (1991) state that the quantity of essential nutrients entering an ecosystem each year from outside that ecosystem is generally low compared to the amount of cycling within the system. Thus, it is essential that tree based land-use systems be exploited to increase the nutrient cycling efficiency of an agroecosystem.

A large number of studies have been conducted to assess the nutrient cycling ability of agroforestry in general and alley-cropping in particular. Some of the earliest studies on alley-cropping were made by Kang et al. (1981) and Kang et al. (1985). They found that alley-cropping improved the fertility status of the soils and increased agricultural productivity. One of the trials, for example, found that the mean dry matter additions as mulch from pruning of *Leucaena leucocephala*, ranged between 5.85 - 7.09 Mg $ha^{-1}yr^{-1}$ with a mean nitrogen yield of 171 - 208 kg $ha^{-1}yr^{-1}$. Moreover, these trials found that the dry matter and nitrogen nutrient cycling efficiency of the system can be improved by initial application of fertilizers at the start of the cropping season.

Comparisons of nutrient yields of different tree species have also been a subject of interest. Kang and Wilson (1987) reported results of long term alley cropping with *Leucaena leucocephala* and *Acioa barteri* in a degraded alfisol in southern Nigeria. Estimated nitrogen yields ranged from 246.5 kg $ha^{-1}yr^{-1}$ with *Leucaena* to 40.5 kg $ha^{-1}yr^{-1}$ with *Acioa*. Phosphorous ranged from 19.9 - 3.6 kg $ha^{-1}yr^{-1}$ and potassium from 184 - 20.4 kg $ha^{-1}yr^{-1}$ for *Leucaena leucocephala* and *Acioa barteri*, respectfully. In another instance, Yamoah et al. (1986a) assessed dry matter yield and the potential contribution of N, P, and K of some woody perennials. *Cassia siamea* showed the highest dry matter yield with 29.5 Mg $ha^{-1}yr^{-1}$ followed by *Gliricidia* and *Flimingia* with 14.5 and 6.8 Mg $ha^{-1}yr^{-1}$, respectively. *Gliricidia* showed the highest N contribution partly because of its high leaf N content. *Flemingia* had lower N content followed by *Cassia* with the lowest leaf nitrogen.

Periodic addition of hedgerow pruning as mulch also helps in the improvement of soil physical properties. Hullugale and Kang (1990), in a study to determine the long term effects of alley- cropping on the physical properties surface oxic soils in Nigeria, report that alley plots of *Leucaena*, *Gliricidia*, *Alchornia cordifollia* and *D. bateri* had lower soil bulk density, lower diurnal temperature fluctuation and higher water infiltration than the control without tree alleys. Among the hedgerows, soil compaction was lower with *Leucaena leucocephala* and *Acioa barteri*. Similar studies were also made by Kamara and Haque (1992) under an agroforestry system with *Faidherbia albida* on vertisols of Ethiopia. The study showed that apparent increases in organic matter and N, P, and K levels under the tree canopy compared to levels outside the tree canopy. Soil pH, exchangeable Na, Ca, and Mg also showed similar results. However, available water was 1.5 to 2 times more under the trees. The soil texture and over all quality of the vertisols were improved due to the addition of soil organic matter.

However, other researchers have also reported mixed results. Lal (1989b) reports that intensive cultivation and sequential cropping (corn/cow pea) for six years, resulted in a decrease in soil organic matter content, total nitrogen, pH, and exchangeable bases compared to under alley-cropping. The trial found that crop yields were, however, lower under alley cropping. The reasons given for the drop in crop yield were the shading effect of the trees, root competition for water, nutrient immobilization by mulch, and possible allopathic effects. It was suggested by (Lal 1989b) that caution be used when interpreting the recycling hypotheses where the sub-soil is extremely low in nutrients and cations. There must be something to cycle if cycling is going to be an advantage of the alley-cropping system.

Biomass production and nutrient cycling efficiency of agroforestry systems can be improved by initial application of fertilizers. Fernandes et al. (1993) found that there was a significant ($p \leq 0.05$) fertilizer and time factor effect on quantity and quality of hedgerow biomass as well as nutrient quantity. The biomass of hedgerows was also significantly

($p \leq 0.05$) greater in hedgerows next to fertilized plots than in non-fertilized plots, even though fertilizers were only applied to the alley food crops. The fertilizer application increased the biomass yield of hedgerows by an average of 18%. The nutrient content of prunings was also significantly different ($p \leq 0.05$) in the fertilized hedgerows than in the non-fertilized ones. On average the prunings contained 82 - 147 kg of N, 4 - 10 kg P and 33 - 60 kg ha^{-1} of K. These accounted for 25% of the N, 29% of the P and 20% of the K increases from the non-fertilized alleys.

Similar studies on fertilizer as a starter were conducted by Chirwa et al. (1994) where he found initial fertilization helped the companion food crop. The trial showed that maize plants which had hedgerow pruning and fertilizer applied to them produced significantly ($p \leq 0.05$) greater total maize biomass than the non-fertilized hedgerows. The maize plants, with fertilized hedgerows, also had twice as much grain yield as the unfertilized alleys. This is because fertilizer applied together with hedgerow pruning is readily available and is a more effective source of nutrients than prunings only, which may take time for decomposition and mineralization. The effect of prunings as a source of nutrients was not evident in the absence of the inorganic fertilizer. Thus, supplemental fertilizer is crucial in order to realize the advantages of hedgerow pruning. Regulation of nutrient release from added biomass and litterfall is one important aspect of improved management of alley-cropping systems.

The synchronization of application of biomass with the demand for nutrients by the crop is also important to improve the productivity of the food crop. Timing of hedgerow pruning and the application of mulch into the soil has been an area of intensive research in alley-cropping. If the timing of the application of mulch and decomposition and release of nutrients matches with nutrient demand of the companion crop the nutrient cycling efficiency increases. The quality, quantity and rate of decomposition of leaves, twigs and soft stems that may be added to the soil as mulch differs considerably from species to species. Yamoah et al.(1986a) in a study on decomposition, nitrogen release, and weed control by mulching of shrub species found that *Gliricidia* released all or most of its nitrogen in pruning for crop use within the 120 day growing season of the crops. About 96% of the pruned material of *Gliricidia* decomposed within 120 days after planting. *Flemingia* and *Cassia* had 58% and 46% dry matter decomposition, respectively, from the initial prunings added to the soil. Soon after the 120 days, *Gliricidia* prunings decayed completely while *Cassia* lost 85% and *Flemingia* 73% of their initial weight. *Gliricidia* released 95 kg ha^{-1}, *Flemingia* 40 kg ha^{-1}, and *Cassia* only 15 kg/ha of N before the harvest of the maize crop. The slow release of N by *Flemingia* and *Cassia* may have benefited the companion crop. The slow rate of decomposition of the plant material might also have been important for soil moisture conservation, soil temperature regulation as well as weed control. Others say that slow decomposition has the opposite effect and suggest that the nutrient recycling efficiency of the shrub species could be improved by choosing the right method and right time of mulch application. Palm (1988) and Fernandes et al. (1993) report that decomposition of *Inga* leaves were close to 30% of the original leaf mass after 30 weeks of decomposition. After 20 weeks the decomposing *Inga* leaves still had close to 50% N and P remaining. This slow decomposition of prunings may promote hedgerow root growth into the alleys due to the positive effect of mulching on moisture and slow release of nutrients and may increase root competition with food crops. To minimize the competition for nutrients released from pruning, it may be preferable to use hedgerow species with prunings that decompose rapidly. Plant material that is high in nutrients, especially nitrogen, decomposes very rapidly, whereas, woody residues and other lignified materials such as crop stalk and straws are more resistant to decomposition and are of lower nutrient quality.

Materials that are high in nitrogen and thus have low carbon to nitrogen (C:N) ratio decompose rapidly and release relatively larger quantities of nitrogen. Materials with high C:N ratios provide a source of energy, carbon, to microorganisms. The microbes subsequently multiply rapidly and draw upon the nutrient N reserves in the soil. With a very low N ratio a temporary immobilization or unavailability of nitrogen is created. When carbon is depleted the microbial population declines and the nitrogen that had been temporarily incorporated in microbial tissues once again is released to the soil and is available for plant uptake. This is how the addition of large quantities of a low quality litter to a standing crop in the field results in nitrogen deficiency for the crop and conversely, how the addition of a high quality litter benefits the crop (Nair 1993). Budelman (1988) has reported the C:N ratios of *Leucaena leucocephala*, *Gliricidia sepium* and *Flemingia macrophylla* as 12:1, 12:1, and 21:1 respectively. The mineralization of other essential nutrients also had similar relationships to the quality of mulch from each species.

Another important venue by which tree legumes in agroforestry, in general, and alley-cropping, in particular, would help sustain soil fertility is through their ability to fix nitrogen in symbiosis with microorganisms in the soil. Taiz et al. (1991) says that about 90% of the nitrogen made available by natural processes is fixed through the action of microbes in symbiotic and non symbiotic association with plants. Soils under *Acacia albida*, in Senegal, showed a greater increase in fertility under the canopy than in the open (Danso et al. 1992). Leguminous trees such as *Acacia saligna* play an important agroforestry role in parts of Northern Africa which receive 250-400 mm rainfall per year. Significant accumulation of nitrogen has been observed under *Prosopis* canopies and *Casuarina equistifolia*, in symbiosis with the actinomycete Frankia (Danso et al. 1992). These species are extensively used in sandy coastal soils due partly to their nitrogen fixing ability.

Large differences exist in biological nitrogen fixation capacities of different multipurpose species. Nair (1993) in his review of various research results reported that *Acacia mearnsii* had nitrogen fixation rates of 200 kg ha^{-1} yr^{-1}, *Casuarina equistifolia* had 60 - 110 kg ha^{-1}, *Gliricidia sepium* 13 kg ha^{-1}, *Leucaena leucocephala* 100 - 500 kg ha^{-1} and *Inga jinicuil* 35 - 40 kg ha^{-1} of N. Danso et al. (1992) reported that *Leucaena leucocephala* and *Sesbania rostorta* can accumulate up to 500 kg ha^{-1} yr^{-1} of N in their biomass while others like *Acacia* species and *Sesbania sesban* accumulate less than 50 kg ha^{1} yr^{-1}.

According to Danso et al. (1992) biological nitrogen fixation can be enhanced by management practices like inoculation of trees at the nursery stage with the right *Rhizobium* strains or Frankia. Mycorrhizal inoculation can be used to increase the growth of the woody species and thus the biological nitrogen fixing ability in low phosphorous soils. Pruning intensity and frequency are also reported to affect the ability of biological nitrogen trees to fix N. Most importantly, however, species that fix nitrogen usually have high nutrient demands and their efficiency depends on the availability of adequate nutrients. The application of optimal amounts of N, P, and K and in some cases Ca on nitrogen-fixing trees can increase the efficiency of biological nitrogen-fixation of multipurpose species (Nair 1993).

Roots and Root Systems

Plant growth depends upon the uptake of nutrients and moisture by the roots. When roots are unable to absorb sufficient amounts of nutrients and water, the above-ground biomass and yield of plants is adversely affected. To function properly and grow to maturity a plant must develop a root system with sufficient absorptive capacity to meet its growth demands. In addition to nutrient and water absorption, roots provide anchorage, synthesize various essential compounds, such as growth regulators, and store food (Kramer, 1988).

Atkinson (1980) in describing the importance of roots says leaves are only required to "harvest" light, carbon dioxide, and oxygen from a relatively stable source of supply; while in contrast roots supply variable amounts of around 15 elements and water against the background of rapidly fluctuating reserves. While the significance of the claim may over state the leaf and root contrast, it indicates the dependence of plants on roots as a major source of nutrients.

Atkinson (1980) points out that the absorptive capacity of plants is directly proportional to the volume of soil occupied by their roots. Therefore, plants with deep rooting habits and strong root systems are more tolerant of drought than shallow rooted plants. Soil characteristics also affect the distribution of roots. In deep and well aerated soils, roots penetrate to great depths and spread widely, while root growth is restricted in heavy and poorly aerated soils. The absorption capacity of roots can also be expanded by structures created through symbiotic association of mychorrhizal fungi. Mychorrhizae increase the rate of mineralization and solubilization as a result of increased supply of minerals especially of phosphorous (Kramer and Boyer 1995).

To sum up, chances of survival of the plant is dependent upon the depth and extent of its root growth. The depth and spread of lateral roots in turn is largely affected by the environment. Bohm (1979) lists the important ecological factors that influence root growth as bulk density and soil strength, water, air and nutrient contents of the soil and suggests that the goal of ecological studies of roots should focus on investigating the influence of these environmental factors on the development of plant root systems.

Above-ground growth and development of plants has been the subject of much study and has reached a relatively advanced stage. Various parameters including leaf area index, leaf thickness, and leaf activities are well understood (Atkinson 1989). In contrast, root research is less developed. The reason is chiefly the methodological difficulty associated with root research. Methods currently employed to study roots are tedious, time consuming and the accuracy of the result is often not very good. As a result many researchers are discouraged and shy away from doing such root studies (Bohm 1979; Atkinson 1989).

Root research in agroforestry is a very recent phenomenon. As a result, agroforestry yield results obtained in research fields were usually overestimated and the effect of root competition usually over-looked. The effect is even more pronounced in semi-arid areas where moisture shortage can be very acute. Hauser (1993) reported that, at an IITA site in Nigeria, roots of *Senna siamea* extended to 15 m and it was estimated that the alley-cropping treatment affected an area six times its plot size of 18 X 20 m. This assessment shows that root interference can be so high and extend to such lengths that research results obtained in small research plots are not adequate enough to fully evaluate the system and clearly come up with accurate results. Increasingly, there is a growing agreement among researchers that competition between trees and crops is likely to outweigh the positive benefit of mulching, especially competition for moisture in the dry lands of the tropics.

Hairiah et al. (1992) studied biomass production and root distribution of *Gliricidia sepium* and seven other species. Within one year after planting all species had their tap roots grown into the subsoil and horizontally spread their roots throughout the top soil. Good root penetration into the subsoil was observed in *Erythrina*, *Calliandra* and *Peltophorum* while *Leucaena* and *Gliricidia* roots had limited penetration. It was concluded that *Calliandra*, *Peltophorum* and *Erythrina* may form a safety net of roots underneath the crop roots. However, *Leucaena* and *Gliricidia* had no safety net function that would avoid competition with food crops. Because of its deep rooting habit the local tree, *Peltophorum* was found the least competitive and therefore the most suitable tree species for alley-cropping in southern Sumatra.

Fine roots account for most of the root absorptive capacity of nutrients and water and knowing their vertical and horizontal distribution is of great value in understanding the competition that may exist in agroforestry. Jonsson et al. (1988) studied the vertical distribution of fine roots (≤ 2 mm in diameter) of five tree species in a pure two-year old stand in Morogoro, Tanzania. The rooting pattern showed slow decline of fine root mass with increasing depth from 0-100 cm. Except for *Eucalyptus* which had its roots distributed evenly through the soil profile, *Cassia siamea* . *Eucalyptus tereticornis*, *Leucaena* *leucocephala*, and *Prosopis chilensis* had similar declining habits with increasing depth. The root biomass production of all tree species considered was roughly twice as much as maize which indicates that the tree species will compete with maize and other annuals of similar rooting habit. The root biomass also decreased with increasing distance away from the tree hedgerows indicating the importance of inter-row spacing.

Hauser (1993) in a study of root distribution of *Acioa barterii* and *Cassia siamea* found that there was a stronger suppression of cassava (food crop) roots in *Cassia siamea* alleys which had a higher rooting density than *Acoia* alleys. There were very few cassava roots below 40 cm although the crop could penetrate to a depth of 120 cm. There was considerable root expansion of the tree species such that there were no locations within the non-tree control plots that were not within the range of root propagation of one of the adjacent hedgerow species. In some instances, these root expansions into the control plots could be reasons for incorrect interpretations of results in agroforestry research. Ruhigwa et al. (1992) found that *Archornia cordifolia, Cassia siamea, Gmelina arborea* and *Acioa barteri* had their roots spread throughout the soil profile of 120 cm depth and to 200 cm lateral width in the cropping zone of the alleys. This soil layer had 73, 76 and 74% of the total *Archornia cordifolia, Cassia siamea* and *Gmelina arborea* fine roots, respectively, while *Acioa barteri* had fewer fine roots (about 49%) in the surface soil and decreasing root concentration away from the tree base. A similar trend was observed for root length density of fine roots. *Alchornia cordifolia, Cassia siamea* and *Gmelina arborea* had high root length density in the upper soil horizons. The root length ranged between 0.48 - 1.22 , 0.37 - 1.34

and 0.26 - 0.77 cm cm^{-3} for *Alchornea cordifolia*, *Cassia siamea*, and *Gmelina arborea*, respectively, while *Acioa barteri* had less with 0.15 - 0.49 cm cm^{-3} at 20 cm depth.

Budelman (1990) in a study of *Gliricidia* and *Leucaena* with yam crops in Nigeria observed that about three quarters of the fine root dry weight was concentrated in the first 20 cm of the soil layer. The yam crop roots were also found concentrated in this same soil layer. The study also found *Gliricidia* had a much weaker root system compared to the more aggressive *Leucaena.* Moreover, *Gliricidia* plant density didn't result in proportionally more fine roots in the top 40 cm depth. Since choice of species is based on the fact that the fine roots are mostly responsible for the water and nutrient uptake, the relative competitive power of *Leucaena leucocephala* can be a relevant measure of its suitability as an alley-cropping species.

The existence of competition between plant root systems is a well known fact although the manner by which root systems compete is not yet well understood. Cadwell (1987) and Vance and Nadkarni (1992) state that although competition for light is apparent in dense plant communities, much of the competition actually takes place below-ground. They further suggest that competition among roots for resources can result if roots of one plant deplete the soil resource more quickly than other roots of the other plant or if roots of the more successful competitor deplete resources to levels below which other plant roots cannot extract sufficient quantities for growth and survival. Through resource depletion one plant interferes with the growth of the other and often has the advantage over the other. The influence of competition is clearly indicated by the improved vegetative growth, seed yield and water status of plants that occur when neighboring plants are removed or by an increase in plant size with distance from the competitor plant. Depending on environmental conditions competition between plants in mixed plantations differs markedly. In desert areas where water stress is high, the below-ground competition for water might be considerable while light competition may be less of a priority. In areas of abundant moisture, competition for water may be apparent but over-crowding and less light penetration affect growth of plants more.

Singh et al. (1989), in a study in a semi-arid conditions, found that growth and yield of crops increased from 30 - 150 % as the distance from the hedgerows increased from 0.3 - 5 m. The presence of a root barrier in each plot had a marked effect on crop growth and completely eliminated any reduction in crop yield. The study concluded that in alley-cropping systems, in the semi-arid tropics, competition for moisture between trees and crops is the main reason for severe reduction in crop yield.

Cadwell (1987) observed that root systems are of strikingly different morphology. Those with deep rooting habits may avoid competition because they overlap little with those that have shallow fibrous or horizontal roots. The degree of overlap depends not only on the species but also the density of the plants. With denser plantings the degree of overlap increases while root systems of widely spaced plants are almost discrete and only occasionally intermingled. The behavior of plant root systems changes with proximity of neighboring plants such that plants grown in crowded environments produce a proportionally higher percentage of fine roots from those grown alone in open spaces. This assertion is supported by the following study in an agroforestry setting (Puri et al. 1994).

In this study on biomass production and the effect of spacing on root production of *Populous deltoids* in India, it was shown that most of the fine roots could be concentrated in the top soil competing with the food crop and that tree density had an effect on root distribution pattern. Coarse root biomass decreased with an increase in spacing from 29.8 Mg ha^{-1} in a stand of 2 m × 2 m to 5 - 6 Mg ha^{-1} in a stand of 6 m × 6 m. This accounted for 5-6 times less in biomass production in the wider spacing. Fine root production also decreased dramatically with an increase in spacing. Fine-root biomass was 23 Mg ha^{-1} at 2m × 2m spacing compared to 13.8 Mg ha^{-1} at the 6 m × 6 m spacing. Based on the available data, it was concluded that the bulk of the root biomass were found near the surface of the soil and hence root competition with agricultural crops was inevitable (Puri et al 1994).

Methods of root study

Schuurmann et al. (1965) and Bohm (1979) have suggested that ecological root studies should aim at elucidating the important properties of the root system. Dry root biomass has been one important parameter in the ecological study of roots. The amount of roots in weight gives measure of the absorptive capacity of the root system being investigated. Generally, root weight determination involves a simple process where washed roots are dried to a temperature of 65-70 °C and their weight determined (Linscott 1962; Bohm 1979; Noordwijk 1991; Taylor et al. 1991). Seldom is fresh weight used, especially in plant pathology studies of nematodes and fungi (Bohm 1979). Usually washed and cleaned roots are oven-dried for dry matter determination. The drawback with root weight as a parameter is that it doesn't give an accurate measure of the absorbing capacity of roots.

However, root weight still is the most commonly used parameter in the study of roots and root systems.

Schuurmann et al. (1965); Bohm (1979); Drew et al. (1980) and Kumar et al. (1993) state that although root weight can be a valuable parameter in estimating the root mass in a given soil and a measure of photosynthate allocation to below-ground parts, it is not as important as root length and distribution in estimating the capacity of the plant to absorb water and nutrients.

Root length density is one of the best variables for calculating uptake of water by plant roots. The functional significance of measuring root length is to determine the total root system size that is effective for water and nutrient absorption. Atkinson (1980), in a study with apple trees, observed that there was a relationship between root length and the uptake of P_{32} by apple trees in the top 15 cm soil surface. In another experiment, Evans (1978) assessed that as root length increased so did the maximum water deficit showing the direct relationship between root length and competition.

Hughes and Gandar (1992) described root length density as length of root per unit volume soil and/or root weight density as weight of roots per unit volume of soil. Root length is becoming popular with the belief that it is one of the best root properties for calculations of water uptake. Bohm (1979) observed that many research workers in the field of plant nutrition preferred root length to root weight or other root parameters.

According to (Bohm 1979: Atkinson 1980: Atkinson 1989) root length can be measured directly by eye inspection, where a graph paper ruled in millimeters is placed in a flat glass dish and the lengths determined or calculated more rapidly by counting intersections between roots and a regular pattern of lines. Then the root length can be calculated by the equation:

$$R = \pi AN/ 2H$$

Where R is the total length of roots in a field of area A and N is the number of intersections between the roots and random straight lines of total length H.

Soil Water

Water is one of the most important environmental factors for plant growth. Its supply controls growth and distribution of plants. The quantity and distribution of water determines the type of vegetation that grows in a given area ranging from dense rain forests to savanna and grasslands to sparse desert scrub.

In semi-arid and arid climates plant growth and agricultural production are constrained by highly variable and low rainfall with long hot dry seasons. As a result periodic drought and consequent crop failures are common in these dry lands. If crops are mixed with trees as in alley-cropping there is likely to be even more competition for moisture. Soil water is therefore a key environmental variable for the establishment of crops and trees in alley- cropping. As Nair (1993) pointed out, competition between trees and crops for soil moisture in dry lands is possibly the most serious problem encountered in agroforestry. Differences in water use by different species and plant densities can impact the rate of soil moisture depletion and consequently affect the productivity of the system.

Most studies on alley-cropping were made in the humid and semi-humid tropics. As a result there was little interest in research in moisture and the below-ground environment under agroforestry. Only limited literature is available on soil moisture in the tropics.

In a study in the humid tropics of Nigeria. Lal (1989a) found that soil moisture content at 50-100 cm away from hedgerows was more in all alleys than in the controls (no trees). Hedgerows served as windbreaks and decreased soil moisture evaporation. The soil moisture content was in the order of *Leucaena* > *Gliricidia* > no-till > plow till treatments. The study also found that hedgerow spacing had little effect on soil moisture conditions.

Kang et al. (1985) in another study made in the humid zones of Nigeria found that deep rooted *Leucaena leucocephala* appeared to extract more soil moisture from lower soil horizons. This indicated that there was an apparent root stratification where *Leucaena* extracted moisture from below 50 cm soil layer while the maize crop taped the surface layers above 50 cm depth. It was also observed that mulch from *Leucaena* pruning substantially increased the moisture retention of the top soil. Moisture content at depth 5-15 cm was greater in the mulched treatment than the unmulched treatment.

In more arid and dry conditions research reports indicate more unfavorable soil moisture conditions. Tree hedgerows may compete with adjacent agricultural crops. A case in point is the study made by Singh et al. (1989) in a semi-arid region of India. Severe reduction in yield was observed due mainly to competition for water. The presence of a shallow root barrier affected the absence or presence of tree roots in the upper soil layer and consequently affected the soil moisture conditions. The treated plots were wetter than the untreated ones.

Eucalyptus tereticornis planted around farm boundaries, in dry areas of India, similarly caused reductions in yield of mustard and wheat. Within 10 meter wide strips there was a 47 and 34% reduction in mustard and wheat yield, respectively. The lower yield was again attributed to moisture depletion by the aggressive *Eucalyptus* (Malik and Sharma 1990).

Under situations where both trees and crops have to use the same water reserve it is likely that competition for water will remain detrimental to the productivity of agroforestry. Management options that lower moisture competition have to be identified and researched. There is evidence that water use efficiency of plants varies among species (Kramer and Boyer 1995). Selection of drought tolerant species with high water use efficiency is likely to aid agroforestry productivity. In addition use of wider inter and intra-row spaces and use of deep rooting species are among the management options available.

CHAPTER 3: PRODUCTION AND DISTRIBUTION OF *ACACIA SALIGNA*, *GLIRICIDIA SEPIUM* AND *SORGHUM BICOLOR* (VAR. SEREDO) ROOTS IN AN ALLEY-CROPPING SYSTEM IN THE HARARGHE HIGHLANDS OF ETHIOPIA

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Abstract

Competition of tree and/or shrub roots with companion food crops for available water and nutrients is a major cause of crop yield reduction in alley-cropping system. Quantitative information concerning root production and distribution has a practical value to minimize competition and maximize productivity in an alley-cropping. A field experiment was conducted to study root biomass production and distribution of *Acacia saligna* (Labill) Wendl., *Gliricidia sepium* (Jacq) Walp. and *Sorghum bicolor* (var. seredo) in an alley-cropping system in the Hararghe highlands of eastern Ethiopia. The tree hedgerows were planted on either side of a 4 m wide crop alley. Intra-row spacing between trees within the hedgerows was 25, 50 and 100 cm. In October, 1994 and March, 1995 soil samples were taken at depths of 0-10 cm and 10-30 cm at 50 cm and 200 cm away from the tree hedgerows using direct coring. A second method was employed using buried mesh bags to trap incoming roots. Roots were separated from the soil by wet-sieving and root weight and root

length density (RLD) were determined. Grain yield and above-ground dry matter production of the sorghum crop were also determined. Tree fine-root (≤ 2 mm) mass of *Acacia saligna* was significantly ($p \leq 0.05$) higher than *Gliricidia sepium* in the top 0-30 cm soil layer at 50 cm from hedgerows. No significant differences ($p \leq 0.05$) were observed at the 200 cm distance from hedgerows. Further break down of the soil profile also showed that *Acacia saligna* had over 45% of its fine roots concentrated in the top 0-10 cm of soil while *Gliricidia* had a less developed root system with only 30%. The presence of fine roots decreased by about 55% and 40% for *Acacia* and *Gliricidia*, respectively, as the distance increased from 50 cm to 200 cm from the hedgerows. Increase in tree root mass was accompanied by proportionally decreased crop root mass. The average sorghum fine root mass at a 30 cm depth ranged from about 170 kg ha^{-1} under *Acacia saligna* to 690 kg ha^{-1} under the control plots with no hedgerows. Results of the March samples showed that the long dry period is when trees allocate a higher proportion of carbon to the root system to stay competitive under the adverse conditions. The strong similarity of root estimates (R^2=0.95) for soil cores vs mesh bags and the potential sources of variation between the two methods is discussed. Intra-row tree spacing had little effect in minimizing the extent of root development and the 25 cm, 50 cm and 100 cm intra-row spaces used in this experiment were not sufficient enough to mitigate the competition. Sorghum grain and dry matter yield were significantly ($p \leq 0.05$) higher under *Gliricidia sepium* and the control plots with no hedgerows than under *Acacia saligna*. It was concluded that root competition for water and nutrients is one of the most important factors contributing to yield reduction in these alley-cropping systems.

Introduction

Sustainability in alley-cropping systems depends on the ability of trees and/or shrub species, grown as hedgerows, to maintain soil quality through cycling of nutrients from the deeper soil layers (Kang and Wilson 1987). Ideally, trees and shrubs are deep rooted and therefore compete little with the companion food crops, while withdrawing nutrients from lower soil layers. These nutrients accumulate in the above ground biomass where, upon pruning, they are added to the soil as amendments, improving soil fertility. The system offers considerable opportunity to use limited land resources for maximum production of multiple tree and crop products (Atta-krah et al. 1993; Kang et al. 1993).

A major production constraint in alley cropping is the below-ground competition between trees and food crops. A number of studies, especially those from the semi-arid tropics, have shown that there is a serious yield reduction in alley cropping systems largely due to below-ground competition (Singh et al. 1989; Ong et al. 1991). Singh et al. (1989) reported that there was severe crop yield loss in alley-cropping systems in the semi-arid tropics of India that likely was a consequence of the competition for scarce water resources.

Trees that have shallow root systems will compete with food crops for available water and nutrients while deep rooted species will likely avoid the competition (Owino, 1989). Appropriate intra-row and inter-row spacing of hedgerows will alleviate some of the domination of the below-ground space by the trees. This in turn improves the competitive ability of the companion crop and results in increased crop productivity. To minimize competition and maximize crop production studies must be conducted using various tree.

shrub and crop combinations at various spacing. Estimates of hedgerow and crop root competition must be compared to above-ground tree and crop production.

This study reports on root production and distribution of two major multipurpose tree species and sorghum as influenced by intra-row spacing in an alley-cropping system in the Hararghe highlands of eastern Ethiopia. The specific objectives of the study were to: 1) compare the root biomass production and root distribution of *Acacia saligna, Gliricidia sepium* and *Sorghum bicolor* (var. seredo) in the 0-30 cm depth of the soil profile of the cropping alley; 2) determine the influence of intra-row spacing on the below-ground productivity of the tree species and the sorghum, and 3) compare the above-ground productivity of sorghum grown with and without the two hedgerow tree species.

Materials and Methods

The Study Site

The research was conducted as part of an on-going alley-cropping study at Alemaya University of Agriculture, Ethiopia. The research was initiated by the university in 1990, in collaboration with the Alley Farming Network for Tropical Africa (AFNETA), Ibadan, Nigeria. The site had been used by the university for the previous thirty years for maize and sorghum production.

The site has an average annual rainfall of 850 mm. The general rainfall pattern is bimodal. A short rainy season starts in April and ends in May while the main rainy season extends from June to September. The temperature is mild and ranges between 15 °C to 19 °C with little seasonal variation. The length of the growing season is 180 to 270 days (Poschen

1987). The soil at the research site is a sandy loam, isothermic, typic Usthorthent, locally known as the Alemaya series. This soil has formed in situ (residual) mostly on truncated erosional surfaces on landscapes with slopes of 4 to 15% (Tamirie, 1984). Generally, the soil is low in organic carbon, total nitrogen, available phosphorous and cation exchange capacity and has a pH value of near neutral (Tamirie 1981; Haile 1991).

Layout and Establishment of the Experiment

The study consisted of 6 m long plots with tree hedgerows of *Acacia saligna* and *Gliricidia sepium* with three intra-row spaces of 25, 50 and 100 cm. The inter-row spacing between hedgerows was 4 meters. Thus the trial consisted of treatment combinations of the two tree species and the three intra-row spaces as well as a control with no hedgerows.

The experiment was laid out as a factorial arrangement in a randomized complete block design with three replications (Figure 1). Seeds for establishment of *Gliricidia sepium* were procured from the International Institute for Tropical Agriculture (IITA), Ibadan, Nigeria and seeds for *Acacia* were collected from local sources. Seeds of both species were treated with sulfuric acid (H_2SO_4) to facilitate germination. The required number of seedlings were raised at the Alemaya University of Agriculture nursery and transplanted to the field in August 1990. The 4 m wide alley between the hedgerows of trees was cropped with sorghum. Sorghum is the major staple food crop in the Hararghe highlands of eastern Ethiopia. A 75 cm inter-row and 30 cm intra-row spacing was used giving a population of 44,500 sorghum plants ha^{-1}.

Replication 1

As25	As50	As100	Gs25	Gs50	Gs100	No trees

Replication 2

Gs50	No trees	Gs25	As50	As100	As25	Gs100

Replication 3

As100	Gs25	Gs100	No trees	As25	Gs50	As50

Treatment combinations:

As25- *Acacia saligna* at 25 cm intra-row spacing, As50- *Acacia saligna* at 50 cm intra-row spacing, As100- *Acacia saligna* at 100 cm intra-row spacing; Gs25- *Gliricidia sepium* at 25 cm intra-row spacing; Gs50- *Gliricidia sepium* at 50 cm intra-row spacing; Gs100- *Gliricidia sepium* at 100 cm intra-row spacing; control (no trees)

Figure 1. Field layout and unit plot dimensions for of the alley-cropping study

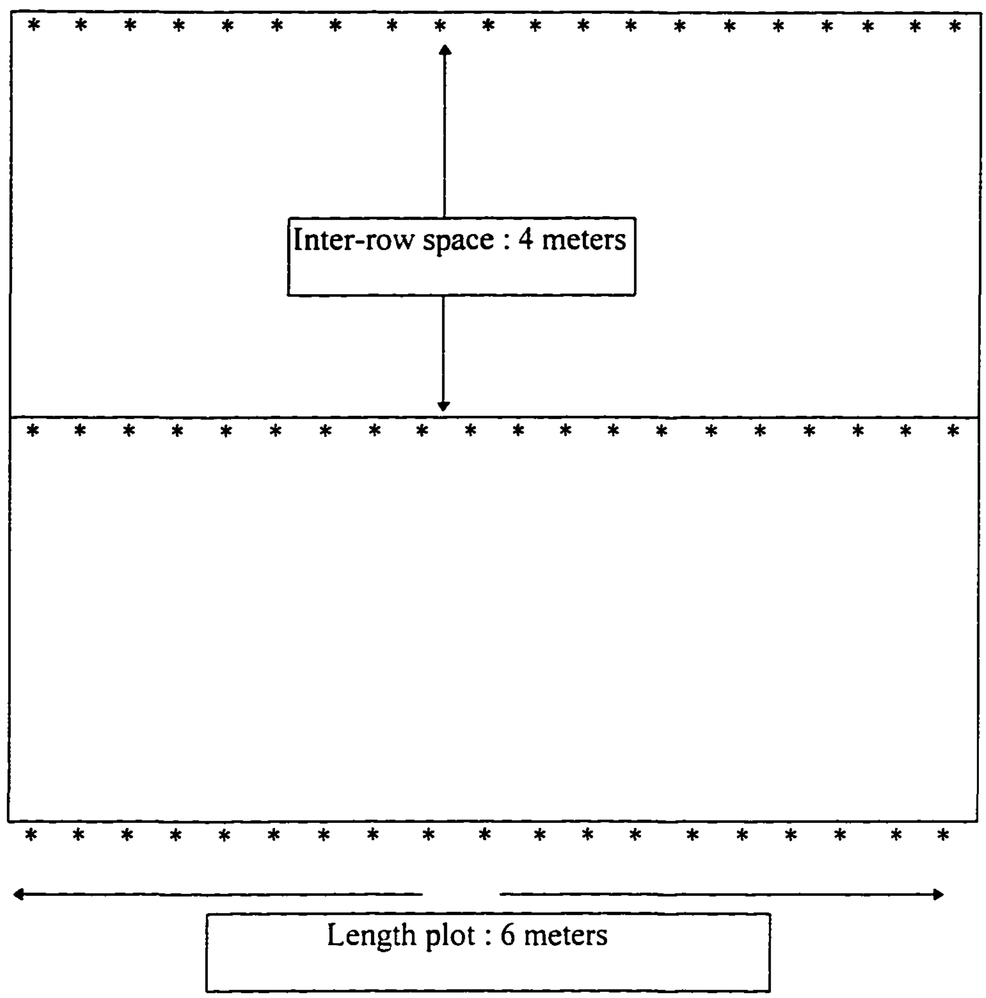

Figure 1 Cont.

Unit plot (experimental unit, i.e. As25)

Methods for Determining Root Biomass Production and Distribution

At the start of the 1994 growing season a plastic barrier was installed in a 1 m deep trench dug along the edge of the hedgerows around the perimeter of each plot. Tree roots had grown several meters laterally and trees in one plot were sending their roots into neighboring plots. The plastic barrier was installed to prevent interference and avoid misleading data on root biomass production and crop yields (Singh et al. 1989).

Two methods were employed to determine the extent of root biomass production and distribution in the cropping alleys. The first method used a 10 cm diameter soil core sampler to directly core in situ soil. Soil core samples were taken along 3 transects across the cropping zone in each experimental plot (Figure 2). In each transect samples were taken at 50 cm and 200 cm distances away from the hedgerows and at depths of 0-10 cm and 10-30 cm. The experimental plot data for each distance and depth is an average of three soil core samples. Soil samples were collected in October, 1994 when sorghum plants were just past their flowering stage and possibly at their maximum root development stage (Mengel and Barber, 1974). The second set of soil samples were taken in March 1995 at the end of the long dry season when the trees had grown for 4 months without the companion crops. The March sampling was done to compare it to October data and assess root activity during the long dry periods.

Roots were separated from each sample by soaking them in water overnight and washing them over a series of 1 mm and 2 mm mesh sieves (Schuurman 1965 Bohm 1979). The October roots were cleaned and separated into crop and tree roots through a rigorous

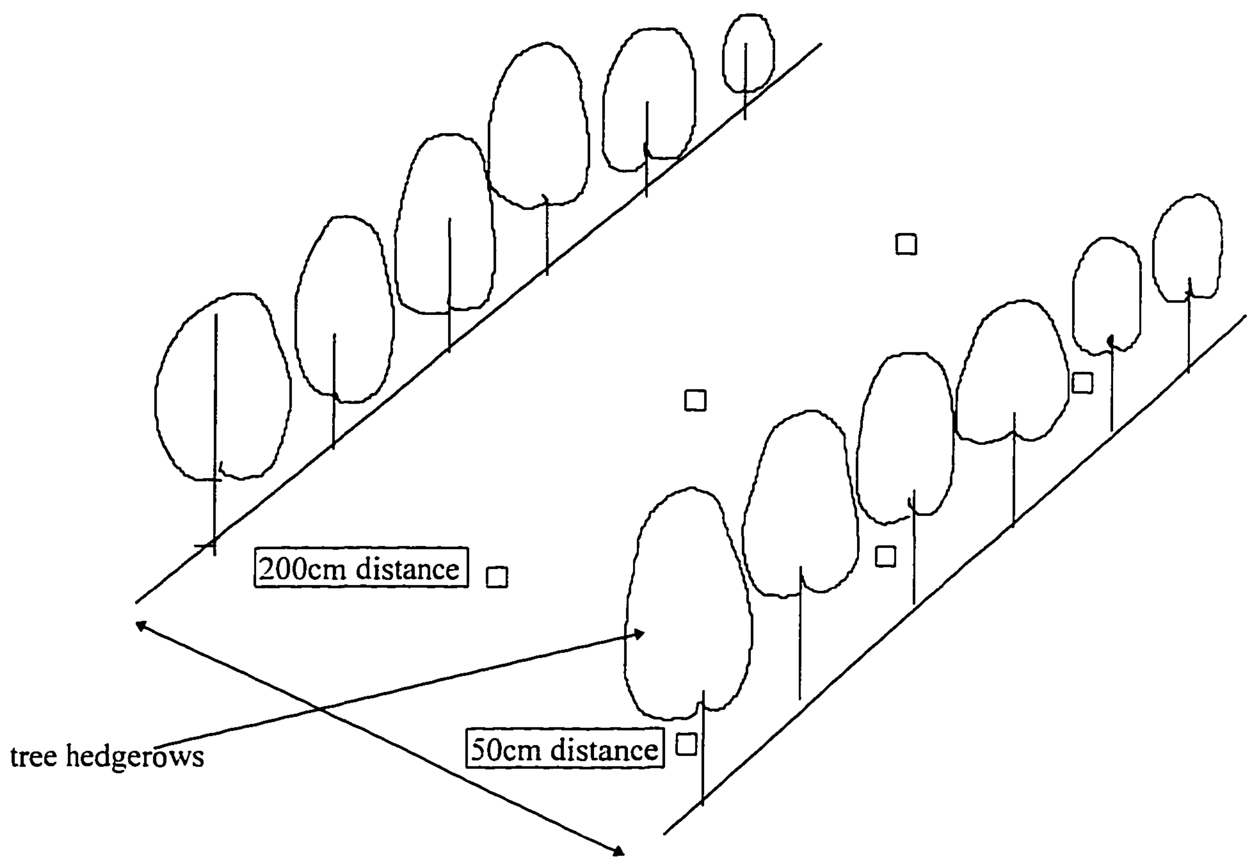

Figure 2. Layout of the experimental plot showing root sampling distances.

examination of color ("yellowish" for tree roots), texture, elasticity, presence of nodules and other structures (Atkinson 1980; Sutton and Tinus 1983).

The roots were separated into two classes, fine roots (≤ 2 mm in diameter) and larger roots (> 2 mm in diameter) and dried at 70 °C. In this experiment only the fine root differences between treatments were considered because they are primarily responsible for water and nutrient uptake and thus are the most relevant in the context of plant competition under an alley-cropping system. Root dry weight was measured to the nearest 0.01g in each experimental plot and then converted to a hectare basis. Root length density was determined by direct measurements (Bohm 1979). The length of all root segments were added to estimate root length per unit volume of soil; which was then converted into root length per cm^3 of soil (Bohm 1979; Atkinson 1980; Atkinson 1989).

The second method for examining root biomass and distribution employed the use of mesh bags to trap roots coming in through the perforated plastic bags. A modified form of mesh bags reported, by Lund et al. (1970), was used. The bags were 10 cm in diameter and 30 cm long and were perforated with 1 cm × 2 cm rectangular holes and 1 cm apart. The bags were filled with sieved and slightly moist soil from the surrounding area and then placed into previously dug holes of the same size. The top of the bag was level with the soil surface. The bags were placed at 50 cm and 200 cm distances away from the hedgerows along the same transects as the soil cores were taken. Thus, each experimental plot had 6 bags. Bags from each location were pulled out after 4 months, in October 1994, and divided into 0-10 cm and 10-30 cm portions. The same method that was used to separate roots from the soil cores was used for the bags. Soil samples were soaked, separated, cleaned and oven dried at 70°C.

Root dry weight was measured to the nearest 0.01g for individual bags in each experimental plot and then converted to a hectare basis.

Determination of Sorghum Above-ground Yield

Plant height, plant biomass and grain yield of sorghum were collected from randomly selected plants representing about 25% of the total plants in an experimental plot. Plant height was measured on standing plants. The plants were then harvested and grain yield and plant biomass determined. The sorghum seeds were separated, dried to 12% moisture content and weighed. The sorghum stalks were weighed and a sub-sample dried at 70 °C to a constant weight for dry matter determination. All the parameters were expressed on a hectare basis.

Statistical Analysis

Analysis of variance was used to see if there were significant differences among treatments. When analysis of variance showed significance differences, further comparisons of individual treatment means were made. Contrast test procedures were used to compare selected treatment means of root dry biomass and Fisher's mean separation test, $p=0.05$ was used for evaluating root length density and crop yield.

Results and Discussion

Roots and Root Systems

Fine-root mass (≤ 2 mm) of trees and crop from the October root samples, obtained by soil coring, are presented in Table 1. Tree fine-root mass showed significant differences ($p \leq 0.05$) between *Acacia saligna* and *Gliricidia sepium* at the 50 cm distance from hedgerows. No significant differences ($p \leq 0.05$) were observed at the 200 cm distance. Averaged over intra-row spaces, tree fine-root mass at the 50 cm distance, ranged between over 1063 kg ha^{-1} and 477 kg ha^{-1} for *Acacia saligna* and *Gliricidia sepium*, respectively. This represents a difference of more than 100%.

Contrast tests were made to compare the total fine-root mass (tree plus crop) between treatments at 50 cm from the hedgerows (Table 2). Comparison of treatment means showed that the total fine-root mass (tree plus crop) in the alley-cropped plots was significantly ($p \leq 0.05$) higher than in the sole- cropped (control) plots. Further contrast tests among the alley-cropped plots showed *Acacia saligna* plots, on average, had significantly ($p \leq 0.05$) more total fine-root mass (tree plus crop) than *Gliricidia sepium* plots. The total fine-root mass for *Gliricidia sepium* at 100 cm spacing was also significantly ($P \leq 0.05$) lower compared to all other treated plots.

The tree species also showed differences in the relative abundance of fine roots with depth. Further break down of the soil profile showed that over 45% of the fine roots produced by *Acacia saligna* were located in the top 10 cm of the soil while *Gliricidia sepium* had only 30% of its fine roots produced in that soil layer (Table 3). This difference was significant ($p \leq 0.05$). The distribution of fine roots in the soil profile of many agroforestry

Table 1. Tree and crop fine-root production (kg ha^{-1}) in *Acacia saligna*, *Gliricidia sepium* and control plots at 0-30 cm depth and 50 and 200 cm distances from the hedgerows using soil coring in October 1994

	Distance from the hedgerows					
	50 cm			200 cm		
	tree root	crop root	tree + crop	tree root	crop root	tree + crop
Species (spacing, cm)			(kg ha^{-1})			
A. saligna (25)	1210	110	1320	570	160	730
A. saligna (50)	1000	150	1150	375	120	495
A. saligna (100)	980	260	1240	520	170	690
means	1063	173	1240	490	150	640
G. sepium (25)	610	275	885	340	230	570
G.sepium (50)	490	220	710	235	200	435
G.sepium (100)	330	300	630	335	300	635
means	477	265	742	303	243	547
control		690	690		540	540
LSD (0.05)	360	170			150	

Table 2. Contrast tests for selected treatment means of total fine-root mass (tree + crop) from soil cores taken at 50 cm from the hedgerows.

Source	df	p> |T|
C vs all	1	0.0151
6 vs all	1	0.0352
1 2 3 vs 4 5 6	1	0.0086
1 vs 4	1	0.1217
2 vs 5	1	0.3400
3 vs 6	1	0.0170

C = control, 1= *Acacia* at 25 cm, 2 = *Acacia* at 50 cm, 3 = *Acacia* at 100 cm, 4 = *Gliricidia* at 25 cm, 5 = *Gliricidia* at 50 cm, 6 = *Gliricidia* at 100 cm

Table 3. Average fine-root production (kg ha^{-1}) and distribution in *Acacia saligna*, *Gliricidia sepium* and sole-cropping plots at 0-10 cm and 10-30 cm depth and at 50 cm and 200 cm distances from the hedgerows, from soil cores collected in Oct. 1994

	Distances from the hedgerows			
	50 cm		200 cm	
Species(Spacing, cm)	tree roots	crop roots (kg ha^{-1})	tree roots	crop roots
Acacia saligna				
0- 10	480	65	165	50
10-30	580	105	325	100
Gliricidia sepium				
0-10	130	65	90	80
10-30	340	200	210	160
Control				
0-10		215		90
10-30		475		445
LSD (0.05)				
0-10	314		111	
10-30		154		82

species varies widely, with reported values ranging from 20% to 80% of fine roots in the 15-30 cm soil layer (Jonsson et al. 1988; Ruhigwa et al. 1992; Toky and Bisht 1992; Puri et al. 1994).

In terms of lateral distribution, the presence of fine-roots of both species decreased with increased distance from the edge of the trees. On average fine root mass decreased by about 55% and 40% for *Acacia* and *Gliricidia*, respectively, as the distance increased from 50 cm to 200 cm from hedgerows (Table 1). However, there was still a significant difference ($p \leq 0.05$) between the two species at 10-30 cm depth at the 200 cm distance (Table 3).

Generally, *Acacia saligna* exhibited aggressive root growth in the upper soil profile with a shallow and lateral growth habit. Other factors of management like addition of large biomass as mulch and higher organic matter levels in *Acacia* plots may have favored increased root density in the 0-10 cm soil layer (Abdelkadir and Schultz, unpublished data). Positive correlation between root density and soil organic matter is known to exist and roots tend to grow along old root channels which contain more organic matter as it provides enough absorptive surface area to exploit water and nutrient especially under low rain fall and low soil fertility areas (Ojeniyi 1987; Toky and Bisht 1992).

The slow rooting habit of *Gliricidia sepium* may indicate that it poses less competition to companion crops than *Acacia* and that it is a more suitable tree species for alley-cropping. Similar fine-root mass values have been reported for *Gliricidia sepium*. Budelman (1990) reported that *Gliricidia sepium* developed a much smaller root system compared to *Leucaena leucocephala* with values ranging from 380 to 480 kg ha^{-1} in the top 25 cm of soil. Lower fine-root mass ($\leq$ 2 mm) with values of 130 to 256 kg ha^{-1} in the top 50 cm of soil has also been reported by Schroth and Zech (1995b). Similarly, other comparable results have been reported for root production under alley-cropping using different tree and/or shrub species by researchers working in various parts of the tropics (Jonsson et al. 1988; Hairiah et al. 1992; Hauser 1993).

Increase in tree fine-root mass was accompanied by proportionally lower crop root mass at both 50 cm and 200 cm distances. Averaged over the various intra-row spaces, at the 50 cm distance from hedges, sorghum fine-root mass ranged between about 170 kg ha^{-1} and 690 kg ha^{-1} in *Acacia saligna* and control plots, respectively. Because of its much smaller root system sorghum roots developed better when planted with *Gliricidia sepium*. The average sorghum fine root mass in *Gliricidia sepium* plots was about 265 kg ha^{-1} (Table 1).

Similar observations were made by Hauser (1993), where there was stronger suppression of *Cassava* roots under the higher root density of *Senna siamea*. The low level of crop fine-root mass in *Acacia saligna* plots may be the result of the presence of *Acacia saligna* fine roots in large quantities that were effective in depleting soil resources and occupying the soil volume to the partial exclusion of the sorghum root system. In addition, there may have been other factors of interaction such as allellopatic effects to depress sorghum root growth (Cadwell 1987; Schroth 1995). The bias due to position of sampling may have also contributed to the under-estimation of crop roots since soil cores were taken at predetermined positions of 50 and 200 cm from hedgerows and thus at mid-points between the crop rows.

The tree fine-root production was higher in March (Table 4) than in October. There were significant differences ($p \leq 0.05$) between the two species at all intra-row spaces at both 50 and 200 cm from hedgerows. It seems that during the dry period is when trees allocate a higher proportion of carbon to the root system to stay competitive under the adverse conditions. A similar periodicity of root production and carbon allocation to the below-ground was observed for *Gliricidia sepium* by Schroth and Zech (1995b). By allocating higher carbon to its roots *Acacia saligna* stays productive despite extremely dry conditions.

Table 4. Tree fine-root production (kg ha^{-1}) in *Acacia saligna* and *Gliricidia sepium* at 0-10 and 10-30 cm depths at 50 and 200 cm distances from the hedges from soil cores collected in March 1995

		Distance from hedgerows			
		50 cm		200 cm	
		0-10	10-30	0-10	10-30
Species	Spacing (cm)	(kg ha^{-1})			
A. saligna	25	606	1051	183	468
A.saligna	50	589	743	161	417
A.saligna	100	394	497	116	360
G.sepium	25	89	486	28	194
G.sepium	50	78	337	31	86
G.sepium	100	55	143	19	40
LSD (0.05)		76	275	76	223

Root Length Density (RLD)

Estimation of root length density (root length per unit volume of soil) is important because it relates to the absorption capacity and potential competition of trees with their companion plants (Newman 1966; Drew et al. 1980; Hughes et al. 1992; Kumar et al. 1993). Data on root length density (RLD) of fine roots (≤ 2 mm) for *Acacia saligna* and *Gliricidia sepium* are presented in Table 5. Similar to root weight, RLD also showed high variability but with some evidence of patterns and trends. There were significant differences ($p \leq 0.05$) in RLD between the two species at 50 cm from the hedgerows. At the 200 cm distance there was a significant difference ($p \leq 0.05$) between *Acacia saligna* at 100 cm and *Gliricidia sepium* at 100 cm intra-row spacing. At the 50 cm distance the actual RLD ranged between

0.7 cm /cm^3 for *Acacia saligna* at the 25 cm intra-row spacing to 0.14 cm /cm^3 for *Gliricidia sepium* at the 100 cm intra-row spacing. Comparable results were obtained for *Gliricidia sepium* in West Africa by Schroth and Zech (1995a). Over all, the mean RLD in the plots of both species was about 50% less at 200 cm than at 50 cm from the hedgerows.

Table 5. Root length density (RLD) in cm /cm^3 of fine-roots of *Acacia saligna* and *Gliricidia sepium* at 50 cm and 200 cm distances from hedgerows obtained from soil cores collected in October 1994.

Species	Spacing (cm)	Root Length Density (cm/cm^3)	
		50 cm	200 cm
Acacia saligna	25	0.70^{a} [1]	0.35^{a}
	50	0.50^{b}	0.25^{ab}
	100	0.45^{b}	0.26^{ab}
Gliricidia sepium	25	0.25^{c}	0.15^{b}
	50	0.15^{c}	0.10^{bc}
	100	0.14^{c}	0.05^{c}

[1)] Values in the same column followed by the same letter are not significant at $p \leq 0.05$ level according to Fisher's LSD

As with the soil core method there were significant differences ($p \leq 0.05$) in tree fine-root mass in *Acacia saligna* and *Gliricidia sepium* plots (Table 6) as measured in the mesh bags. The total fine-root mass (tree plus crop) showed significant differences ($p \leq 0.05$) between the two species (Table 7). Similarly, crop root production estimates from the mesh bags showed a decrease in crop root mass with increases in tree root mass (Table 8). Crop fine-root mass was significantly ($p \leq 0.05$) higher in the control plots than in *Acacia saligna* plots. There were no significant differences ($p \leq 0.05$) between *Gliricidia sepium* and the control plots at the 200 cm distance from hedgerows.

Both direct and mesh bag methods showed similar trends in tree root production estimates for both species at the various depths, distances, and intra-row spaces. The correlation test value between the two methods for the 50 cm distance was $R^2 = 0.95$ showing the strong similarity of the results obtained for tree fine-root from both methods. However, the crop root estimates from mesh bags were higher than the estimates from the soil core method. This variation could have arisen from the over-all change of environment in the

Table 6. Tree and crop fine-root production (kg ha^{-1}) in *Acacia saligna, Gliricidia sepium* and control plots at 0-30 cm depth and at 50 and 200 cm distances from hedgerows using mesh bags collected in October 1994.

	Distance from hedgerows					
	50 cm			200 cm		
	tree root	crop root	tree +crop	tree root	crop root	tree +crop
Species (spacing, cm)	(kg ha^{-1})					
A.saligna (25)	775	330	1105	400	365	765
A.saligna (50)	535	160	700	390	265	660
A.saligna (100)	720	280	1000	380	370	750
means	677	257	935	390	333	725
G.sepium (25)	315	290	610	240	535	775
G.sepium (50)	230	375	605	105	760	865
G.sepium (100)	105	480	585	80	835	915
means	217	382	600	142	710	852
Control		740			980	
LSD (0.05)	455	185		180	430	

Table 7. Contrast tests for selected treatment means of total fine-root mass (tree +crop) from mesh bags at 50 cm distance from hedgerows.

Treatment	df	p> |T|
C vs all	1	0.94
1 2 3 vs 4 5 6	1	0.02
6 vs all	1	0.12
1 vs 4	1	0.056
2 vs 5	1	0.70
3 vs 6	1	0.054

C =control, 1 =*Acacia* at 25 cm, 2 = *Acacia* at 50 cm, 3 =*Acacia* at 100 cm. 4 =*Gliricidia* at 25 cm, 5 =*Gliricidia* at 50 cm, 6 =*Gliricidia* at 100 cm

Table 8. Average fine-root production (kg ha^{-1}) and distribution in *Acacia saligna*, *Gliricidia sepium* and control plots at 0-10 cm and 10-30 cm soil depth and at 50 and 200 cm distances from the hedgerows using mesh bags collected in Oct. 1994

	Distance from hedgerows			
	50 cm		200 cm	
Species (spacing)	tree root	crop root	tree root	crop root
Acacia saligna				
0-10 cm	210	100	110	115
10-30 cm	470	160	280	220
Gliricidia sepuim				
0-10 cm	54	145	50	380
10-30 cm	160	200	90	330
Control				
0-10 cm		290		305
10-30 cm		450		675
LSD (0.05)				
0-10 cm	190		60	200
10-30 cm	306	60	140	186

bags from the surrounding area that might have favored growth of crop roots over tree roots. The variation could also have arisen from the under-estimation of crop roots using soil cores. Soil core samples were taken from predetermined distances of 50 and 200 cm from hedgerows and at mid point between rows. Rooting density is higher near the rows and decreases exponentially with increase in distance to the mid-point between rows (Kumar et al. 1993). Therefore, the sampling scheme may have had an effect of under-estimation of the crop roots using soil coring. On the other hand, mesh bags were buried for 3-4 months allowing sufficient time for root growth and minimizing the temporal variation of root distribution.

In agroforestry systems trees and/or shrubs stay long after crop plants have been harvested. Competition between crop and tree roots may result in partial exclusion of competing roots both spatially and temporally. Therefore, large spatial variation in root mass in the cropping area is to be expected (Jonsson et al. 1988). The mesh bag method "implanted soil mass technique" (Lund et al. 1970) requires small soil volume and allows ample replication in sampling. As many bags as required can be put in a single plot and carefully placed to account for the spatial and temporal variation in crop and tree root distribution. From the results obtained from mesh bags it can be inferred that similar estimates can be obtained using this method as with soil coring. It is a simple and cheap method of root sampling.

Sorghum Crop Performance

Sorghum dry biomass, grain yield and height are presented in Table 9. Over-all sorghum performed better under *Gliricidia sepium* and control than it did under *Acacia saligna.* There was a significant (P≤ 0.05) increase in grain and dry matter yield of sorghum in *Gliricidia* and control plots compared to *Acacia* plots. However. there was no significant difference (P≤ 0.05) in grain yield and height between *Gliricidia* at 1 m intra-row spacing

Table 9 : Grain yield, dry matter and height of sorghum grown in an alley-cropping system with *Acacia saligna* and *Gliricidia sepium.*

Treatment	Grain yield (kg ha^{-1})	Dry matter yield (kg ha^{-1})	Height (cm)
A. *saligna* (25cm)	580^{a}	1548^{a}	88^{a}
A. *saligna* (50 cm)	680^{a}	1560^{a}	87^{a}
A. *saligna* (100 cm)	640^{a}	1880^{b}	89.5^{a}
G. *sepium* (25 cm)	1670^{bc}	2591^{c}	108.5^{b}
G. *sepium* (50 cm)	1230^{b}	2784^{d}	105^{b}
G.sepium (100 cm)	1910^{cd}	2673^{d}	110^{b}
control (no-tree)	2090^{d}	3375^{e}	111^{b}

[1)] Values in the same column with the same letter are not significant at (P ≤ 0.05) according to Fisher's LSD

and the control plots. The weak competition from *Gliricidia* roots enabled sorghum to perform better and this makes *Gliricidia* more suited for alley cropping systems.

The sorghum yield reduction under *Acacia saligna* is likely due to the competition. As seen earlier, *Acacia saligna* produced an extensive root system in the top soil where the sorghum crop roots were also concentrated. This likely resulted in competition for soil moisture and other soil resources between the sorghum and *Acacia.*

This was further complicated by the low rainfall during the short rainy period of April and May 1994 which coincided with the time of crop planting. The unusually low and intermittent rains during this period resulted in extreme moisture stress in germination an poor early vegetative growth of sorghum. Benefits from the quantities of added biomass as mulch and nutrients may not be realized under these circumstances.

Summary and Conclusion

Results of this study on the below-ground environment in an alley-cropping system showed that root competition could be one of the major factors contributing to yield reduction in alley cropping systems and that the top soil of the cropping zone was not immune from invasion by tree roots. *Acacia saligna* had roots spread throughout the soil profile where most of the crop roots were also concentrated. This is indicative that this species can have a profound effect on the productivity of the food crop. The effects of competition are clearly indicated by the poor above-ground productivity of sorghum. Sorghum seed yield, dry biomass, and height were significantly reduced when grown in association with *Acacia saligna.*

The study also found that intra-row spaces between 25 and 100 cm between trees had little effect in minimizing the competition between crops and *Acacia*. Irrespective of differences in intra-row spaces the trees tend to fill the intra-row spaces quickly. The 4 m alley width used in this experiment was also not sufficiently wide to mitigate the competition between trees and crops. *Acacia* roots were able to spread out quickly over the whole cropping area. A condition that makes it imperative not to recommend *Acacia* for inter-cropping without a much wider spacing than was used in this study. Alley widths of 6. 8 and 10 m have been recommended by Fernandes et al. (1993) for *Inga* species. Slightly wider inter-row spaces may have to be considered for *Acacia saligna.* It was observed that fine root production decreased dramatically with an increase in distance away from the hedgerows. In fact, in some instances the reduction was by about 50%, indicating that by allowing a wide enough alley between trees the competition influence can be greatly minimized. One potential use of *Acacia saligna* is in Runoff Agroforestry (RAS). The low lying arid and semi-arid areas of Ethiopia that cannot be cultivated but can be used to raise livestock are potentially suited for *Acacia.* The species is fast growing and produces large amount of fresh biomass, in this study as much as 20 tons $ha^{-1}yr^{-1}$ of fresh biomass. The species produces quality and palatable fodder for livestock (Haile and Abdelkadir 1990). Livestock production in these dry lands has come under pressure from dwindling fodder supplies and the use of *Acacia saligna* in the form of agroforestry can supplement the needed fodder for livestock and firewood.

Gliricidia sepium developed a much weaker root system than *Acacia.* Intra-row spacing had a significant effect on its root distribution at the 100 cm spacing thus minimizing the resultant competition with the sorghum. Sorghum yields in the alley with *Gliricidia sepium* at 100 cm intra-row spacing showed no significant yield differences ($p \leq 0.05$) from the control. There is an opportunity that the sorghum yield under *Gliricidia* can even be increased by increasing the intra-row spacing to 125-150 cm and the inter-row spacing to 5-6m. Moreover, the tree species could contribute additional wood material which can be used as a source of fuelwood in the wood scarce Hararghe highlands. Addition of mulch from pruning of hedgerows will also contribute to the maintenance of soil organic matter and the sustainability of the land in the long run. Overall the weak competitive ability of *Gliricidia sepium* makes it the better candidate for alley-cropping at the alley widths and intra-row widths used in this study.

CHAPTER 4: EFFECT OF *ACACIA SALIGNA* AND *GLIRICIDIA SEPIUM* HEDGES ON SOIL ORGANIC MATTER, SOIL MOISTURE, AND SORGHUM YIELD IN AN ALLEY-CROPPING SYSTEM IN THE HARARGHE HIGHLANDS OF ETHIOPIA

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Abstract

Soil moisture and below ground competition are key factors for yield improvement. This study was conducted to determine whether below-ground competition between trees and crops could be minimized through planting density and matching suitable trees and crops in alley-cropping system. Effect of *Acacia saligna* and *Gliricidia sepium* alleys on soil organic matter, soil moisture and sorghum yield were studied in an alley-cropping system in the Hararghe Highlands of eastern Ethiopia. The tree alleys were established at 25. 50 and 100 cm intra-row spaces. Measurements of soil organic carbon and total nitrogen for the depth of 0-60 cm were made. Field tensiometers were installed at 10, 30. and 60 cm depths to monitor soil water potential. Soil water content was monitored periodically using gravimetric techniques, at similar depths. Sorghum grain yield. above-ground dry matter and height for the 1994/1995 cropping season were determined. The leaf and twig dry matter of

Acacia saligna was significantly ($p \leq 0.05$) higher than the dry matter yield for *Gliricidia sepium* across the various intra-row spaces. The highest dry biomass was produced by *Acacia saligna* at a 25 cm intra-row spacing with 7700 kg ha^{-1} and the lowest was recorded for *Gliricidia sepium* at a 50 cm intra-row spacing with 1600 kg ha^{-1}. Addition of high amounts of biomass in the form of pruning under *Acacia* helped maintain the soil organic matter after six years of continuous cultivation. Soil organic matter was lower by about 20% in the control (no-trees) and 10% in the *Gliricidia sepium* plots compared to *Acacia saligna* plots. The slow decomposition of leaves of *Acacia saligna* had beneficial effects on long term soil organic matter maintenance. On average *Acacia saligna* plots had approximately 2-3% lower soil moisture content than the control and *Gliricidia sepium* plots during the cropping period. Soil moisture content did not differ between the control and the *Gliricidia sepium* plots. The lowest soil moisture content was recorded at 0-10 cm in all treatments. This could be due to evaporative loss of water at the top soil layer. Water potential measurements also showed similar trends in soil moisture depletion. Sorghum biomass, grain yield and height were significantly ($p \leq 0.05$) higher with *Gliricidia sepium* and control than with *Acacia saligna.* There was no significant ($p \leq 0.05$) difference in grain yield for sorghum in the control or with *Gliricidia sepium* at 100 cm intra-row spacing. The sorghum yield reduction with *Acacia saligna* is largely due to competition for soil moisture.

Introduction

Alley-cropping, also known as hedgerow inter-cropping, is defined by Kang and Wilson (1987) as an agroforestry system in which agricultural crops are grown in-between alleys between hedgerows of trees and/or shrubs. The trees help maintain soil fertility, fix nitrogen, recycle nutrients from below the crop root zone and increase soil organic matter by adding above-ground and below-ground litter (Kang 1993).

Much of the research on major food crop yields in alley-cropping systems has been conducted in the humid and sub-humid tropics (Kang et al. 1985; Yoamha et al. 1986b; Dugma et al. 1989; Atta-krah et al. 1993; Kang 1993). Most of these studies were conducted in the humid tropics with high rainfall and reported positive effects of tree and shrub alleys on the companion crops. However, results from the semi-arid tropics have shown some serious negative effects on yields of food crops grown in association with trees in alley-cropping systems (Singh et al. 1989; Ong 1994).

Soil moisture and below-ground competition are key factors for yield improvement. Competition for water can be detrimental for plant growth, especially in the semi-arid tropics. Singh et al. (1989) observed that there was severe reduction of yield in alley-cropping systems in the semi-arid tropics that were likely a consequence of competition for water. Therefore, below-ground competition must be minimized in order to maximize crop yield (Ong 1994).

This study was conducted in the Hararghe highlands of eastern Ethiopia to:
1) compare soil moisture regime and nutrient accumulation under different tree species and different intra-row spacing; and 2) determine the relationship between tree density, soil

moisture, and sorghum yield in alley-cropping with different tree species and intra-row tree spacing.

Materials and Methods

The study site, field layout and establishment of the hedgerows have been described in Abdelkadir and Schultz (unpublished data). The research was conducted in an established experimental field at Alemaya University of Agriculture, Alemaya, Ethiopia. The site has an average annual rainfall of 850 mm which falls mainly between June-September. The soil at the research site is a sandy-loam, isothermic, typic Usthorthent, locally known as the Alemaya series. The soil is low in organic carbon content, total nitrogen, available phosphorous, and cation exchange capacity. The soil has a pH value of near neutral (Tamirie 1984; Haile 1991).

The alley-cropping system included tree hedgerows composed of *Acacia saligna* and *Gliricidia sepium* with three intra-row spacing of 25, 50, and 100 cm. The inter-row cropping alleys between hedgerows were 4 m wide and the hedgerow lengths were 6 m. The experiment was laid out as a factorial arrangement in a randomized complete block design with three replications. The cropping alleys between hedgerows of trees were cropped with *Sorghum bicolor* (var. seredo). Sorghum is the major staple food crop in the Hararghe highlands.

Tree hedgerows were pruned periodically during the growing period. *Acacia saligna* was pruned three times to a 1m height. This pruning height seemed to suit the species which coppices profusely. *Gliricidia sepium* is a relatively slow growing species and was pruned twice per season to a height of 50 cm. Biomass measurements were taken from randomly selected trees of each species. The sampled trees accounted for 25% of all trees in each plot. The leaves and twigs were separated from the stem and weighed for total fresh biomass. A 1000 g, fresh-weight sub sample, was oven dried at 70 °C and re-weighed to estimate the dry matter yield of the hedgerows. The rest of the leaf and twig biomass produced was incorporated into the soil as a mulch.

Plant Tissue Analysis

Plant tissue samples were collected from each plot for laboratory analysis. The samples included mature leaves and twigs from the top, middle and bottom of the crown from each cardinal direction. Each sub-sample was oven dried at 70 °C and transported to Iowa State University for laboratory analysis. Plant samples were ground in a mill to pass through a 1mm mesh. The standard Kjeldahl procedure was followed for tissue digestion and analysis (Plant Tissue Analysis Manual, Hach Inc. 1989). A 0.25 gm tissue sample was subjected to high temperature digestion at 400 °C with concentrated sulfuric acid (H_2SO_4) and hydrogen peroxide (H_2O_2) as a catalyst. Nitrogen, phosphorous, and potassium in the digest were determined using a Hach DR/3000 Spectrophotometer (Hach Inc., Colorado).

Soil Sampling and Analysis

Soil samples were collected from each plot at depths of 0-10, 10-30, and 30-60 cm. A total of 12 cores were collected in an X design in each plot The samples from each depth in each plot were then combined and mixed completely to make a composite sample. A 600 ml sub-sample was prepared for each depth and plot. The samples were dried at about 50 °C to reduce weight and transported to Iowa State University for laboratory analysis. The samples were ground in a mill to pass a 2 mm sieve. Ten milligram sub-samples were prepared for analysis of organic carbon and total nitrogen using Carlo Erba Elemental Analyzer (Carlo Erba, Milan, Italy).

Soil Moisture Determination

Soil moisture content was determined gravimetrically once a month throughout the cropping season of July to November 1994. Three samples were collected in each plot at 50 cm and 200 cm distances from the hedgerows. Using a soil core sampler, samples were collected at 0-10 cm, 10-30 cm, and 30- 60 cm depths. Soil moisture was determined using the standard procedures described for gravimetry with oven drying to a constant weight of 105 °C for 24 hours (Gardner 1965; Slavik 1974). Simultaneously, soil water potential (centibars) was monitored during the period of July to October 1994. Tensiometers were installed at depths of 10, 30 and 60 cm. Because of the expense, tensiometers were only placed at a 50 cm distance from the hedgerows. Readings were collected daily at 7:00 a.m. when water use by plant roots would be at its minimum.

Both methods of soil moisture determination were used to complement each other and thus arrive at an accurate estimate about the soil moisture conditions under the various treatments.

Grain Yield and Crop Biomass Determination

Plant height, plant biomass, and grain yield of sorghum were collected from randomly selected plants representing about 25% of the total plants in a unit plot. Plant heights were averaged to a mean height for the plot. The plants were harvested and grain yield and plant biomass determined. The sorghum seeds were separated, dried to 12% moisture content, and weighed. The sorghum stalks were weighed and a sub-sample oven dried at 70 °C to a constant weight for dry matter determination. All the parameters were calculated and converted to a hectare basis.

Statistical Analysis

Analysis of variance was used to identify if significant differences existed among the treatment means of the various parameters measured in the experiment. When analysis of variance showed significance differences at $p \leq 0.05$ further mean separations were made using Fisher's LSD mean separation test with a $p=0.05$ significance level.

Results and Discussion

Dry Matter Yield and Nutrient Contribution of Hedgerows

Dry matter yield and N, P, K contributions (kg ha^{-1}) of *Acacia saligna* and *Gliricidia sepium* leaves and twigs are presented in Table 1. *Acacia saligna*, a fast growing species, produced large amounts of above-ground biomass. The leaf and twig dry matter of *Acacia* was significantly ($p \leq 0.05$) higher than for *Gliricidia* across the various intra-row spaces. The largest dry biomass was obtained from *Acacia* at 25 cm intra-row spacing with 7700 kg

ha^{-1} of dry matter and the lowest obtained from *Gliricidia* at 50 cm intra-row spacing with only 1600 kg ha^{-1}. However, these dry matter yields represent a substantial amount of biomass production by both species that can be added as mulch to the soil or act as a supplemental feed to animals where these resources are scarce. Not included in this study is the woody material produced by both species. The wood that is produced from stem cuttings is substantial, especially for *Acacia saligna* (Negussie et al. 1994). This can be a source of additional income in areas where fuel wood is so scarce that crop residues constitute about 50% of the fuel for all households (Poschen 1987).

Table 1. Estimated leaf +twig dry matter and nutrient contributions (kg ha^{-1}) of *Acacia saligna* and *Gliricidia sepium* in alley-cropping system in the Hararghe highlands of eastern Ethiopia.

Species	intra-row spacing (cm)	Dry matter (kg ha^{-1})	N %	N kg ha^{-1}	P %	P kg ha^{-1}	K %	K kg ha^{-1}
Acacia	25	7700^a	2.4	187^a	0.17	13^a	0.44	34^a
	50	7600^a	2.2	168^a	0.16	12^a	0.43	33^a
	100	7200^a	2.1	155^a	0.16	11^a	0.41	29^a
Gliricidia	25	2100^b	3.2	67^b	0.23	5^b	0.56	12^b
	50	1600^b	3.4	55^b	0.32	5^b	0.42	7^b
	100	1800^b	2.7	49^b	0.15	3^b	0.56	10^b

1)Values in the same column and the same letter are not significant at 0.05 level according to Fisher's Least square difference.

Gliricidia sepium leaves and twigs showed higher percentage of N. P. and K than *Acacia saligna* leaves. However, the higher percent nutrient content was not sufficient to compensate for the low level of biomass production by *Gliricidia* and thus, the overall nutrients contribution (N, P, K) of *Acacia* was significantly ($p \leq 0.05$) higher than *Gliricidia sepium*. Lehmann et al. (1995) have reported high nutrient contents in all plant parts of *Gliricidia* grown in the humid tropics of west Africa. There were no significant ($p \leq 0.05$) differences in dry matter and nutrient yields among the various intra-row spaces within each species. This could be attributed to the rapid growth of the hedgerows which closed the gaps.

Soil Organic Carbon and Nitrogen

Table 2 shows that soil organic carbon was higher in alley-cropped plots than in the control plots at both 0-10 and 10-30 cm depths. On average organic carbon was lower by over 20% and 10% in the control and *Gliricidia* plots, respectively, compared to *Acacia* plots. Organic carbon declined significantly ($p \leq 0.05$) with increasing depth. Increasing depth also narrowed down differences among treatments and there were no observable differences between treatments at the 60 cm depth. Therefore, it appears that the additions of high plant biomass in the form of prunings, especially under *Acacia saligna*, has enabled the soil to maintain the organic matter in the soil for six years of continuous cultivation. Under the control, the decline was faster, depriving the soil of the single most important factor of soil quality (Sikora et al. 1996). Similar results have been reported for *Leucaena*

Table 2. Percent soil organic carbon and nitrogen in *Acacia saligna, Gliricidia sepium* and control (no-tree) plots in an alley-cropping system in the Hararghe highlands of eastern Ethiopia

	% Organic carbon			% Nitrogen		
Depth (cm)	0-10	10-30	30-60	0-10	10-30	30-60
Species						
A.saligna	1.93^{a}	1.44^{b}	1.10^{b} [1]	0.17^{a}	0.13^{b}	0.12^{b}
G.sepium	1.78^{a}	1.42^{ab}	1.02^{b}	0.15^{a}	0.13^{ab}	0.12^{b}
sole-cropping	1.61^{a}	1.23^{ab}	1.00^{b}	0.15^{a}	0.11^{b}	0.09^{b}

1) values in the same row with the same letter are not significantly different ($p \leq 0.05$)

leucocephala in studies conducted in the humid tropics of west Africa (Lal 1989c). Kang (1993) reports the same trend of slow decline when after six years of alley-cropping with *Leucaena leucocephla* the organic C level in the surface soil declined to a very low level in the control (no-tree) treatment with 0.59% as compared to the alley-cropped plot with 0.94%. Similar beneficial effects of prunings in maintaining the original organic C level of the soil have been reported in various parts of the tropics (Yamoah et al. 1986a: Kang and Ghuman 1991; Rosecrance et al. 1992).

Sikora et al. (1996) state that soil organic matter decline is stimulated by decomposition following plowing or cultivation and a decrease in plant residue additions. *Acacia saligna* produced large quantities of prunings that decompose slowly. The slow decomposition has the beneficial effect of long term soil organic maintenance (Hulugale and Kang 1990). *Acacia saligna* is also known to produce large quantities of fine-root biomass

(Abdelkadir and Schultz, unpublished data). Decomposition of these fine roots may have an influence on the organic carbon of the soil. Roots play an important role in carbon allocation in less fertile sites where more biomass is produced below-ground (Szott et al. 1991; Lehmann et al. 1995). The relatively low levels of organic matter in *Gliricidia* plots compared to *Acacia* could be the result of the low amount of biomass production and relatively rapid decomposition of *Gliricidia* leaves and twigs (Kang 1993; Lehamnn et al. 1995)

Soil N contents showed a similar trend to that of organic carbon. Soil nitrogen content in the top 0-10 cm soil layer declined on average from 0.17% in *Acacia saligna* plots to 0.15% in the control plots. *Acacia saligna* at the 50 cm intra-row spacing had the highest nitrogen content with about 0.19% N (not shown). Percent N also showed a decline with increasing depth. Similar results have been reported for *Gliricidia sepium* in studies conducted at the International Institute of Tropical Agriculture(IITA) Nigeria by Lal (1989). Unlike organic carbon, the nitrogen content in the lower depths was slightly higher in alley-cropped plots compared to control plots. This may be partly due to nitrogen fixed symbiotically by the leguminous shrub leaching to the lower layers (Lal 1989b).

Soil Moisture

The soil moisture content at the 50 cm distance from hedgerows is given in Figures 1-3. Averaged over intra-row spacing, *Acacia saligna* plots had approximately 2-3% lower soil moisture content during the sampling period than the control and *Gliricidia sepium* plots. There were no pronounced differences in soil moisture content between *Gliricidia sepium* and the control plots. The soil moisture content at 30 cm depth was consistently higher than the soil moisture content at 10 cm and 60 cm soil layers in all the treatments. This may be partly due to loss of soil water due to evaporation and the extraction of water by tree roots in the 60 cm depth. Visual observation at 60 cm revealed clay hardpans created by continuous plowing. This in turn has resulted in poor percolation and consequently drier condition. Moreover, the soil moisture depletion profile in hedgerow plots showed that soil loss in the top 10 cm was higher at 200 cm from hedgerows than at 50 cm distance (Table 3). This may be attributed to the fact that trees shade the area near them thus reducing water loss by evaporation.

Similar trends to soil water content were also observed in soil water potential as shown in Figures 4-6. Earlier in the season (July and August) there were no observable differences in water potential between the treatments. The higher rainfall in July and August tended to minimize the differences in water suction. As the season advanced, however, the water in the soil of *Acacia saligna* plots was held by greater tension (drier) and water stress peaked in September compared to other treated plots. This period coincides with the seeding period of sorghum crop in the Hararghe highlands. Root system studies have shown that *Acacia saligna* produced a higher amount of fine roots in the upper soil layers where crop roots were also concentrated (Abdelkadir and Schultz, unpublished data). These fine roots of trees and crops confined to the same soil zone, probably shared the available water from the same soil volume. This has obviously induced the drier condition in the *Acacia* plots. Growth is proportional to the amount of water used (Nambier and sands 1993) and the water stress in *Acacia* plots during this time could be detrimental to the growth and productivity of sorghum. Differences narrowed and attained similar values in the late season (late October and November) when conditions were very dry. Kang et al. (1985) have found similar results under *Leucaena leucocephala* where soil water was depleted at lower levels of 60 cm and below due to the extensive rooting habit of the species at this soil layer.

There was no observable change in soil moisture conditions due to changes in intra-row spacing, indicating that the intra-row spaces used in this trial were not sufficient enough to affect soil water uptake by the trees. However, none of the comparisons regarding soil

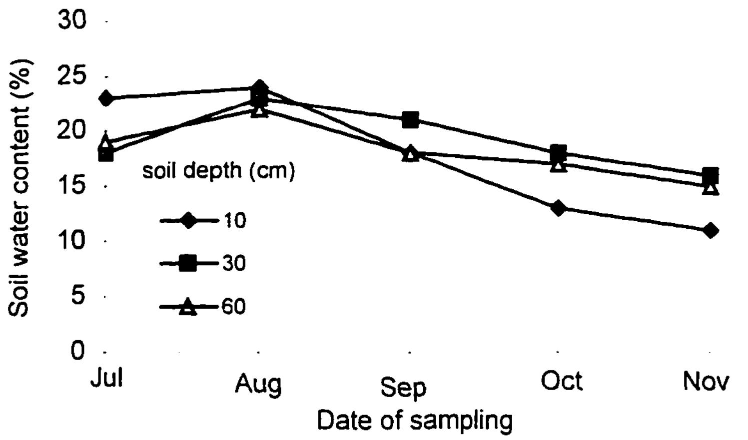

Figure 1. Soil moisture content (%) within a sorghum alley, 50 cm from *Acacia* hedges.

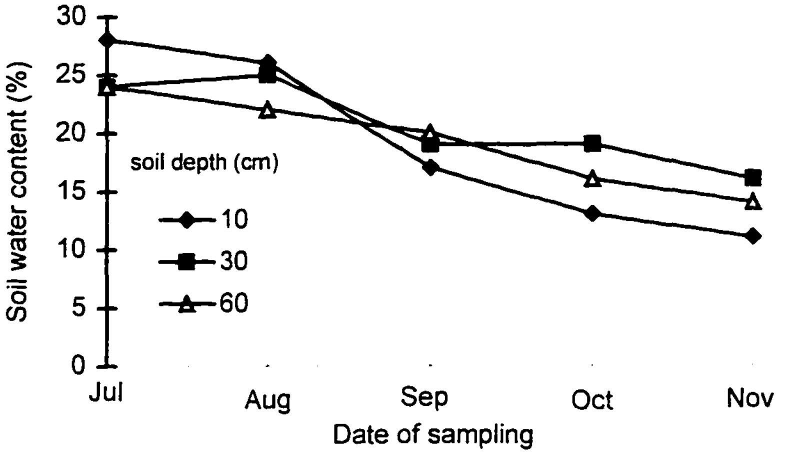

Figure 2. Soil moisture content (%) within a sorghum alley. 50 cm from *Gliricidia* hedges.

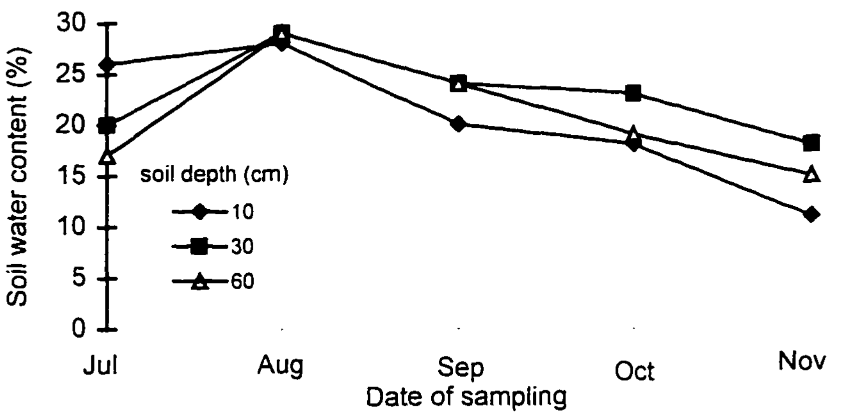

Figure 3. Soil moisture content (%) in control plots at 50 cm distance from the edges.

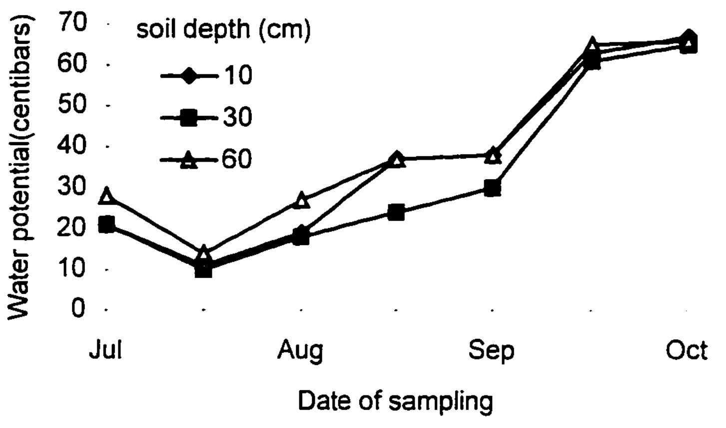

Figure 4. Soil moisture potential (centibars) within a sorghum alley. 50 cm from Acacia hedges.

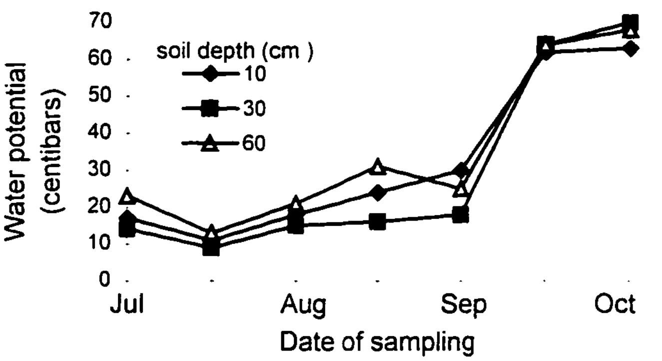

Figure 5. Soil moisture potential (centibars) within a sorghum alley. 50 cm from *Gliricidia* hedges

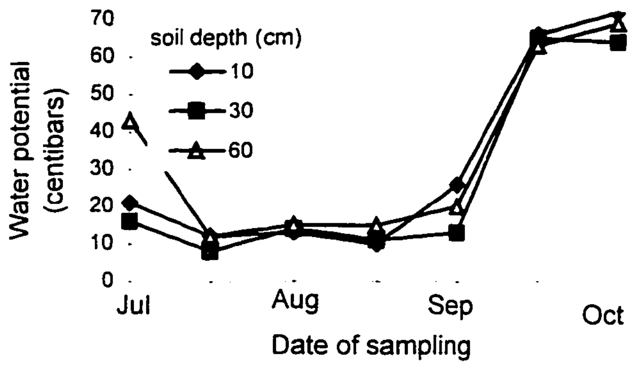

Figure 6. Soil moisture potential (centibars) in control plots at 50 cm distance from the edge.

Table 3. Soil moisture content (%) in *Acacia saligna*. *Gliricidia sepium* and control plots at 200 cm distance from hedgerows.

Species	Depth(cm)	Jul	Aug	Sep	Oct	Nov
A. saligna	0-10	23	23	15	13	12
	10-30	24	24	17	16	16
	30-60	20	20	18	17	15
G. sepium	0-10	22	23	19	15	10
	10-30	18	24	20	17	17
	30-60	18	22	19	18	17
Control	0-10	25	26	17	16	11
	10-30	19	27	18	17	15
	30-60	19	22	20	17	16

moisture conditions can be conclusive because of the lack of clearly defined depletion zones within each treatment and between treatments.

Sorghum Crop Performance

Sorghum dry biomass, grain yield and height are presented in Table 4. There was a significant increase ($P \leq 0.05$) in grain and dry matter yield of sorghum in *Gliricidia* and control plots compared to *Acacia* plots. However, there was no significant difference

Table 4. Grain yield, dry matter and height of sorghum grown in alley-cropping system in the Hararghe highlands of eastern Ethiopia

Treatment	intra-row spacing (cm)	Grain yield (kg ha^{-1})	Dry matter yield (kg ha^{-1})	Height (cm)
A. *saligna*	25	580^{a} [1]	1548^{a}	88^{a}
A. *saligna*	50	680^{a}	1560^{a}	87^{a}
A. *saligna*	100	640^{a}	1880^{b}	89.5^{a}
G. *sepium*	25	1670^{bc}	2591^{c}	108.5^{b}
G. *sepium*	50	1230^{b}	2784^{d}	105^{b}
G.sepium	100	1910^{cd}	2673^{d}	110^{b}
control		2090^{d}	3375^{e}	111^{b}

1)Values in the same column and same letter are not significant at ($p \leq 0.05$) according to Fisher's LSD (after Abdelkadir and Schultz, unpublished data)

($P \leq 0.05$) in grain yield and height between *Gliricidia* at 1 m intra-row space and the control. The less competition from *Gliricidia* roots enabled the sorghum to perform better and this makes the species more suited for alley cropping systems

The sorghum yield reduction with *Acacia* could be due to the competition for soil moisture conditions. Soil moisture content and soil water potential observations. suggested drier soil condition which could have resulted in competition for soil moisture between the sorghum and *Acacia*. A similar conclusion was made by Singh et al. (1989) in a study made in semi-arid areas of India.

Summary and Conclusion

Repeated application of pruning material as mulch resulted in higher organic matter levels in alley-cropped plots than in control plots. *Acacia saligna* produced large quantities of dry matter and with its slowly decomposing leaves may have helped maintain the soil organic matter throughout the six years of cropping period.

Soil water content and soil water potential measurements indicated that soil moisture levels were lower in *Acacia* plots than either *Gliricidia sepium* or sole-cropping plots. As a result, crop yield reduction in *Acacia* plots may have been partly due to competition for water. Competition for soil moisture is the single most important factor that limits growth in the arid and semi-arid areas of the tropics (Singh et al. 1989). Benefits from added biomass of *Acacia* may not be realized under these circumstances.

The competition with *Acacia* was further complicated by the low rainfall during the short rainy period of April and May which coincided with the time of crop planting. The usually low and intermittent rains during this period resulted in extreme moisture stress at germination and poor early vegetative growth of sorghum.

Gliricidia sepium showed less competition. Sorghum yields under *Gliricidia* were not significantly different from the control. With the additional benefits of fuel wood and mulch, *Gliricidia* is a potentially useful tree species for alley-cropping system in the Hararghe highlands of eastern Ethiopia.

Finally, one potential use of *Acacia saligna* is in a runoff agroforestry system (RAS). The low lying arid and semi-arid areas of Ethiopia that cannot be cultivated but can be used to raise livestock are potentially suited for *Acacia saligna.* The species is fast growing and produces large amounts of fresh biomass, in this study as much as 20 tons ha^{-1} $yr^{-1}$of fresh biomass. The species produces quality and palatable fodder for livestock (Haile and Abdelkadir 1990). Livestock production in these dry lands has come under pressure from dwindling fodder supplies as a result of shrinking grazing shrub lands.

Through water conservation, especially water harvesting, runoff can be channeled to and concentrated by dykes and small dams. The water harvested by these dams can provide sufficient water needed to grow the tree species (Pedro Berliner, personal communication, 1996). Using *Acacia saligna* in this form of agroforestry can provide dry areas the needed fodder for livestock and firewood.

The species can also be used to improve the soil fertility status of the soils. Most soils of the arid and semi-arid areas are characterized by easily erodible soils with inherent low fertility. In these dry lands the major storehouse of soil fertility is the soil organic matter. The organic matter in the top 30 cm of a typical soil contribute about 30-40% of soil's CEC (Tabor 1995). The loss of this organic matter through erosion is one major reason for low agricultural productivity even during good rainy season. With its slow decomposing leaves and high biomass production, the species is ideal for restoring the soil organic matter in these areas.

CHAPTER 5: GENERAL CONCLUSION

An important outcome of this research is that understanding below-ground competition is a key factor for yield improvement in an alley-cropping system. Competition for moisture and nutrients can be detrimental for plant growth and may result in a reduction in the yield of alley grown food crops. The research was intended to search for relationships between tree hedgerow density, root production, soil moisture conditions, and sorghum yield grown in association with *Acacia saligna* and *Gliricidia sepium* in an alley-cropping system.

The results in Chapters 3 and 4 indicated that tree roots spread throughout the portion of the soil profile where most of the crop roots were also concentrated. There was a relationship between the presence of tree roots in the upper soil profile, soil moisture conditions and the productivity of sorghum. *Acacia saligna* had extensive rooting habit and lower soil moisture compared to *Gliricidia sepium* and control (no-tree). The effects of competition were clearly indicated by the poor above-ground productivity of sorghum. Sorghum seed yield, and above-ground biomass were significantly reduced when grown in association with *Acacia saligna*. *Glricidia* developed a much weaker root system and was less competitive and thus a better candidate for alley-cropping.

Overall, there is considerable role for agroforestry in the intensification and improvement of agriculture and generating additional income to the farming communities of Hararghe Highlands, in particular, and Ethiopia, in general. However, to make this step feasible research is needed with more attention to the below-ground and above-ground environment. In addition to testing the biophysical potentials of agroforestry. research should also focus on evaluating agroforestry technologies through on-farm and farmer participatory research and facilitation of the adoption of potential agroforestry practices by the farmers.

APPENDIX: ADDITIONAL STATISTICAL INFORMATION

Table 1: Fine-root mass estimates from samples of October 1994 by soil coring at 0-10 cm depth at 50 cm from hedgerows

Source of variability	DF	Sum of Squares	Mean Squares	F value	Probability of Larger F
Treatment	7	874606	124943	2.40	0.10
Species	1	560740	560740	10.80	0.0082
Spacing	2	32857	16428	0.32	0.7355
Spp* Spa	2	5385	2692	0.05	0.9497
Block	2	275623	137811	2.66	0.1187
Error					

Table 2: Fine-root mass estimates from samples of October 1994 by soil coring at 10-30 cm depth at 50 cm from hedgerows

Source of variability	DF	Sum of Squares	Mean Squares	F value	Probability of Larger F
Treatment	7	513139	73305	2.56	0.0865
Species	1	256089	256089	8.94	0.0136
Spacing	2	117925	58962	2.06	0.1785
Spp*Spa	2	27639	13819	0.48	0.6310
Block	2	111484	55742	1.95	0.1934
Error	10	286545	28654		

Table 3: Fine-root mass estimates from samples of October 1994 by mesh bag at 0-10 cm depth at 50 cm from hedgerows

Source of Variability	DF	Sum of Squares	Mean Square	F value	Probability of Larger F
Treatment	7	185116	26445	1.64	0.2311
Species	1	106414	106414	6.59	0.0280
Spacing	2	2288	1144	0.07	0.9321
Spp*Spa	2	10683	5341	0.33	0.7259
Block	2	65730	32865	2.04	0.1813
Error	10	161490	16149		

Table 4. Fine-root mass estimates from samples of October 1994 by mesh bag at 10-30 cm depth at 50 cm from hedgerows

Source of variability	DF	Sum of Squares	Mean square	F value	Probability of Larger F
Treatment	7	982181	140311	3.36	0.0408
Species	1	423813	423813	10.16	0.0097
Spacing	2	105368	52684	1.26	0.3244
Spp*Spa	2	29633	14816	0.36	0.7096
Block	2	423365	211682	5.07	0.0301
Error	10	417278	41727		

Table 5. Fine-root mass estimates from samples of March 1995 by soil coring at 0-10 cm depth at 50 cm from hedgerows

Source of variability	DF	Sum of Squares	Mean Square	F value	Probability of Larger F
Treatment	7	1233923	176274	4.42	0.0174
Species	1	934344	934344	23.42	0.0007
Spacing	2	53795	26897	0.67	0.5312
Spp*Spa	2	30652	15326	0.38	0.6906
Block	2	215132	107566	2.70	0.1157
Error	10	398901	39890		

Table 6. Fine-root mass estimates from samples of March 1995 by soil coring at 10-30 cm depth at 50 cm from hedgerows

Source of variability	DF	Sum of Squares	Mean Square	F value	Probability of Larger F
Treatment	7	165974	238524	7.09	0.0032
Species	1	879138	873138	26.14	0.0005
Spacing	2	603986	301993	8.98	0.0059
Spp*Spa	2	36412	18206	0.54	0.5981
Block	2	150137	75068	2.23	0.1580
Error	10	336370	33637		

Table 7. Soil organic carbon in alley-cropped and sole-cropped plots.

Source of variability	DF	Sum of Squares	Mean Squares	F value	Probability of Larger F
Model	9	5.95517	0.66168	7.20	0.0001
Species	2	0.13600	0.13600	1.49	0.2294
Spacing	2	0.03103	0.01552	0.17	0.8447
Depth	2	4.78714	2.39357	26.10	0.0001
Spp* Spa	2	0.60758	0.30379	3.32	0.0455
Block	2	0.39341	0.19670	2.15	0.1288
Error	44	4.02891	0.09156		

Table 8. Soil nitrogen in alley-cropped and sole-cropped plots.

Source of variability	DF	Sum of Squares	Mean Squares	F value	Probability of Larger F
Model	7	0.04476	0.006394	8.13	0.0001
Species	1	0.00086	0.000864	1.10	0.3001
Spacing	2	0.00026	0.000132	0.17	0.8458
Depth	2	0.04086	0.020433	25.98	0.0001
Block	2	0.00276	0.001383	1.76	0.1836
Error	46	0.03618			

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