MOISTURE RELATIONS IN AGROFORESTRY WITH MAIZE/*LEUCAENA LEUCOCEPHALA* ALLEY CROPPING IN A SEMI-ARID ENVIRONMENT AT CHALIMBANA IN ZAMBIA.

by

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DECLARATION

I, MUNSHIMBWE G. CHITALU, declare that this dissertation represents my own work and that it has not previously been submitted for a degree at this or another University.

Signature: Chitalu Date: 09-03-92

APPROVAL

This dissertation of Mr. MUNSHIMBWE G. CHITALU is approved as fulfilling part of the requirements for the award of the degree of Master of Science in Agronomy (Crop Science) by the University of Zambia.

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ABSTRACT

Alley cropping offers great potential for increased and sustained crop production. However, there is currently limited understanding of the effects of maize/leucaena interactions on water distribution. A field trial was conducted to investigate the distribution of soil water and performance of maize grown in three year leucaena alleys. Maize was planted in plots with and without leucaena alleys, and was either fertilized (177 kg N/ha plus 92 kg P_2O_5/ha) or not fertilized. The treatments were laid out in a factorial design with a split plot arrangement with alley or no alley in the main plots and fertilizer treatments in subplots. The experiment was replicated three times. Soil water was measured weekly in maize and leucaena rows to a depth of 90 cm. Maize parameters measured include leaf area, plant height, position of secondary cob from ground level, number of harvested plants, days to tasseling and silking and dry matter, empty cob and grain yields. Leucaena alleys had more soil water than no-leucaena alleys by 8%. Leucaena hedge had 16% more water ($p < 0.01$) than maize rows. Row water content reduced with increasing distance from the hedge. Seasonal water use in the hedge and maize rows were different ($p < 0.01$). No water competition existed between maize and

leucaena. Fertilization of alley maize boosted dry matter production from 7.47 to 15.86 t/ha exceeding fertilized sole maize by 4.57 t/ha. With inorganic nitrogen supplementation, alley cropping can function as a system of sustainable crop production. These observations need be investigated further over several seasons in order to obtain tangible conclusions.

To my dear wife naChinsenge and daughter Chinsenge and to the parents banaKafwanka and bashiKafwanka David. I love you all.

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LIST OF ACRONYMS

AD.	Anno domini - In the year of our Lord
DM	Dry matter
Eta	Actual evapotranspiration
FAO	Food and Agricultural Organisation
GTZ	German Agency for Technical Co-operation
ha	Hectare
ICRAF	International Council for Research in Agroforestry
LL+F0	_Leucaena leucocephala_ treatment without application of inorganic fertilizer
LL+F1	_Leucaena leucocephala_ treatment with application of inorganic fertilizer
N	Nitrogen
NL+F0	Unfertilized no-_leucaena_ treatment
NL+F1	Fertilized no-_leucaena_ treatment
NMM	Neutron Moisture metre (Neutron Probe)
pf	Potential of free energy
SACCAR	Southern African Centre for Cooperation in Agricultural Research and Training
SADCC	Southern Africa Development Coordination Conference
t/ha	Tonnes per hectare
UNESCO	United Nations Education Scientific and Cultural Organisation
UNZA	The University of Zambia

1 INTRODUCTION

1.1 General

The practice of growing tree species in intimate association with agricultural crops has been done for a long time now, but little thought in research appears to have been given in the practice to the agricultural situation. *Earlier agroforestry was designed and* implemented solely for the forester to establish forests (King, 1987).

A growing need to restore environmental capacity to sustain the ever rising population pressures has led to invention of new agricultural technologies aimed at improving food production; these have led to increased food production in the tropical countries of Africa, Asia and Latin America (Swaminathan, 1987). More often than not, these increases are due to improved productivity as opposed to increased farm size (Swaminathan, 1987).

Heavy reliance on area expansion to meet food sufficiency together with traditional methods of shifting, slash-and-burn cultivation and bush fallow have resulted in deforestation. Kang et al. (1990) reviewed alley cropping and reported that 70% of deforestation in Tropical Africa was due to shifting cultivation, and that an area equivalent of 28% and 16% of the remaining closed forests in Africa and Asia, respectively, are under forest fallow resulting from shifting cultivation.

Environmental damage accompanying deforestation hinges on post deforestation soil management and cropping (Kang et al., 1990). Inappropriate soil management and cropping may result in ecological imbalances (Kang et al., 1990).

The slash-and-burn systems of cultivation have persisted for years partly because they rejuvenate and restore soil productivity through fallowing. However, the long periods of fallowing that these methods require make them unsuitable as sustainable farming systems if they are to sustain the ever increasing population pressures (Kang, 1987).

Various ecologically sound, economically viable and socially acceptable technologies aimed at increasing food production through improved land productivity (Kang, 1987) have been sought and `probably' found.

One such technology (Kang et al., 1981) is alley cropping for food production. Alley cropping (hedgerow intercropping) is a `system in which food crops are planted in alleys between rows of fast growing "leguminous" trees requiring regular pruning during the cropping season to avoid or reduce shading and competition with food crops in the alleys' (Kang et al., 1990).

Huxley (1983), defines agroforestry as a `term given to sustainable land use systems which involve more or less intimate and interacting associations of agricultural or horticultural crops and wood perennials all on the same unit of land'. Tree species are deliberately grown in association with crops, or with pastures-with-animals or with both crops and pastures-with-animals. Steppler and Nair (1987) classified the three systems as agrosilvicuture, silvipastoral culture and agrosilvipastoral culture, respectively.

Reasons for alley cropping are numerous and include allowing continuous cropping of a piece of land, maintenance of soil fertility and reduction of inorganic fertilizer requirements, improvement of soil water conservation on sloping land, reduction of weed growth during the dry season so obviating the need for bush fires to clear land, provision of supplementary browse to ruminants and staking material for certain crops and for fuel wood in some instances (Rocheleau et al., 1988).

In his review of biomass productivity of mixtures, Trenbath (1974) reported that mixtures of field crops 'are still extensively grown' in traditional agriculture while Francis (1989) contended that the 'practice is common in farms with limited resources and low level of technology'. Moreover, mixed cropping offers risk aversion and provides more efficient utilisation of inputs and resources (Francis, 1989). In addition, some intercrops, particularly legumes, help in improving fertility of the soil.

1.2 Rationale

Alley cropping can foster sustainable agriculture once adopted as a farming system. Research findings by Kang et al. (1981; 1985), Swaminathan (1987), Gichuru and Kang (1989), and Lawson and Kang (1990) support this assertion.

Despite this fact, little is known about the type of crop mixture interactions particularly of water in alley cropping. Equally, little work has been done to investigate water relations between component crops in agroforestry crop mixtures. The essence of this study was to come up with currently lacking basic information on water relations in alley cropping of maize with leucaena so that their best management system could be identified. The idea was to establish whether or not mutual inhibition, cooperation or competition (Francis, 1989) exist in maize/leucaena alley cropping at various nitrogen fertilization levels with respect to water.

1.3 Objective

The objective was to determine whether or not the existing water relationship in maize/leucaena alley cropping system is competitive or not.

Specifically the study concentrated on finding out the following:

1 The amount of water in the soil and its distribution across the rows in the alleys.

2 The amount of water present in the hedgerow.

3 The type of interaction between maize and leucaena for water.

4 Whether or not the distribution of water in the maize rows depend on the amount of inorganic nitrogen fertilization, mulching or on both.

5 The differences, if any, in evapotranspiration across maize rows in the alleys.

6 Whether or not relationships exist between evapotranspiration and the following maize parameters:

a) plant height

b) leaf area

c) dry matter, empty cob and grain yield.

It was assumed that water distribution in the rows of no-leucaena treatments was uniform.

2 REVIEW OF LITERATURE

2.1 The genus leucaena

The genus leucaena is a member of the sub-family mimosoideae of family fabaceae distributed in the low lands of Mexico and growing to the maximum height of 15 to 20 m, (Brewbaker, 1987; Burley, 1987) and diameter of 50 centimetres (Brewbaker, 1989). Flowering is from January to March. Members of this genus fix nitrogen (Burley, 1987) and are used extensively in agroforestry practices as multipurpose trees.

Brewbaker (1987;1989) reported that the genus has thirteen species of which the amphiploid Leucaena leucocephala is the most common species used in agroforestry. Quoting de Witt (1783) Brewbaker (1987) reports that it is also known as white headed leucaena with leaflet length of 10 mm and 2n = 104. Dommergues (1987) made an observation that the giant species leucocephala of this genus nodulates with rhizobium which is not generally found inherent in the soil. As such, L. leucocephala responds positively to inoculation and produces about 34% to 39% of its total nitrogen (Mulongoy and Sanginga, 1990).

Adaptation to a wide range of environmental conditions makes leucaena a widely used multipurpose tree in agroforestry. Leucaenas do best in areas where annual rainfall is more than 1 000 mm but can survive, once well established, with annual rainfall as low as 500 mm (Brewbaker, 1989). Problems exist when the members of this genus are grown in environments with low pH, low phosphorus, low calcium, high salinity, high aluminium saturation and water logging (Brewbaker, 1987).

According to Brewbaker (1987) leucaenas have been used since the first millennium AD as a green manure and possibly as a food crop in Yucatan peninsula in Mexico. They are now grown for fuel wood, leaf fodder, fruit fodder, posts, and as a soil fertility restorer (Brewbaker, 1987; Dommergues, 1987; Rocheleau et al., 1988). Its good copicing ability makes it unbeatable for most agroforestry practices which require pruning.

2.2 Effects of genus leucaena on the soil

Leucaena fixes nitrogen into the soil through its nodules (Burley, 1987). Dommergues (1987) reported that 100 to 500 kg of nitrogen are fixed per hectare per year by leucaena. Mulongoy and Sanginga (1990) found an average of 104.5 kg nitrogen (difference between fertilized and unfertilized plots) and 116 kg nitrogen (^{15}N dilution technique) fixed in six months by leucaena which was inoculated with two strains of rhizobium.

Kang (1987) reports that prunings (twigs and leaves) of a five year old L. leucocephala yielded, in kg ha^{-1}. yr^{-1}., 246.5 nitrogen, 19.9 phosphorus, 184 potassium, 98.2 calcium and 16.2 magnesium and a total biomass of 7.4 $t.ha^{-1}$. yr^{-1}. Siaw (1989) found 4.1% nitrogen content in the leucaena prunings. The shading effect of leucaena on the soil was found to be beneficial in that it helps maintain a favourable environment for soil fauna whose activity improves. The increase in earth worm activity in particular, leads to improvement of soil properties of a degraded Alfisol (Kang, 1987).

2.3 Cultivated maize

The cultivated species of maize (Zea mays L.) belongs to the family poaceae, tribe maydeae, sometimes called tripsaceae (Kiesselbach, 1980) and genus Zea, species mays. The plant is monoecious with its functional staminate flowers borne in the tassels and functional pistillate flowers borne on the ears. Its origin continues to be intriguing (Galinat, 1977), but it is a native of Central

America (Kiesselbach, 1980).

Maize is adapted to a wide range of climatic conditions (Shaw, 1977) and soil types but does better in deep, medium textured soils (Larson and Hanway, 1977). The water requirements of maize fall between 500 and 800 mm per growing season depending on climate (Doorenbos et al., 1979). The water use rate of maize at the period of maximum leaf area is about 5 to 6 mm per day although it can rise to 9 mm a day on days with a high evaporative demand (Downey, 1971a; Larson and Hanway, 1977) but can be as low as 2.5 mm per day depending on season.

Root growth which Foth (1962) found to occur in a series of stages is associated with top growth. While Foth (1962) divides the growth stages of maize as shown in Appendix 1, Arnon (1975) reports intense activity of most fully developed roots of maize in the range of 70 to 75 cm depth although he concedes individual growth of up to 200 cm depth. However, Downey (1971a) and Kang et al. (1981) found maize root activity for water absorption greatest in the upper 50 cm depth.

2.4 Water and crop growth

Generally, water constitutes a primary factor in plant growth in arid and semi-arid habitats. Francis (1989) asserted that water is the most limiting of the resources that affect crop production. Quoting Sponsler and Bath (1942) Northen, (1953) reported that 85% to 90% of the cell fresh weight was due to water.

As a solvent, water is responsible for the dissolution of soil nutrients so that plant roots can take them up. Water is also involved in maintenance of turgor pressure in plant cells and provides a medium within the plant in which chemical, biochemical and other life supporting reactions occur.

The available growing season is partly determined by the duration of an assured water supply. The major task of water management is, therefore, to ensure maximal supply and efficient use of water in the field (Hillel, 1972).

Since not all soil water is used by plants, consideration is given to available water supply and crop water requirements. The available soil water range in a given soil system lies between matric suctions of 0.1 bar (pf 2) and 15 bar (pf 4.2) and can be defined as the range of adequate soil moisture to meet the evaporative demand and to maximize crop yield per unit of water use (Jamison, 1956).

Availability of soil water to plants depends on the water balance concept (Hanks and Rasmussen, 1982), considering the soil-plant-atmosphere continuum during the entire period of crop growth. The soil water regime and prevailing evaporative demand largely influence the plant water status of the canopy.

2.4.1 Factors influencing soil water availability to plants

Jamison (1956) listed the following plant, climatic and soil factors as being involved in determining soil water availability.

Plant Factors

Rooting depth and ramification determines soil volume explored by plant roots. Stage of plant growth and kind of plant influence the root type, extent of penetration and ramification.

Climatic Factors

Soil-air-temperature affects evaporation. On cold nights, moist vapour moves from warm subsoil layers and condenses in the colder soil surface where it is usually lost by evaporation especially during the warm and dry days.

Humidity and fog complement the available soil moisture in maintaining plant growth. This is usually the case at high humidities when plants absorb moisture through their leaves.

Temperature, wind and humidity work through influencing evapotranspiration. At low humidities on hot windy days, available moisture is lowered and plants may wilt even though available soil moisture in the soil is high.

Freezing lowers available moisture through injury of plant tissues when soil freezes.

Soil Factors

Texture, compaction, stratification and depth of wetting influence soil moisture tension and osmotic potential. High soil moisture tension and osmotic potential lower available moisture and may even lead to soil moisture stress. More water is withdrawn at lower suctions in sandy than in clayey soils. The osmotic potential is also influenced by the salt content of the soil and the range of available moisture decreases the higher the salt content in the soil. Compaction and stratification usually impede water movement and so affect its availability. Very fine textures are particularly important in impeding water flow.

Other factors

These are indirect factors which work through their influence on root ramification, root depth and lateral root spread. Included in this category, are stand thickness, soil aeration, soil fertility and depth of water table.

The index of measuring crop water requirements, hence use is evapotranspiration (Eta). Evapotranspiration is dictated by climatic factors notably incident solar radiation, advected heat, relative humidity, wind movement (Hillel, 1972) and temperature of the air (Shaw, 1977) while the proportion of plant cover affects the relative magnitude of evapotranspiration (Peters,1960).

2.4.2 Effects of water stress on plants

The response of crop growth to water deficits has been investigated with a wide range of techniques (Hsiao, 1973).

In general, as water deficits increase in the soil, leaf water potentials decline, leading to closure of stomata, visible wilting and dramatic impairment of many metabolic functions. Prolonged deficits can result in retardation of growth, reduction in yield and even death of the plants.

When water requirements of a crop are not met by water supply, actual evapotranspiration will fall below maximum evapotranspiration (ETm). This in turn causes water stress in the plant and adversely affects crop growth and ultimately crop yield. Doorenbos et al. (1979) developed the following relationship for this situation.

$$(1-Ya/Ym) = Ky(1-ETa/ETm) \qquad (1)$$

Where (1 - Ya/Ym) is the relative yield depression Ya, Ym are actual and maximum yields over a given period respectively. Ky is the crop response factor to water deficit and varies with crop growth stage. (1 - ETa/ETm) is the relative water deficit.

The extent of damage due to water stress depends on the growth stage of a plant when stress is induced and the severity of the stress. Too severe a stress may cause the plants to permanently wilt and die. Downey (1971b) outlines the following as water stress effects on maize growth: stunted growth, reduction in light absorption, ground cover, relative turgidity and both dry matter and grain yield.

Water deficits at anthesis followed by the early ear and vegetative stages in that order are most damaging to maize grain yields (Denmead and Shaw, 1960; Barnes and Woolley 1969). According to Vaadia et al. (1961) moisture stress interrupts photosynthesis and checks growth until turgor is restored by removal of stress. Plant water deficits before and during anthesis reduce the number of developed kernels while kernel weight reduces due to stress after pollination. The overall effect is a general reduction in the economic yield. However, too much water is equally damaging and reduces yields too (Lal and Taylor, 1969).

2.5 Plant interactions in crop mixtures

When different plant species are grown on the same piece of land, interactions in resource use are inevitable. These, according to Young (1987) can be competitive as Neumann and Pietrowicz (1987), Kang (1987) and Reshd et al. (1987) found for light, Gaertner (1964) found for water or they can be mutually beneficial such as nitrogen fixation, and nutrient retrieval by tree roots to crops (Jaiyebo and More, 1964) including mycorrhiza (Maronek et al., 1981).

Ofori and Stern (1987) refered to differences in root systems, depth of rooting, lateral root spread and root density as influencing water competition and use of different parts of the soil profile by root systems of different plant species.

Huxley (1983), observed that a continuity of plant cover offers a continued ability to utilize incoming solar radiation which might otherwise be lost by seasonally sown plants, the capacity to enrich the microsite by depositing litter in the top soil and the capacity to modify the microclimate include characteristics which are environmentally beneficial. Offsetting these are strong plant competitive attributes such as shading of understorey plants and domination of water economy.

This is in agreement with Cole and Newton's (1986) report that competition for resources among intercrops is a factor that affects yields of crops in a cropland and Francis's (1989) observation that efficient resource utilisation by plants leads to increased yields and improved land productivity.

Moreover, intercrops may be more efficient in exploring a larger total soil volume if component crops have different rooting characteristics, especially rooting depth. A deep rooted component crop may be forced to develop even deeper roots if grown together with a shallow rooted crop (Whittington and O'brien, 1968). Roots of the intercrop may grow in the same region and thus anchor the intercrops and reduce lodging (Francis et al., 1978).

2.6 Agroforestry and soil water

In agroforestry, it is traditional to prune the shrub or tree species to prevent them from shading the non tree component. The prunings are then incorporated into the soil. Such an activity has resulted in higher moisture contents in the treated plots. An overall improvement in soil moisture retention was reported by Lawson and Kang (1990) as a result of hedgerows and organic residue mulch. Budelman (1989) attributed the higher moisture retention to leaf mulches which act through reduction of soil temperatures.

Lal (1989) concluded that higher water contents in the top soil layer in *L. leucocephala* plots was due to shading and low evaporation from the soil. Potential evapotranspiration was lowered by shading from trees (Neumann and Pietrowicz, 1987). Kang et al. (1985)

observed that prunings applied to soil resulted in higher soil water retention and that water depletion increased with advancing period from planting. L. leucocephala and maize were found to have different major moisture depletion zones being between zero to thirty and sixty to ninety centimetres depth for maize and leucaena, respectively, (Kang et al., 1981).

Chirwa (1991) conducted a study to assess soil moisture depletion pattern in relation to alley cropped maize growth. He found out that fertilized alley maize depletes more water than unfertilized alley maize and that leucaena plots had lower moisture depletion and more soil water compared to maize. This may be due to the fact that fertilization optimizes plant growth and resource use.

2.7 Agroforestry and grain yield

Agricultural grain crops grown in association with tree species more often than not yield higher than their sole cropped counterparts. Swaminathan (1987) observed yield increase when L. leucocephala was planted as a wind break for maize. An average maize grain yield of 2.0 t/ha per year was maintained when leucaena prunings were retained in alleys without any extra input of chemical fertilizer according to a review of alley farming by Kang et al. (1990). Such type of yields were attributed to prunings which were applied to plots (Gichuru and Kang, 1989). Triplett (1962) observed that maize yields in continuous cropping could be increased to a maximum when supplementation with nitrogen is done.

Density of tree species also plays a major role in influencing grain yields. When they compared the productivity of alley and sole cropped maize, Reshd et al. (1987) found higher yields in alley cropped maize at higher leucaena planting densities. Maize grain yield increases of 38% of sole maize and 104% of alley cropped maize were observed when prunings were added to the plots (Mulongoy and Sanginga, 1990).

Mulongoy and Sanginga (1990) suspected competition between leucaena and maize when sole maize yielded 31% higher than alley maize. Earlier, Lal (1989) noted a maize yield reduction of 10% between leucaena rows spaced at two and four metres. He suspected shading which caused stunted growth and death of young maize seedlings. However, in their recent study Lawson and Kang (1990) confirmed that hedgerow pruning at 60 cm after planting kept maize plants relatively shade free.

Although maize responds favourably to added <u>leucaena</u> prunings, the efficiency of use of nitrogen from the same prunings is very low. Mulongoy and Sanginga (1990) found only 3.2% to 9.4% of nitrogen released during decomposition of the prunings was used by maize plants. Earlier, Kang <u>et al</u>. (1981) proposed that low efficiencies were due to rapid decomposition of <u>leucaena</u> leaves and possible leaching while Mulongoy and Sanginga (1990) found 56.9% of added N in prunings recovered in trees or lost through leaching and volatilisation and 33.6% retained in soil organic matter.

3 MATERIALS AND METHODS

3.1 Location

The research was conducted at the SADDC/ICRAF Zonal Research Project at Chalimbana Agricultural Research Station situated at approximately 20 Km East of Lusaka and along the Great East Road. The station lies at an altitude of 1143 meters above sea level, 15°21'32" South and 28°29'56" East.

This region is charecterised by a continental type of climate. Three distinct seasons, namely, a wet, a cool-and-dry and a hot-and-dry season can be distinguished. The rainfall system is unimodal being received between November and April.

Annual rainfall for the area is 883 mm based on a 15 year climatic record for the International Airport which is about 4 Km (Chinene, 1988) north of the station. Rainfall measurements at the station started in 1987 and annual averages of 568, 684 and 1 000 mm have been recorded (Kamara and Mateke, 1989) giving an average of 751 mm for this period.

Temperature measurements have not yet started but for the three years 1987, 1988 and 1989, the average maximum and average minimum temperatures were 27.7°C and 15.0°C (Kamara and Mateke, 1989). The weather conditions for the current (1990/1991) season are shown in Appendix 2 and are based on the UNZA Farm agrometeorological station situated about 2.5 km in the Southwestern direction.

Soils are formed on the quartz muscovite schist parent material and belong to the Katanga geological system in an ustic[1] moisture regime. They are sand veldts with slightly acid to alkaline reaction (Kamara and Mateke, 1989) and have been classified as Luvisol-phaezem (FAO/UNESCO, 1974) or Alfisols (USDA, Soil Conservation Service, 1975). Appendix 3 shows some characteristics of a representative soil profile.

3.2 Design

The overall experiment was a factorial in a split plot arrangement with three replications. It comprised of three multipurpose tree species: L. leucocephala - S1, Flemingia congesta - S2 and Sesbania sesban - S3 at pruning heights of 50 cm (C1) and 100 cm (C2). Two fertilizer rates, Zero

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[1] An ustic moisture regime is one where for 90 cumulative days, all parts of the moisture control section are dry unless they are influenced by a water table.

fertilizer - F0 and 200 kg/ha of diammonium phosphate (DAP[1]) as basal plus 150 kg/ha of Urea[2] as top - F1 were applied. Two control plots, fertilized control - CF1 and unfertilized control - CF0 were also employed. The combination of these treatments, the layout of experiment and the arrangement of the hedgerows are shown in Appendices 4 and 5.

Only two treatment combinations (S1C1F1 and S1C1F0) of L. leucocephala and the two controls (CF1 and CF0) were considered for this study. These were designated leucaena treatments and no-leucaena treatments and were taken as:

1. L. leucocephala with commercial rates of inorganic fertilizer application (LL+F1)
2. L. leucocephala without any fertilization (LL+F0)
3. A no-leucaena treatment with commercial rate of inorganic fertilization (NL+F1)
4. A no-leucaena treatment without any fertilizer application (NL+F0)

Of all the 12 maize rows, only three rows constituted a sampling unit. A three way cross maize (Zea mays L.) hybrid variety (MM 603) was planted on 02-01-1991 at 75 cm inter-row and 20 cm intra-row spacing. The first maize row

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Means diammonium phosphate with 46% P_2O_5.

[2] Contains 46% elemental nitrogen.

was 87.5 cm from the centre (62.5 cm from the edge) of the double hedgerow.

Fertilizers were applied as basal dressing at 200 kg DAP/ha and top dressing at 150 kg Urea/ha to fertilized *leucaena* and fertilized no-*leucaena* treatment plots. Plots with the tree shrubs received the prunings as mulch in addition. The first prunings were incorporated into the soil during land preparation. No-*leucaena* treatments were a simulation of a traditional maize monocrop field.

3.3 Field activities and management of the hedgerows

Appendix 6 shows, chronologically, major activities which were carried out in the plots. *Leucaena* hedgerows were established in 1987 at four metre inter-row and 50 cm intra-row spacing. Shrubs were periodically pruned to maintain a 50 cm height and prunings spread on the soil in their respective plots. Amounts of total nitrogen from *leucaena* fresh leaves and twigs added to the plots in the trial are shown in Appendix 6.

Planting of maize was dalayed due to late onset of the rains. Under normal seasons planting is expected to be completed before January.

3.4 Data collected

Data as soil moisture and plant parameters were collected in each row for the three rows nearest to the hedgerow. Soil textural classification, soil horizons identification and soil classification were done by Kamara and Mateke (1989).

Weekly neutron probe count rates were taken as data of environment below ground (in maize and hedgerows) which were converted to volumetric soil water contents (θ_v) with the help of a calibration curve and bulk density (Γb) (Appendix 3) determined for this purpose.

The neutron probe, a troxler, model 3330 was used for taking count rates in access tubes. Mercury manometer tensiometers were constructed and used for data collection for soil characterisation.

Plant parameters included weekly plant heights, weekly leaf areas, plant counts at maturity, position of secondary cob above ground, dry matter yield, empty cob yield and grain yield. Harvest index was computed as the ratio of grain to dry matter yield. Leaf area was measured with a portable leaf area meter (model 3000A) and a belt conveyer (model

3050A/4).

Plant height, leaf area and position of the secondary cob above ground were taken as an average of four randomly selected plants in each row. Plants within 50 cm distance from the edge of the row were excluded. Only the plants in the central four meter portion of each row were considered. The four meter portion of each row was then divided into what were called sections, each being one meter long. Each section was given a random number. Plants found in each section were also numbered fron south northwards in ascending order.

Four small card boxes were used to symbolise the sections and were given the same numbers as the sections. Each box was filled with nicely cut (2 cm X 2 cm) papers bearing the same numbers as those of the plants in the sections. Each box was agitated before only a piece of paper could be picked from it. The number on the paper so picked indicated the position of the plant to consider for data collection. This exercise was repeated for other rows in each plot.

Harvesting was done on 23-01-1991 in the three rows of maize nearest to the hedgerow discarding two plants at the end of each row. This is an area equivalent of 7.13 m^2 per row. Dry matter was total weight of maize plant above the ground. Empty cob yield refered to weight of cobs devoid of grain. Grain yield was the weight resulting from sun drying and shelling. Dry matter and empty cob yields were also on dry weight basis.

3.5 Installation of access tubes

Three sets of 5.1 cm diameter aluminium access tubes were installed to a depth of 120 cm using a mechanical auger. All tubes were sealed at the bottom before installation and covered on top after installation. A 20 cm portion of the tube was allowed to remain above the soil surface. The installation of access tubes was for the purpose of calibrating the neutron probe, determination of unsaturated hydraulic conductivity of the soil and for actual count rate readings in the plots.

One tube was sunk at the centre of a 5 m X 5 m levelled plot, with a ridge of 15 cm high around, for both the calibration of the probe and characterisation of the soil. Other access tubes were sunk in three maize rows and the double hedgerow in leucaena treatment plots and one access tube in the third row in the no-leucaena treatment.

3.6 Installation of tensiometers

Tensiometers were installed for the purpose of soil characterisation and were placed 50 cm from the access tube. Installation depths were 15, 30, 45, 60, 75 and 90 cm.

3.7 Calibration of the neutron moisture meter

The Americium-Berilium probe was calibrated at the site of the experiment in the field (Section 3.5). The exercise required simultaneous neutron probe count rate readings and gravimetric water content (θ_g) determination in space at 15 cm intervals to a depth of 90 cm. Determinations were done eight times; four times up to 15 cm depth and four between 15 and 90 cm depths according to the soil horizons, that is, twice during the dry period and twice during the wet period following heavy downpours for a particular depth.

Gravimetric moisture contents were converted to volumetric moisture contents by multiplying with bulk densities (Γb, g/cm^3) of respective depths using the following relationship.

$$\theta_v = \theta_g \times \Gamma b \ (\%, cm^3/100cm^3) \qquad (2)$$

A regression analysis whose relationship is shown in the equation below and in Figure 3.7 was determined.

Y[1] $= 0.00286 + 0.0081x$

Y is NMM count rate and x is volumetric (%) water content.

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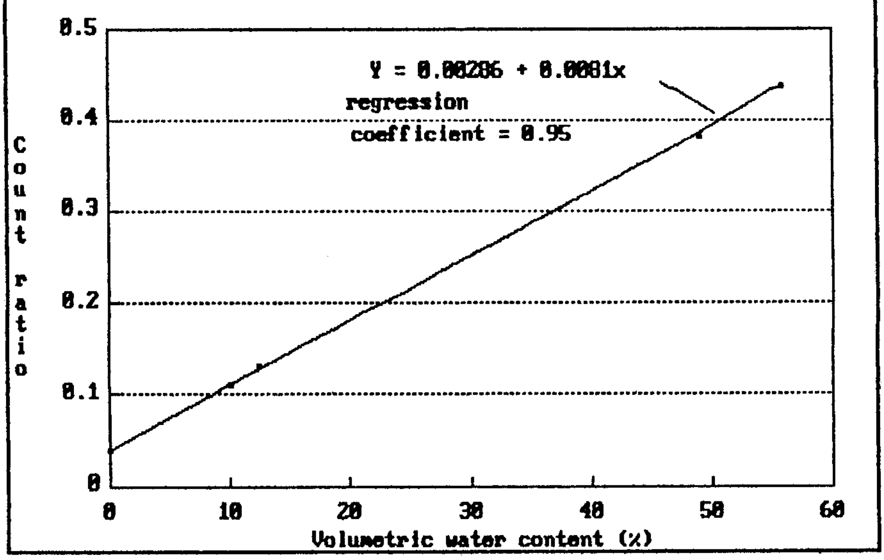
[1] $r^2 = 0.95$

Figure 3.7. Neutron probe calibration curve for Chalimbana soils.



3.8. Soil characterisation (K(θ) Determination)

The internal drainage method was used. The exercise was done in the dry season and needed ponding the 5 m X 5 m plot with subsequent covering with a polyethylene material to prevent evaporation. Tensiometer and neutron probe readings which were used in the calculation of K(θ) were taken at the same time to the same depth yielding the following data.

3.8.1 Tensiometer data

From these data the soil moisture suction (h) was estimated by the following relationship.

$$-h = -Z + Y - 12.6X \quad (4)$$

where

h = matric potential of the soil in cm

X = mercury height (cm) in the tensiometer

Z = depth (cm) of tensiometer installation below the reference (ground) level

Y = fixed distance (cm) from the reference level to the mercury reservoir

Total head (-H) was obtained using the following relationship below.

$$-H = -h + (-Z) \qquad (5)$$

(-H) was then plotted against Z in order to obtain the hydraulic gradient ($\delta H/\delta Z$).

3.8.2 Neutron probe data

The Neutron probe readings were transformed into moisture data using the calibration curve in Figure 3.7.

To compute the soil water stock (S) accumulated over a given period of time, soil water was intergrated over depth as shown below.

$$S = \int \theta \delta Z \quad \text{(in dimensions of length)} \qquad (6)$$

where S is soil moisture stock; θ is volumetric soil water content at depth Z.

Then this was plotted against time on the graph for different depths for obtaining the rate of change of soil moisture stock ($\delta S/\delta t$, an equivalent of flux q_z)

$$q_z = \delta/\delta t \int \theta \delta Z \qquad (7)$$

where q_z is soil moisture flux at depth Z.

$K(\theta)$ was calculated by the re-arrangement of the Darcy equation below as given by Hillel (1980a)

$$q_z = k(\theta)(\delta H/\delta Z) \qquad (8)$$

$$\text{therefore } K(\theta) = q_z/(\delta H/\delta Z) \qquad (9)$$

Plotting the natural logarithm of $K\theta$ against volumetric water contents yielded the following relationship

$$\text{Ln}K\theta = 68\theta - 23.1 \text{ (mm/day)} \qquad (10)$$ [1]

3.9 Determination of actual evapotranspiration

Actual evapotranspiration was determined weekly in the maize and hedgerow. The following steps were employed:

1. Determination of H through use of the potential of free energy (pf) curve. First θ_v values were used to obtain h, which was used as in equation 5.
2. H, Z and θ_v were plotted on one graph. The H/Z relationship was used to compute hydraulic conductivity at the depth of determination of actual evapotranspiration.
3. The rate of change of soil moisture stock (δS) was calculated from equation 7.

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[1] $r^2 = 0.82$

4. The water balance equation (Hillel, 1980b) below was then used.

$$Pe + R_I + H_I + G = D + R_0 + H_0 \pm \delta S + ETa \quad (11)$$

Where R, H and G are run off, subsurface and ground water and subscripts I and O meaning inflow and outflow respectively. S is soil moisture stock, ETa is evapotranspiration, D is drainage.

On a flat land R and H, are negligible and consequently the water balance equation reduces to what Hanks and Rasmussen (1982) gave for measurement of evapotranspiration

$$Pe + G = D + ETa \pm \delta S \quad (12)$$

G and D are merely opposite water movement directions and can both be described by the Darcy equation.

Therefore $$ETa = Pe + q \pm \delta S \quad (13)$$

The depth of calculation of actual evapotranspiration was conveniently set at 75 cm from the first to the last week of water measurements. This was in accordance with the findings of Foth (1962) on rooting characteristics of maize and position of zero plane of flux[1].

3.10 Construction of potential of free energy (pf) curve

For the construction of the pf curve, eight samples were taken for each pf value determination per horizon to the depth of interest (90 cm). The following procedures were employed in the construction of the pf curve.

Determination of pf 0

For the determination of pf 0, undisturbed soil sample slices of 1 cm height were cautiously placed on a filter paper lying on sand saturated with water in a closed sand bath. Equilibrium was reached after 24 hours. At equilibrium matric potential of the water in the sample is -1 cm which is equal to pf 0. Moisture content in the sample was then determined gravimetrically.

Determination of pf 2, 2.5 and 4.2

Ceramic pressure plates were used. Respective pressures were applied to undisturbed moist soil samples placed on porous plates. Due to this external pressure, some water drained out of the samples. Samples were then taken out

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[1]The zero plane of flux is the depth at which the first derivative of flux is numerically zero.

for gravimetric moisture determination after they attained equilibrium.

Determination of pf 5.5

Determination of pf 5.5 used the principle of vapour pressure method which is based on the relation between total soil moisture potential (suction) and water vapour pressure (relative humidity) of the surrounding atmosphere.

Five grams of air dry soil samples with diameter less or equal to 2 mm were used. Samples were placed over a concentrated salt solution of ammonium chloride in a desiccator and left to equilibrate in not less than seven days. On the seventh day, gravimetric moisture determination was done on soil samples.

At equilibrium a relation existed from which the following equation was derived.

$$pf = 6.502 + \text{Log}(2 - \text{Log } RH) \qquad (15)$$

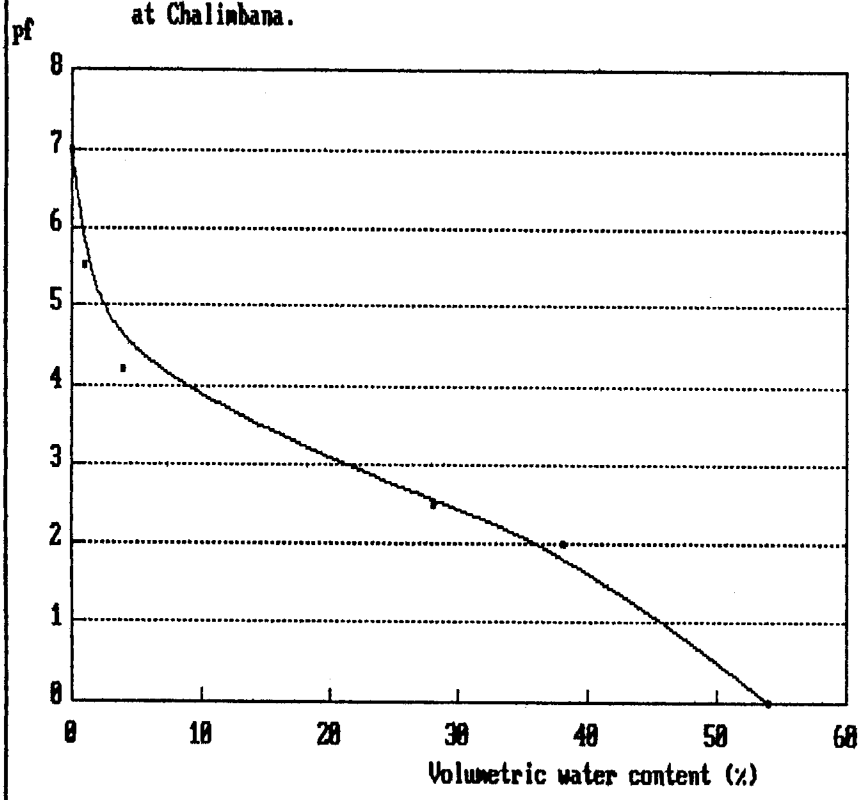
Then all gravimetric moisture contents were converted to volumetric moisture contents as described in section 3.7 and a curve was drawn (Figure 3.10).

3.11 Data analyses

An analysis of variance was done to find any significant differences between factors. A mean separation by Duncan's Multiple Range Test was then carried out to quantify the least significant differences among different means of treatments and rows. A correlation analysis was done among Eta, maize height, leaf area and the yields: grain, empty cob and dry matter.

Analysis of data took into account the fact that there were varying levels of nitrogen from different sources in the plots. These sources were leucaena (prunings and fixation through the roots), inherent soil nitrogen and inorganic chemical applications. Inherent soil nitrogen contribution to all plots was considered uniform so that variation in nitrogen in plots was due to prunings, fixation and chemical applications.

Figure 3.10 Potential of free energy (pf) curve at Chalimbana.



4 RESULTS

4.1 Water distribution in maize/leucaena alley cropping

The differences which existed in water content in treatments were significant at 0.01 level of probability and only in week three at 0.05 probability level. Distribution of water varied tremendously between the different treatments. Generally, soil water content was lowest (11.1 to 27.8%) in unfertilized no-leucaena treatment. During most of the growing season while highest water contents were observed in unfertilized leucaena (17.1 to 28.6%) followed by fertilized leucaena treatment (14.7 to 29.1%). No real differences existed between the two no-leucaena treatments. Therefore, inorganic nitrogen had no marked influence over water distribution (Table 4.1.1).

Results of water distribution in rows were most of the time significantly ($p < 0.01$) highest in the hedgerow (20.0 to 28.9%) followed by row one (14.6 to 27.5%) as Table 4.1.2 shows. Although row two stored more water than row three, significance was not discernible.

Taken as an average of the entire growing season, water content differences in treatments were only significant (p

< 0.05 and $p < 0.01$) at greater than 30 cm depth (Table 4.1.3) and all through the depths in rows ($p < 0.01$)(Table 4.1.4).

The unfertilized no-leucaena treatment had lowest seasonal water contents. Fertilized and unfertilized leucaena treatments had same water contents except at 45 cm when the latter had more water. These results are shown in Table 4.1.3. In the same table, it is evident that fertilized no-leucaena treatment had same water contents as unfertilized no-leucaena treatment except at 45 cm when the former had more ($p < 0.05$). The level of signficance was at 0.01 in deeper layers. This clearly shows that alley cropping influenced the amount of water stored in deeper soil layers. Soil moisture was protected by leucaena hedge.

Water contents were significantly higher ($p < 0.01$) in the double hedgerow than any other row except at 60 cm and 75 cm depth (Table 4.1.4). The following are possible explanations for such an observation:

The natural leaf fall from leucaena served as an extra source of organic matter in the hedgerow and closer maize rows. The effect of this was modification of the micro environment, particularly temperature reduction leading to low evaporation as Budelman (1989) observed.

The shade cast by the hedge in hedgerow and nearby maize rows reduced the amount of energy needed for evaporation.

Equally plausible and important was better rainfall infiltration mediated through mulching effect of litter fall on the soil including more water being trapped by the hedge which acted as a barrier. There also existed the possibility of stem flow in the hedgerow for trapped water.

Table 4.1.1. Weekly volumetric (%) water distribution in maize/leucaena alley cropping in different treatments as means over all depths.

WAE	TREATMENT						
	LL +F1	LL +F0	NL +F1	NL +F0	MEAN	CV(%)	LSD
1	29.1a	28.6a	27.0a	22.8b	26.8	5.20	3.82*
2	28.5a	24.1b	26.0ab	19.3c	24.4	2.23	4.04**
3	25.4b	26.2b	26.0b	27.8a	26.4	1.87	1.33*
4	23.6	23.9	25.6	26.6	24.9	4.91	NS
5	20.6	21.8	22.4	21.5	21.6	6.20	NS
6	17.3	19.5	20.3	18.4	18.9	9.00	NS
7	14.7b	18.8a	14.0bc	13.0c	15.1	2.16	1.23**
8	20.2	21.7	21.7	18.9	20.6	12.81	NS
9	18.7b	21.1a	12.8c	11.7c	16.1	3.92	1.77**
10	15.1	18.5	15.9	14.3	16.0	4.91	NS
11	15.1b	17.1a	11.4c	11.1c	13.7	6.54	1.69**
12	16.2	18.0	18.3	17.4	17.5	9.11	NS
MEAN	20.4	21.6	20.1	18.6	20.2	13.00	NS

WAE refers to weeks after emergence.

Entries followed by a common letter within each row are not significantly different from each other according to Duncan's Multiple Range Test.

LL+F1 refers to fertilized alley maize plots
LL+F0 refers to unfertilized alley maize plots
NL+F1 refers to fertilized sole maize plots
NL+F0 refers to unfatertilized sole maize plots

Table 4.1.2. Weekly volumetric (%) water distribution in maize/leucaena alley cropping in different rows as means over all depths.

WAE	ROW NUMBER						
	HEDGE	1	2	3	MEAN	CV(%)	LSD
1	28.9	27.5	26.6	26.6	27.4	5.20	NS
2	24.5b	24.2b	25.2a	24.1b	24.5	2.23	0.65**
3	27.2a	27.1a	26.0b	25.9b	26.6	1.87	0.59**
4	25.9a	25.9a	24.5ab	24.2b	25.1	4.91	1.46**
5	23.6	22.5	20.9	21.3	22.1	6.20	NS
6	22.2a	19.9b	17.8c	18.9bc	19.7	9.00	1.47**
7	20.0a	16.7b	14.8c	13.9c	16.4	2.16	0.39**
8	25.1	22.1	19.6	20.2	21.8	12.81	NS
9	20.5a	16.9b	15.9c	15.5c	17.2	3.92	0.75**
10	21.1a	17.5b	15.2c	15.2c	17.3	4.91	0.94**
11	21.3a	14.6b	13.4c	13.0c	15.6	6.54	1.07**
12	21.2	18.1	16.8	17.5	18.4	9.11	NS
MEAN	23.5	21.1	19.7	19.7	21.0	5.74	NS

WAE refers to weeks after emergence.

Entries followed by a common letter within each row are not significantly different from each other according to Duncan's Multiple Range Test.

Table 4.1.3. Volumetric (%) water distribution in maize/leucaena alley cropping in different treatments over depth as means over time in weeks.

DEPTH (cm)	TREATMENT						
	LL +F1	LL +F0	NL +F1	NL +F0	MEAN	CV(%)	LSD
15	14.2	14.0	12.8	12.0	13.0	60.30	NS
30	18.3	20.5	19.6	18.3	19.2	33.67	NS
45	21.7bc	23.6a	22.9ab	20.6c	22.2	24.28	1.57*
60	23.5ab	25.2a	22.2bc	20.6c	22.9	21.13	2.78**
75	24.4a	25.6a	23.1ab	20.8b	23.5	17.40	2.64**

Entries followed by a common letter within each row are not significantly different from each other according to Duncan's Multiple Range Test.

LL+F1 refers to fertilized alley maize plots
LL+F0 refers to unfertilized alley maize plots
NL+F1 refers to fertilized sole maize plots
NL+F0 refers to unfatertilized sole maize plots.

Table 4.1.4. Volumetric (%) water distribution in maize/<u>leucaena</u> alley cropping in different rows over depth as means over time in weeks.

DEPTH (cm)	ROW NUMBER						
	HEDGE	1	2	3	MEAN	CV(%)	LSD
15	17.2a	14.0b	12.6b	13.3b	14.3	60.30	2.44**
30	24.1a	20.0b	18.8b	18.7b	20.4	33.67	1.97**
45	26.0a	23.4b	21.6c	21.6c	23.2	24.28	1.64**
60	25.7a	22.3a	22.4b	22.1b	23.1	21.13	1.48**
75	24.4a	24.5a	23.3ab	22.6b	23.7	17.40	1.25**

Entries followed by a common letter within each row are not significantly different from each other according to Duncan's Multiple Range Test.

4.2 Actual evapotranspiration

Significant differences in water use were observed at 0.01. Water use was the same in the first and fourth weeks. Throughout the period of growth, water use in unfertilized *leucaena* and fertilized no-*leucaena* treatment was the same. Marked differences ($p < 0.01$) in water use existed between fertilized *leucaena* and the rest of the treatments in weeks three and five to ten. The unfertilized no-*leucaena* treatment generally registered lowest water use (Table 4.2.1). Evident from this table is that actual evapotranspiration was influenced by inorganic fertilization and organic matter from prunings.

All treatments attained their highest actual evapotranspirations near the time of maximum leaf area of the maize crop, that is five to eight weeks in fertilized *leucaena*, five to seven weeks in unfertilized *leucaena*, six to seven weeks in fertilized no-*leucaena* treatment and at six weeks in unfertilized no-*leucaena* treatment (Table 4.2.1).

Actual evapotranspirations in different rows are tabulated in Table 4.2.2. Water use was highest ($p < 0.01$) in the hedgerow followed by row two. Row one and row three had the same actual evapotranspiration values. Maximum actual evapotranspiration in rows were registered in week six. These coincided with maximum leaf area.

The pruning date results in Appendix 6 revealed that the maximum actual evapotranspiration values in the hedge were registered just before pruning, an indication of maximum leaf area with maximum actual evapotranspiration. This also meant that moisture contents in the soil were not a limiting factor for actual evapotranspiration except maybe after the eighth week. This is so because even for maize the actual evapotranspiration continued to increase with increasing leaf area (See Figure 4.2). The actual evapotranspiration, however, decreased after the fifth week (Table 4.2.2) despite the large leaf areas for both maize rows and <u>leucaena</u>. The high actual evapotranspiration in the hedgerow at weeks two and six were registered barely a day before pruning. The low value of actual evapotranspiration in the hedgerow at week nine was recorded on the same day that pruning was done.

The response of maize to soil water content revealed that higher water use values existed in plots where there was sufficient soil water, hence maize developed the largest leaves.

Table 4.2.1. Actual evapotranspiration (mm) in maize/leucaena alley cropping in treatments in weeks.

WAE	TREATMENTS						
	LL+F1	LL+F0	NL +F1	NL +F0	MEAN	CV(%)	LSD
1	1.3op	1.2opq	1.3op	1.4o	1.3	2.8	0.2**
2	2.5l	2.5l	2.1m	1.9n	2.3	2.8	0.2**
3	3.2k	3.7hi	3.8gh	3.9fgh	3.7	2.8	0.2**
4	4.1f	4.0fg	3.9fgh	4.0fg	4.0	2.8	0.2**
5	5.5b	4.7cd	4.5de	4.1f	4.7	2.8	0.2**
6	6.9a	4.9c	4.9c	4.9c	5.4	2.8	0.2**
7	5.7b	4.9c	4.9c	4.1f	4.9	2.8	0.2**
8	5.7b	4.4e	4.5de	3.6ij	4.5	2.8	0.2**
9	3.8gh	3.5j	3.4jk	2.5l	3.3	2.8	0.2**
10	1.9n	2.5l	2.4l	1.1pq	2.0	2.8	0.2**
11	1.2opq	1.4o	1.2opq	1.0q	1.2	2.8	0.2**
MEAN	3.8a	3.4b	3.4b	3.0c	3.4	2.8	0.082**

WAE refers to weeks after emergence.

Entries followed by a common letter within each row are not significantly different from each other according to Duncan's Multiple Range Test.

LL+F1 refers to fertilized alley maize plots
LL+F0 refers to unfertilized alley maize plots
NL+F1 refers to fertilized sole maize plots
NL+F0 refers to unfatertilized sole maize plots

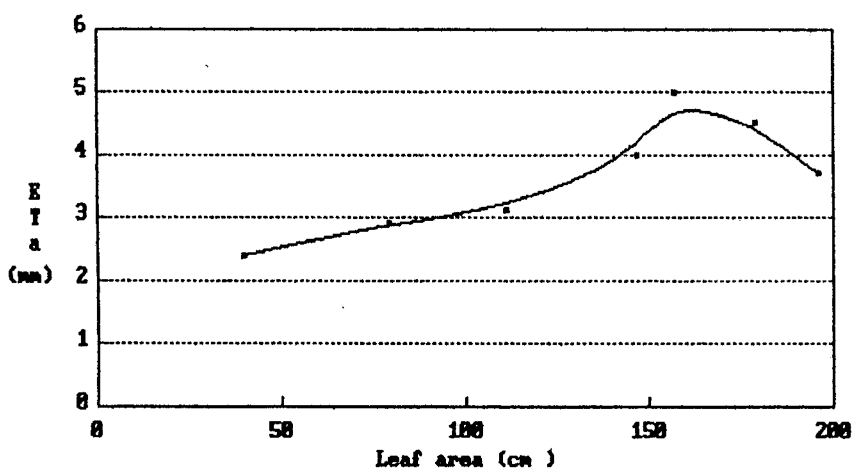
Table 4.2.2. Actual evapotranspiration (mm) in maize/<u>leucaena</u> alley cropping in rows in weeks.

WAE	ROW NUMBER						
	HEDGE	1	2	3	MEAN	CV(%)	LSD
1	5.5a	1.4pq	1.5p	1.3pq	2.4	3.1	0.11**
2	5.5a	2.0o	2.1no	2.0o	2.9	3.1	0.11**
3	4.5c	2.8l	2.8l	2.5m	3.1	3.1	0.11**
4	5.5a	3.0kl	4.1ef	3.3ij	4.0	3.1	0.11**
5	5.7a	4.3cde	5.7a	4.4cd	5.0	3.1	0.11**
6	5.7a	4.3cde	5.7a	4.4cd	5.0	3.1	0.11**
7	5.7a	3.7gh	4.8b	3.8g	4.5	3.1	0.11**
8	4.3cde	3.3ij	3.9fg	3.3i	3.7	3.1	0.11**
9	4.2de	3.1jk	3.5hi	3.4i	3.6	3.1	0.11**
10	4.4c	1.2q	2.3mn	1.2q	2.3	3.1	0.11**
11	4.1ef	0.5r	0.7r	0.7r	1.5	3.1	0.11**
MEAN	5.0a	2.7c	3.4b	2.8c	3.5	3.1	0.087**

WAE refers to weeks after emergence.

Entries followed by a common letter within each row are not significantly different from each other according to Duncan's Multiple Range Test.

Figure 4.2. Relationship between actual evapotranspiration (mm) and leaf area (cm) in maize rows.



4.3 Morphological features

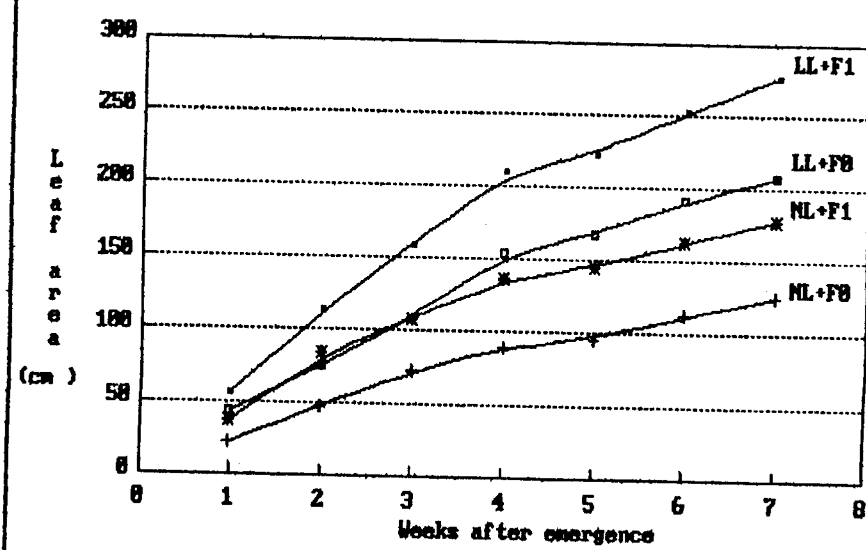
The results for the entire growing period of maize and at maximum morphological growth are reported for which a growth curve was developed for both the treatments and distance from the double hedgerow.

Leaf area

The results for the entire growing period are shown in Table 3a. All the leaf areas were different between fertilized and unfertilized leucaena treatments, being larger in the former all through the growing season except for week one and week two. Leaf areas in unfertilized leucaena treatment and fertilized no-leucaena treatment were throughout the growing period the same although the latter had generally smaller leaves. Unfertilized no-leucaena treatment produced the smallest leaf areas. Figure 4.3a also shows the results.

Leaf areas in rows two and three were the same except in week one when maize in row two had highly significant lower leaf area. Row one plants had smallest leaf area. Week three was the only time when the leaf areas in row one and row two were the same. Week two showed no differences in leaf areas in rows (Table 3b and Figure 4.3b).

Figure 4.3a. Individual plant leaf areas (cm) in treatments over time.



At maximum morphological growth, leaf areas in treatments were different at 0.01 (Table 3c and Figure 4.3c). Treatments involving leucaena had larger areas although the areas in unfertilized leucaena treatment were the same as those in fertilized no-leucaena treatments. The unfertilized no-leucaena treatment had smallest leaf areas which differed significantly from the rest. This represented a leaf area increase of 121%, 66% and 42% in fertilized leucaena, unfertilized leucaena and fertilized no-leucaena treatments, respectively over the unfertilized no-leucaena treatment.

Smallest leaf areas were also observed in row one as shown in Figure 4.3d. Means in row two and three differed significantly ($p < 0.01$) from those in row one. This was equivalent to 17% and 24% leaf area increase in row two and row three, respectively, over row one. No differences existed between row two and row three (Table 3d).

The influence of nitrogen over leaf growth was irrespective of the nitrogen source. Alley cropping alone had no advantage over fertilizer as there were no differences in leaf area in alley cropping of unfertilized leucaena and fertilized no-leucaena treatment. Supplementation of alley cropping with inorganic nitrogen enhanced leaf expansion.

Table 4.3a. Individual plant leaf areas (cm^2) in maize/<u>leucaena</u> alley cropping in different treatments over time in weeks.

WAE	TREATMENTS						
	LL +F1	LL +F0	NL F1	NL F0	MEAN	CV(%)	LSD
1	55.8a	43.4ab	37.2bc	22.3c	39.7	8.53	17.11*
2	112.9a	74.6ab	82.8ab	47.2b	79.4	17.84	41.18**
3	158.2a	107.6b	107.2b	72.3b	113.3	18.91	41.25**
4	209.0a	153.5b	136.2b	88.6b	146.8	8.82	23.38**
5	221.5a	167.1b	144.0b	94.9c	156.9	8.33	31.93**
6	251.8a	190.5b	162.1b	111.4c	178.9	4.62	29.71**
7	275.8a	207.0b	177.0bc	124.8c	196.1	5.23	42.56**

WAE refers to weeks after emergence.

Entries followed by a common letter within each row are not significantly different from each other according to Duncan's Multiple Range Test.

LL+F1 refers to fertilized alley maize plots
LL+F0 refers to unfertilized alley maize plots
NL+F1 refers to fertilized sole maize plots
NL+F0 refers to unfatertilized sole maize plots

Table 4.3b. Individual plant leaf areas (cm^2) in maize/leucaena alley cropping in different rows over time in weeks.

WAE	ROW NUMBER					
	1	2	3	MEAN	CV(%)	LSD
1	32.2c	39.7b	47.2a	39.7	8.53	4.04**
2	76.5	79.8	81.8	79.4	17.84	NS
3	99.8b	108.7ab	125.5a	111.3	18.91	18.22*
4	133.9b	152.1a	154.5a	146.8	8.82	15.43**
5	141.9b	166.2a	162.5a	156.8	8.33	15.59**
6	159.3b	186.0a	191.5a	178.9	4.62	9.86**
7	172.4b	201.9a	214.1a	196.1	5.23	12.22**

WAE refers to weeks after emergence.

Entries followed by a common letter within each row are not significantly different from each other according to Duncan's Multiple range Test.

Figure 4.3b. Individual plant leaf areas (cm) in rows over time.

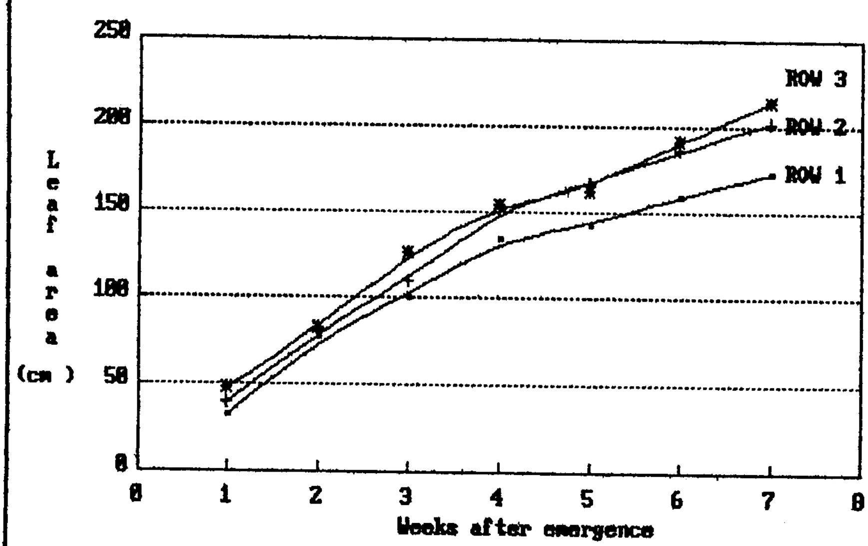


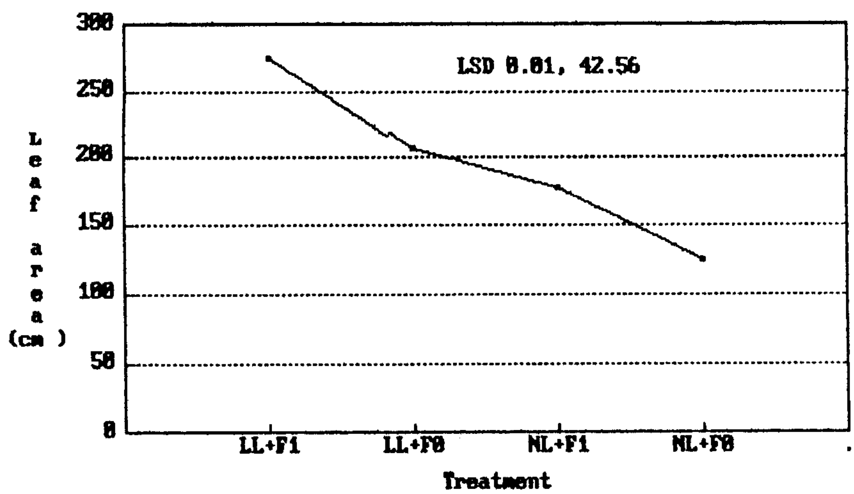
Table 4.3c. Leaf area (cm^2), position of cob above ground (cm) and reproductive growth parameters of maize in maize/<u>leucaena</u> alley cropping in different treatments.

PARAMETER	TREATMENT						
	LL +F1	LL +F0	NL +F1	NL +F0	MEAN	CV(%)	LSD
Leaf area (cm^2)	275.8a	207.0b	177.0b	124.8c	196.2	5.23	42.56**
Cob position above ground (cm)	68.1a	42.8bc	49.0ab	29.0c	47.2	15.90	19.32**
Days to 50% tasseling	61.4c	68.6ab	67.6b	69.0a	66.7	2.51	1.42**
Days to 100% tasseling	72.8b	81.2a	78.8a	80.2a	78.3	3.41	4.69*
Days to 50% silking	68.7b	78.8a	7.6a	82.9a	77.0	3.15	7.82**
Days to 100% silking	77.1b	82.6ab	80.3b	86.3a	81.6	1.86	5.54**

Entries followed by a common letter within each row are not significantly different from each other according to Duncan's Multiple Range Test.

LL+F1 refers to fertilized alley maize plots
LL+F0 refers to unfertilized alley maize plots
NL+F1 refers to fertilized sole maize plots
NL+F0 refers to unfatertilized sole maize plots.

Figure 4.3c. Individual plant leaf areas (cm) at maximum morphological growth in treatments.



Data in rows created an impression of competition between maize and *leucaena* for plant growth factors. This competition was stronger in row one and less and less in row two and row three. Conversely, it suggests an overall beneficial effect of alley cropping on the maize in row two and row three.

Plant height

Fertilized *leucaena* treatments had significantly ($p < 0.01$) taller maize plants than any other treatment. Unfertilized no-*leucaena* treatment, fertilized no-*leucaena* treatment and unfertilized *leucaena* showed the same height (Table 4.3e).

Although no differences existed in plant height throughout the growing season in rows, the growth of the plant is shown in Figure 4.3e.

Like leaf area, nitrogen had a profound effect on plant height. Although this parameter was independent of individual sources of nitrogen, the role of *leucaena* in promoting plant height was not as much as that of inorganic fertilizer application. There was no influence by the distance from the hedgerow on this parameter.

Table 4.3d. Leaf area (cm^2) and number of days to 100% tasseling of maize in maize/leucaena alley cropping in different rows.

PARAMETER	ROW NUMBER					
	ROW 1	ROW 2	ROW 3	MEAN	CV(%)	LSD
Leaf area (cm^2)	172.4b	201.9a	214.1a	196.1	5.23	12.22**
Days to 100% tasseling	79.9a	76.8b	78.0ab	78.2	3.41	2.31*

Entries followed by a common letter within each row are not significantly different from each other according to the Duncan's Multiple Range Test.

Figure 4.3d. Individual plant leaf areas (cm^2) at maximum morphological growth in rows.

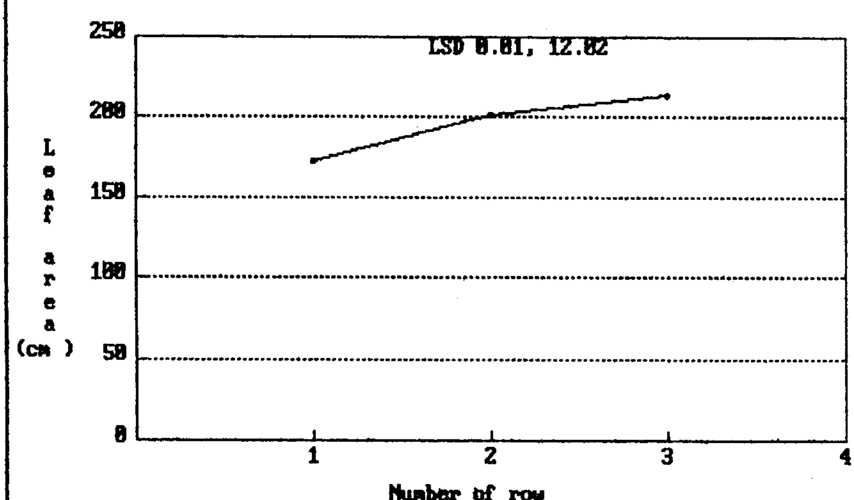


Table 4.3e. Individual plant heights (cm) in maize/leucaena alley cropping treatments over time in weeks.

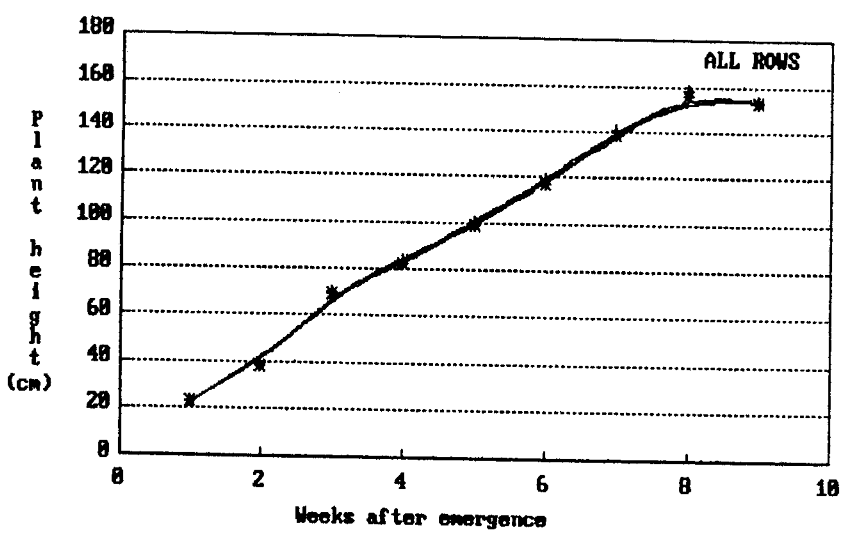
WAE	TREATMENTS						
	LL +F1	LL +F0	NL +F1	NL +F0	MEAN	CV(%)	LSD
1	31.9a	22.3b	20.7b	18.1b	23.0	3.78	4.23**
2	53.5a	35.7b	34.7b	30.3b	38.6	3.68	6.85**
3	97.1a	64.2b	62.4b	54.3b	69.5	3.30	14.74**
4	117.3a	66.0b	75.7b	73.9b	82.2	3.37	16.2**
5	140.7a	88.8b	90.8b	79.5b	100.0	2.98	19.59**
6	167.4a	105.2b	107.3b	94.6b	118.6	3.05	24.78**
7	197.5a	124.1b	126.5b	111.8b	140.0	3.04	29.30**
8	225.2a	138.8b	141.3b	123.3b	157.2	3.03	33.59**
9	218.6a	135.6b	138.2b	120.1b	153.1	3.94	25.34**

WAE refers to weeks after emergence.

Entries followed by a common letter within each row are not significantly different from each other according to Duncan's Multiple Range Test.

LL+F1 refers to fertilized alley maize plots
LL+F0 refers to unfertilized alley maize plots
NL+F1 refers to fertilized sole maize plots
NL+F0 refers to unfatertilized sole maize plots.

Figure 4.3e. Individual plant heights (cm) in rows over time.



Position (cm) of secondary cob above ground level

The distance of the maize row from the hedge had no effect on the position of the cob above ground. Similarly, the organic source of fertilization had no influence over secondary cob position above ground.

A highly significant ($p < 0.01$) difference in position of secondary cob above ground level among treatments existed (See Table 3c). Maize in fertilized *leucaena* treatments had higher positions than in unfertilized *leucaena* treatment and unfertilized no-*leucaena* treatment. Fertilized no-*leucaena* treatment behaved just the same as unfertilized *leucaena* treatment and fertilized *leucaena* treatment. In magnitude of descending order in fertilized *leucaena*, fertilized no-*leucaena* treatment and unfertilized *leucaena*, these positions represent a rise of 135%, 69% and 48% over the unfertilized no-*leucaena* treatment.

The effect of nitrogen from inorganic source was to raise the position of the secondary cob from 40 to 68 cm above ground level (Table 3c).

4.4 Number of harvested plants

No differences ($p < 0.05$) were observed among treatments in the number of harvested plants per hectare. Plant populations at harvest were, however, significantly higher in row two than those in either row one and row three which did not differ from one another (not shown).

The number of plants harvested depended not on the treatment but on the distance of the maize from the hedgerow. Competition for growth factors was therefore suspected. However, the sphere of influence for obtaining benefits from alley cropping was not infinite. Therefore, while there was overall competition in row one and overall beneficial effects in row two, there was a declining influence of the hedge further than 162.5 cm.

4.5 Reproductive growth

Days to 50% tasselling

Fertilized leucaena treatment reached this stage of growth significantly earlier ($p < 0.01$) than any other treatment (Table 3c). No differences existed between fertilized no-leucaena treatment and unfertilized leucaena treatment and between unfertilized no-leucaena treatment and fertilized leucaena treatment (Table 3c).

Days to 100% tasselling

At 100% tasselling, all but fertilized leucaena treatment had higher ($p < 0.05$) number of days to reach this growth stage (Table 3c). The situation in rows was such that tasselling was faster in row two, differing significantly ($p < 0.05$) with row one which was equal to row three. Row three and row two required the same number of days to reach 100% tasselling. Table 3d shows the results.

Days to 50% silking

Time to 50% silking was highly significantly different ($p < 0.01$) in treatments (Table 3c). All but fertilized leucaena treatment required the same number of days to attain 50% silking. Silking in fertilized leucaena treatment was earlier.

Days to 100% silking

The unfertilized no-leucaena treatment and unfertilized leucaena treatment required the same number of days which was significantly ($p < 0.01$) higher than the days needed by both fertilized leucaena treatment and fertilized no-leucaena treatment which behaved similarly (Table 3c). Unfertilized leucaena on the other hand needed the same number of days as the fertilized no-leucaena treatment to attain this growth stage.

Generally, the results showed that reproductive growth attainment by maize in alley cropping was shortened by the application of nitrogen. The application of inorganic nitrogen significantly reduced the days to 50% tasselling and days to 100% silking. 50% silking and 100% tasselling were brought forward only when inorganic nitrogen was applied to leucaena.

The results of the rows led to the conclusion that row one did not have enough nitrogen to promote 100% tasselling while there was high enough nitrogen in row two for the same purpose. The suspected low level of nitrogen might be a result of leaching or denitrification as a result of a lot of water and nitrogen mobility in alley cropping nearer to the hedge. This was one way in which the competition effect could be explained. However, a deliberate study is required for such a statement to be valid.

4.6 Yield

Dry matter production

Fertilized leucaena treatment produced significantly ($p < 0.01$) higher maize dry matter than unfertilized leucaena treatment and unfertilized no-leucaena treatment. Fertilized no-leucaena treatment yielded as much dry matter as fertilized leucaena treatment (Table 4.6a and Figure 4.6a). This means dry matter production improved by 96% by inorganic fertilization alone, 32% by alley cropping alone and 172% by combining leucaena and inorganic fertilization.

In row two, maize produced significantly ($p < 0.05$) higher dry matter than in row one and in row three. Row one and row three dry matter production was the same (Table 4.6b and Figure 4.6b).

Cobs devoid of grain (empty cob yield)

Empty cob yields in unfertilized leucaena and unfertilized no-leucaena treatment were significantly ($p < 0.05$) lower than the fertilized leucaena treatment. Statistically, the yields were the same as those in fertilized no-leucaena treatment. Similarly, fertilized leucaena and fertilized no-leucaena treatment yielded the same (Table 4.6a and Figure 4.6a). It means 174%, 41% and 96% empty cob yield increase over no fertilization of alleys by combining inorganic fertilizer with alley cropping, by leucaena alone, and inorganic fertilizer alone, respectively.

Yields in row two were significantly ($P < 0.05$) higher than those in row one but not significantly higher than those in row three. The yields in row one did, however, not differ from those in row three (Table 4.6b and Figure 4.6b).

Grain yield

The results are presented in Table 4.6a and Figure 4.6a. The yielding ability of maize in fertilized leucaena treatment was significantly ($p < 0.05$) higher than in unfertilized leucaena and in unfertilized no-leucaena treatment but was the same as the yielding ability in the fertilized no-leucaena treatment. The fertilized no-leucaena treatment yield (2.69 t/ha) was higher than the unfertilized no-leucaena treatment (0.80 t/ha) and the same as unfertilized leucaena treatment (1.56 t/ha) yields. On the other hand, the unfertilized leucaena treatment yielded as much as the unfertilized no-leucaena treatment. Alley cropping combined with inorganic fertilization gave a rise in grain yield of 390% compared to 95% and 236% rise due to alley cropping alone and fertilization without alley cropping, respectively.

Table 4.6a. Maize yields (t/ha) in maize/leucaena alley cropping in different treaments.

PARAMETER	TREATMENTS						
	LL +F1	LL +F0	NL +F1	NL +F0	MEAN	CV(%)	LSD
Dry matter	11.19a	5.43b	8.07ab	4.11b	7.20	17.45	4.98*
Empty cobs	0.74a	0.38b	0.53ab	0.27b	0.48	40.74	0.29*
Grain	3.93a	1.56bc	2.69ab	0.80c	2.25	19.77	1.57*

Entries followed by a common letter within each row are not statistically different from each other according to Duncan's Multiple Range Test.

LL+F1 refers to fertilized alley maize plots
LL+F0 refers to unfertilized alley maize plots
NL+F1 refers to fertilized sole maize plots
NL+F0 refers to unfatertilized sole maize plots.

Figure 4.6a. Maize yields (t/ha) in treatments.

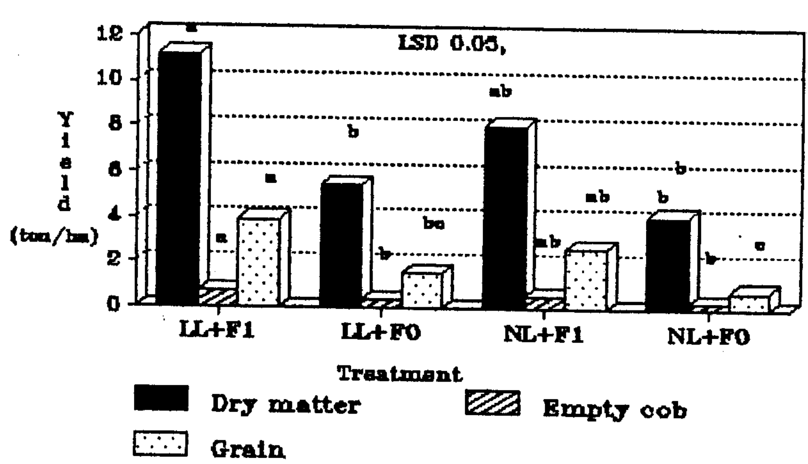


Table 4.6b. Maize yields (t/ha) in maize/<u>leucaena</u> alley cropping in different rows.

PARAMETER	ROWS					
	ROW 1	ROW 2	ROW 3	MEAN	CV(%)	LSD
Dry matter	6.54b	8.21a	6.85b	7.20	17.45	1.09*
Empty cobs	0.41b	0.61a	0.44ab	0.48	40.74	0.17*
Grain	1.99b	2.59a	2.16b	2.25	19.77	0.38*

Entries followed by a common letter within each row are not statistically different from each other according to Duncan's Multiple Range Test.

Figure 4.6b. Maize yields (t/ha) in rows

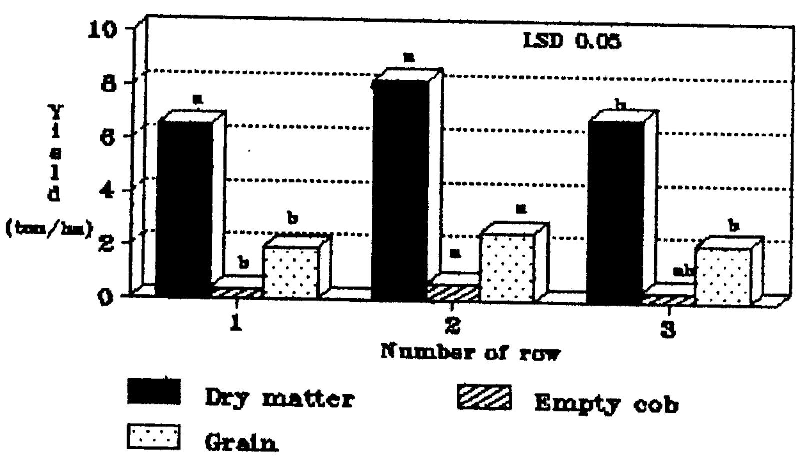


Table 4.6b and Figure 4.6b also show the grain yields of maize in rows. Significantly ($P < 0.05$) higher yields in row two (2.58 t/ha) were observed than in row one (1.99 t/ha) and row three (2.16 t/ha) which statistically had the same yield.

Fertilized leucaena treatment performed exceptionally better than any other treatment whereas unfertilized no-leucaena treatment was the poorest in performance. Unfertilized leucaena treatment and fertilized no-leucaena treatment were intermediate in performance (Table 4.6a). Harvest index reduced from a maximum in fertilized leucaena (0.35) through fertilized no-leucaena (0.33) and unfertilized leucaena (0.29) to a minimum in unfertilized no-leucaena (0.19) treatments.

Accross treatments, maize performance was most superior in row two. Performances in row three and row one were without any significant differences (See Table 4.6b). The harvest index was same (0.32) in rows two and three being higher than in row one (0.30).

Nitrogen application, led to increased production of dry matter, empty cobs and grain. The use of alley cropping and inorganic nitrogen source independent of one another did not improve the dry matter and empty cob production of maize. However, when they were used in combination, they significantly increased dry matter and empty cob yield. Use of inorganic fertilizer alone increases grain yield significantly. Nonetheless, maximum productivity of maize grains could be achieved by combining alley cropping with inorganic nitrogen. In the same way, alley cropping alone could not exclusively be used as a technology for increased food production.

Although the use of nitrogen supports the production of both empty cobs and grain, its use should be encouraged because it favours a higher proportion of grain than empty cob formation.

The yielding ability of maize also depended on how far the plants were from the hedgerow. With respect to dry matter, the crop performed best in row two. The lower yields in row one might be due to competition for resources other than water. The real differences observed in row performance were due to certain unknown factors.

A correlation analysis revealed that actual evapotranspiration and leaf area were significantly ($p < 0.01$) correlated in treatments (Table 4.6c). Significant ($p <$

0.01) correlations also existed between grain yield and dry matter, grain yield and empty cob yield and between dry matter and empty cob yield.

Empty cob yield and actual evapotranspiration were correlated significantly ($p < 0.01$) in rows. Other significant correlations were between dry matter and actual evapotranspiration ($p < 0.05$) and dry matter and empty cob yield ($p < 0.05$). No association existed between maize height and actual evapotranspiration and any other maize parameters namely grain yield, empty cob yield and dry matter yield (Table 4.6d).

Table 4.6c. Correlations of actual evapotranspiration and maize parameters in treatments.

PARAMETER		YIELD (t/ha)			MAIZE	
	Eta (mm)	Grain	DM	Empty cob	Height (cm)	Leaf area (cm^2)
Eta	1					
Grain yield (t/ha)	0.936	1				
Dry matter (t/ha)	0.924	0.998**	1			
Empty cob yield (t/ha)	0.943	0.998**	0.999**	1		
Maize height (cm)	0.906	0.896	0.913	0.919	1	
Maize leaf area (cm^2)	0.990*	0.887	0.878	0.901	0.918	1

*, ** means significanlty correlated at $p < 0.05$ and $p < 0.01$ respectively
Values without an asterict are not significantly correlated.

Table 4.6d. Correlations of actual evapotranspiration and maize parameters in rows.

PARAMETER	Eta (mm)	YIELD (t/ha) Grain	DM	Empty cob	MAIZE Height (cm)	Leaf area (cm^2)
Eta	1					
Grain yield (t/ha)	0.989	1				
Dry matter (t/ha)	0.999*	0.995	1			
Empty cob yield (t/ha)	1.000**	0.990	0.999*	1		
Maize height (cm)	0	0	0	0	1	
Maize leaf area (cm^2)	0.387	0.517	0.426	0.393	0	1

*, ** means significanlty correlated at $p < 0.05$ and $p < 0.01$ respectively
Values without an asterict are not significantly correlated.

5 DISCUSSION

The results for water distribution in weeks are in conformity with the findings of Kang et al. (1985), Budelman (1989) and Lawson and Kang (1990) that organic residue mulch conserves more water in leucaena treatments.

Earlier, Jamison (1956) recognised that climatic factors work through actual evapotranspiration in influencing soil moisture and concluded that the higher the actual evapotranspiration the lower the soil moisture content. Later, Lal (1989) observed that low actual evapotranspiration resulted in high soil water contents in the hedgerows of leucaena.

Current results show higher actual evapotranspirations where shading was obvious (i.e. in hedges) and higher moisture contents where actual evapotranspirations were high. However, the absolute values of actual evapotranspiration in both treatments and rows for maize fall below the range (5 - 9 mm/day) given by Downey (1971a) and Larson and Hanway (1977) at maximum leaf area.

Doorenbos et al. (1979) associated higher actual evapotranspiration values with low relative water deficits hence, higher relative yields. This is in conformity with the current findings with respect to maize rows and treatments in that higher yields were recorded in rows and plots with high actual evapotranspiration values.

Better maize performance in treatments receiving nitrogen was expected. However, better performance of maize in unfertilized leucaena treatment could be attributed partly to fixed nitrogen as Burley (1987), Dommergues (1987) and Mulongoy and Sanginga (1990) reported and partly to nitrogen from prunings as Kang et al. (1981;1985) asserted.

Mulongoy and Sanginga (1990) attributed low nitrogen use efficiency to rapid decomposition of the prunings and leaching while Cole and Newton (1986) deduced that low nitrogen use efficiencies were due to competition among component crops in mixture. Not forgetting the fact that nitrates in the soil are very mobile, the former is in more agreement with the current findings since low yields and small leaf areas were observed in row one. Row one had highest soil water content of all the maize rows. This might have resulted in leaching or denitrification of nitrates in the soil.

Since the leaf areas in row two and row three were not significantly different, it is expected that the two rows would yield equally, all other factors being equal. However, the yield was higher in row two than in row three.

Both the leaf area and days to 100% tasseling data indicated poorest performance in the maize row nearest to the hedgerow. On the other hand, highest water contents were measured in this row. Contrary to water distribution, row one and row three gave low evapotranspiration rates. From this, a conclusion is drawn that poor crop performance was not due to competition for water by maize and leucaena. Chirwa (1991), Ofori and Stern (1987) and Kang et al. (1985) made similar conclusion. The low maize performance was due to other undetermined factors which could have reduced water use by maize nearest to the hedgerow.

Shading which might have caused a reduction in soil temperatures and a decline in root activity might have been responsible. Competition for more available inorganic nitrogen by both species could not be ruled out and high water contents in row one might have caused leaching or decomposition of nitrates in the root zone.

Lal and Taylor (1969) observed that too much water in the root zone reduced crop performance. This ties up well with the current findings of the first maize row performing poorly when it had more water content than any other row. Other researchers (Kang, 1987; Neumann and Pietrowicz, 1987; Reshd et al., 1987; Lal, 1989) have reported that shading of understorey crops may be a crucial factor leading to low crop performance in agroforestry practices. But later Lawson and Kang (1990) established that hedge pruning to 60 cm height is very effective in preventing shading of maize by leucaena. The nature of the crop performance in maize rows depicted in Tables 4.3c and 4.6b upholds the concept of both competitive and beneficial effects of agroforestry reported by Huxley (1983). The competitive effects include shading in row one and domination of water economy in row three. Litter deposition in the top soil in row one is among other beneficial effects of alley cropping.

Although leucaena has the ability of increasing grain yield by as much as 38% of sole maize and 104% of alley maize (Mulongoy and Sanginga, 1990) and 380% of alley maize (Kang et al., 1990), current results indicate that maximum yields can be attained when supplementation with inorganic nitrogen is done.

6 CONCLUSION

The results of the study lead to the following inferences:

1. Organic matter and mulch from prunings of leucaena improves water holding capacity of the soil.
2. The trend of water distribution in alley cropped maize and leucaena is such that the highest water contents exist in the hedgerow and the values decrease with increasing distance from the hedgerow.
3. Although leucaena uses more water than maize, it does not enter into competition with maize for this resource but competition for other resources is likely to exist.
4. Alley cropping is a promising technology in improving food production but only when it is supplemented with inorganic fertilization can it increase maize yields to a higher level.

Being a new technology, agroforestry has a lot of un answered questions. The results of this study raise some specific questions for further studies.

1. How can the light, water and nutrient factors be separated in order to determine the real limiting factor?

2. Will the performance of other maize cultivars and other non legume crops be the same in alley cropping?

To examine the first question deliberate studies using specialised equipment can be carried out. For light in particular, solarimeters or pyranometers can be used to measure radiation in the rows. Should light be found to be a serious limiting factor, shade tolerant cultivars could be developed through breeding.

Water effects can be studied by including different irrigation regimes; while for nitrogen the lima[1] and half lima packages can be incorporated in the study to suit not only `typical' peasant and large scale commercial farmers, but also subsistence, emergent and small scale commercial farmers.

The second question can be answered by including even non hybrid maize cultivars which may include open pollinated and local cultivars to suit the needs of small scale and traditional farmers. The inclusion of other non legume crops is desired in that it carters even for those farmers who do not grow maize. Other cereal crops like millets and

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[1]A package of input recommendations for peasant farmers.

sorghums can be included in future study plans. If this is done, then the whole broadspectrum of SADDC farmers will have been considered.

The results reported here are for one season (1990/1991) on which valid conclusions can not be based without a repeat of the study for more seasons.

REFERENCES

Arnon, I., 1975; Mineral nutrition of Maize, Bern Swizerland. IPI, pp. 3-35.

Barnes, D.L. and Woolley, D.G., 1969; Effects of moisture stress at different stages of growth. 1. Comparison of single-eared and two-eared maize. Agronomy J. Vol. 61, pp. 788-790.

Brewbaker, J.L., 1987; Leucaena; a multipurpose tree genus for tropicalagroforestry. In H.A. Steppler and P.K.R. Nair (eds) Agroforestry: a decade of development, ICRAF, Nairobi. pp. 289-323.

Brewbakek, J.L., 1989; Can there be such a thing as a perfect tree? Agroforestry today V.1, # 4 pp. 4-7.

Budelman, A., 1989; The performance of selected leaf mulches in temperature reduction and moisture conservation in the upper soil stratum. Agroforestry Systems, Vol. 8, pp. 53-66.

Burley, J., 1987; Exploitation of the potential of multipurpose tree shrubs in agroforestry. In H.A. Steppler and P.K.R. Nair (eds) Agroforestry: a decade of development, ICRAF, Nairobi. pp. 273-287.

Chinene, V.R.N.,1988; Detailed soil survey and evaluation of the University farm. Research Branch, Department of agriculture. LUSAKA. 108pp.

Chirwa, P.W., 1991; Soil moisture changes and maize productivity under alley cropping with Leucaena and Flemingia hedgerows in semi-arid conditions in Lusaka, Zambia. M.Sc. Thesis, 112pp. University of Florida, USA.

Cole, E.L. and Newton, M., 1986; Nutrient, moisture and light relations in 5-year old douglas-fir plantations under variable competition. Can. J. For. Res. Vol. 16, # 4, pp. 727-732.

Denmead, O.T. and Shaw, R.H., 1960; Effects of moisture stress at different stages of growth on the development and yield of maize. Agronomy J. Vol. 52. pp. 272-274.

Dommergues, Y.R., 1987; The role of biological nitrogen fixation in agroforestry. In H.A. Steppler and P.K.R. Nair (eds) Agroforestry: a decade of development, ICRAF, Nairobi. pp. 246-271.

Doorenbos, J., Kassam, A.H., Bentsvelsen, C.L., Branscheid,V., Plusje, J.M.G.A., Smith, M., Uittenbogaard, G.O. and Vander Wal, H.K., 1979; Crop response to water. Irrigation and Drainage paper No. 33. 193pp. FAO, Rome.

Downey, L.A., 1971a; Effect of gypsum and drought stress on maize (Zea mays L.). II. Consumptive use of water. Agronomy Journal Vol. 63, pp. 597-600.

Downey, L.A., 1971b; Effect of gypsum and drought stress on maize (Zea mays L.). I. Growth, light absorption and yield. Agronomy Journal Vol. 63, pp. 569-572.

FAO/UNESCO, 1974; Soil map of the World. 1:500 000, Legend. Vol. 1. FAO, Rome. 59pp.

Foth, H.D., 1962; Root and top growth of maize. Agronomy J. Vol, 54, pp. 49-52.

Francis, C.A., Flur, C.A. and Prager, M., 1978; Grain yield variations in Oats associated with differences in leaf area duration among Oatlines. Crop Science, Vol. 18, pp. 760-764.

Francis, C.A., 1989; Biological efficiencies in multiple-cropping systems. In BRADY, N.C. (ed) Advances in Agronomy. Vol. 42, pp. 1-42.

Gaertnar, E.E., 1964; Tree growth in relation to the environment. Botanical review Vol. 30, pp. 393-436. N.Y. Botanical garden.

Galinat, W.C., 1977; The origin of maize. In Sprague (ed), Corn and Corn improvement. Agronomy No. 18. ASA. pp. 1-47.

Gichuru, M.P., and Kang, B.T., 1989; Calliandra calonthysus (meissn.) in alley cropping system with sequentially cropped maize and cowpea in Southwestern Nigeria. Agroforestry Systems. Vol. 9, pp. 191-203.

Hanks, R.J. and Rasmussen, V.P., 1982; Predicting crop production as related to plant water stress. Advances in agronomy, Academic press, Vol. 35, pp. 193-215.

Hillel, D., 1972; Soil moisture control for maximum grass response. The biological utilization of grasses (Younger, V.B. and McKell, C.eds.) pp. 259-270. Academic Press. Newyork, London.

Hillel, D., (1980a); Infiltration and surface runoff. In Applications of of Soil physics, academic press. pp. 5-48.

Hillel, D., (1980b);Water balance and energy in the field. In Applications of Soil Physics, Academic press. pp. 197-215.

Hsiao, T.C., 1973; Plant responses to water stress. Ann. Rev. Plant Physiol. Vol. 24, pp. 519-570.

Huxley, P.A., 1983; Agroforestry: Some comments. In Huxley, P.A. (ed). Plant Research and Agroforestry, ICRAF, Nairobi. pp. 257-270.

Jamison, V.C., 1956; Pertnent factors governing the availability of soil moisture to plants. Soil Science Journal Vol. 81, pp. 459-471.

Jaiyebo, E.O. and A.W. More, 1964; Soil fertility and nutrient storage in different soil vegetation systems in a tropical rain forest environment. Tropical Agriculture (Trinidad), Vol. 41, pp. 129-130.

Kamara, C.S. and Mateke S.M., 1989; Characteristics of the SADDC/ICRAF Zonal Agroforestry project site at Chalimbana. Report No.1. (unpublished).

Kang, B.T., 1987; The development of alley cropping as a promising agroforestry technology. In H.A. Steppler and P.K.R. Nair (eds) Agroforestry a decade of development, ICRAF, Nairobi. pp. 227-243.

Kang, B.T., Wilson, G.F. and Sipkens, L., 1981; Alley cropping maize (Zea mays L.) and (Leucaena leucocephala Lam.) in Southern Nigeria. Plant and soil Vol. 63, pp. 165-176.

Kang, B.T., Grimme, H. and Lawson, L.T., 1985; Alley cropping sequentially cropped maize and cowpea with Leucaena on a sandy soil in southern Nigeria. Plant and Soil, pp. 267-277.

Kang, B.T., Reynolds, L. and N.A. Atta-krah, 1990; Alley farming. Advances in agronomy. Vol. 43, pp. 315-359. Academic press.

Kiesselbach, T.A., 1980; *The structure and reproduction of maize. Nebraska University Press, Linkoln and London. 96pp.*

King, K.F.S., 1987; The history of agroforestry. In H.A. Steppler and P.K.R. Nair (eds) Agroforestry a decade of development, ICRAF, Nairobi. pp. 3-11.

Lal, R., 1989; Agroforestry and soil management of a tropical alfisol: I. Soil moisture and crop yields. Agroforestry Systems, Vol. 8, pp. 7-29.

Lal, R and Taylor, G.S., 1969; Drainage and nutrient effects in field Lysimeter study I. maize yield and soil conditions. Soil Science Journal Vol.33, pp. 937-941.

Larson, W.E. and Hanway, J.J., 1987; Maize production. In Sprague (ed), Corn and Corn improvement. pp. 625-669. Agronomy No. 18. ASA.

Lawson, T.L. and Kang, B.T., 1990; Yield of maize and cowpea in an alley cropping system in relation to available light. Agricultural and forestry meteorology, Vol. 52, pp. 347-357.

Maronek, D.A., Hendrix, J.W. and Kiernan, J., 1981; Mycorrhizal fungi and their importance. In Horticultural crop production. In J. Janick (ed), Horticultural reviews, AVI, Vol. 3, pp. 172-213.

Mulongoy, K and Sanginga, N., 1990; Nitrogen contribution by Leucaena in alley cropping. IITA Research, Vol. 1, pp. 14-17.

Neumann, I.F. and Pietrowicz, P., 1987; Light and water availability in fields with and without trees. An example from Nyabisindu in Rwanda. In Reifsnyder, W.S. and Darnhofer, T.O. (eds) Meteorology and agroforestry. ICRAF, WMO, UNEP, GTZ. Nairobi pp. 401-406.

Northen, R., (1953); Introductory plant science. Second edition, pp. 45-66.

Ofori, F. and Stern, W.R., 1987; Cereal-legume intercropping systems. Advances. Agron. Vol. 41, pp. 41-90.

Peters, D.B., 1960; Relative magnitude of evaporation and transpiration. Agronomy. J. Vol. 52, pp. 536-538.

Reshd, K., Getahum, A. and Jama, B., 1987; The influence of rain fall distribution on the yield of maize under Leucaena leucocephala alley cropping at Mtwapa, Coastal province Kenya. Reifsnyder, W.S. and Darnhofer, T.O. (eds) Meteorology and agroforestry. ICRAF, WMO, UNEP, GTZ. Nairobi pp. 383-389.

Rocheleau, D., Weber, F. and Field-juma, A., 1988; Agroforestry in dryland Africa, ICRAF, Nairobi. pp. 15-49.

Shaw, R.H., 1977; Climatic requirements. In SPRAGUE (ed), Corn and Corn improvement. Agronomy No. 18. ASA. pp. 591-623.

Siaw, D.E.K., 1989; A thesis abstract: Alley cropping for sustainable crop production on an alfisol, using combinations of the woody species Leucaena leucocephala (Lam) de Witt and Acioa barteri HookF. Ex. Oliv.) Engl. Ph.D. Thesis, University of Ibadan, Ibadan, Nigeria. IITA Research 1990, Vol. 1. pp. 18-19.

Steppler, H.A. and NAIR, P.K.R., 1987; Agroforestry: a decade of development, ICRAF, Nairobi.

Swaminathan, M.S., 1987; The promise of agroforestry for ecological and nutritional security. In Steppler, H.A. an Nair, P.K.R., (eds) Agroforestry: adecade of development, pp. 25-41. ICRAF, Nairobi.

Trenbath, B.R., 1974; Biomass productivity of mixtures. Advances in agronomy Vol. 26, Academic press. pp. 177-210.

Triplett, G.B., 1962; Interactions in maize and soybean cropping systems. Agronomy Journal Vol. 54, pp. 106-109.

USDA (soil Conservation Service), 1975; Soil Taxonomy A basic system of classification for making and interpreting soil surveys. Agricultural Handbook No. 436, 754pp.

Vaadia, R.R., Raney, C.R. and Hagen, R.M., 1961; Plant water deficits and physiological processes. Ann. Rev. Plant Physiol. Vol. 12, pp. 265-292.

Whittington, W.J. and O'brien, T.A., 1968; A comparison of yields from plots sown with a single species or a mixture of species. <u>J. Appl. Ecology</u>, V. 5, pp. 209-213.

Young. A., 1987; The environmental basis of agroforestry. In Reifsnyder, W.S. and Darnhofer, T.O (eds), <u>Meteorology and agroforestry</u>, ICRAF, WMO, UNEP. GTZ. pp. 29-43.

APPENDICES

Appendix 1. Maize growth stages as identified by FOTH (1962)

GROWTH STAGE	DESCRIPTION	AVERAGE MAXIMUM ROOT DEPTH
1	Seedling to knee height (27-37 DAP)	6" (15 cm)
2	Up to 54 DAP (Root weight 72% as at maturity)	15" (38 cm)
3	Up to tasselling, Silking and Pollination	25" (65 cm)
4	Ear growth to milk stage	No further root growth
5	Maturation	No further root growth

DAP means Days After Planting

Appendix 2. Mean monthly weather conditions at the UNZA farm for the 1990/1991 growing season.

MONTH	AIR TEMPERATURE (°C)			WIND SPEED (m/s)	RAIN FALL (mm)
	MAX	MIN	MEAN		
NOV.**					38.5
DEC.	29.3	19.0	24.1	1.7	322.9
JAN.	29.1	18.6	23.8	1.4	221.1
FEB.	28.7	17.5	23.1	1.3	156.6
MAR.	26.0	16.3	21.2	1.2	8.0
APR.	24.3	11.9	18.1	1.9	15.3
MAY	26.0	13.8	19.7	1.4	0.0
MEAN	27.2	16.2	21.7	1.5	762.4

** Except for rainfall all data for November is not used in the calculation of means.

Appendix 3. Soil characteristics at Chalimbana by depth.

DEPTH (cm)	*pH ($CaCl_2$)	*CEC (meq/100g) ($g/100cm^3$)	BULK DENSITY	*TEXTURE
0 - 15	5.6	2.09	1.34	Sandy loam
15 - 38	5.7	3.09	1.56	Sandy loam
38 - 130	6.1	3.29	1.56	Sandy clay loam
130 - 210	6.0	4.02	1.56	Sandy clay

(Source. * KAMARA and MATEKE, 1989)

Appendix 4. Experimantal layout of treatment combinations

REP I		REP II		REP III	
S1C1F1	S3C2F1	S3C2F0	S1C2F0	S1C2F0	S3C2F1
S3C1F0	S1C2F0	S2C2F1	S3C1F1	S1C1F1	S3C1F1
S2C1F0	S2C2F1	S2C1F0	S1C1F1	S2C1F1	S2C2F0
CF0	CF1	CF0	CF1	CF1	CF0
CF1	CF0	CF1	CF0	CF0	CF1
S1C1F0	S2C2F0	S2C2F0	S3C1F0	S1C1F0	S1C2F1
S2C1F1	S1C2F1	S2C1F1	S1C2F1	S3C1F1	S2C2F1
S3C1F1	S3C2F0	S1C1F0	S3C2F1	S3C2F0	S2C1F0

N
↑

LEGEND

S1 LEUCAENA

S2 FLEMINGIA

S3 SESBANIA

C1 50 cm

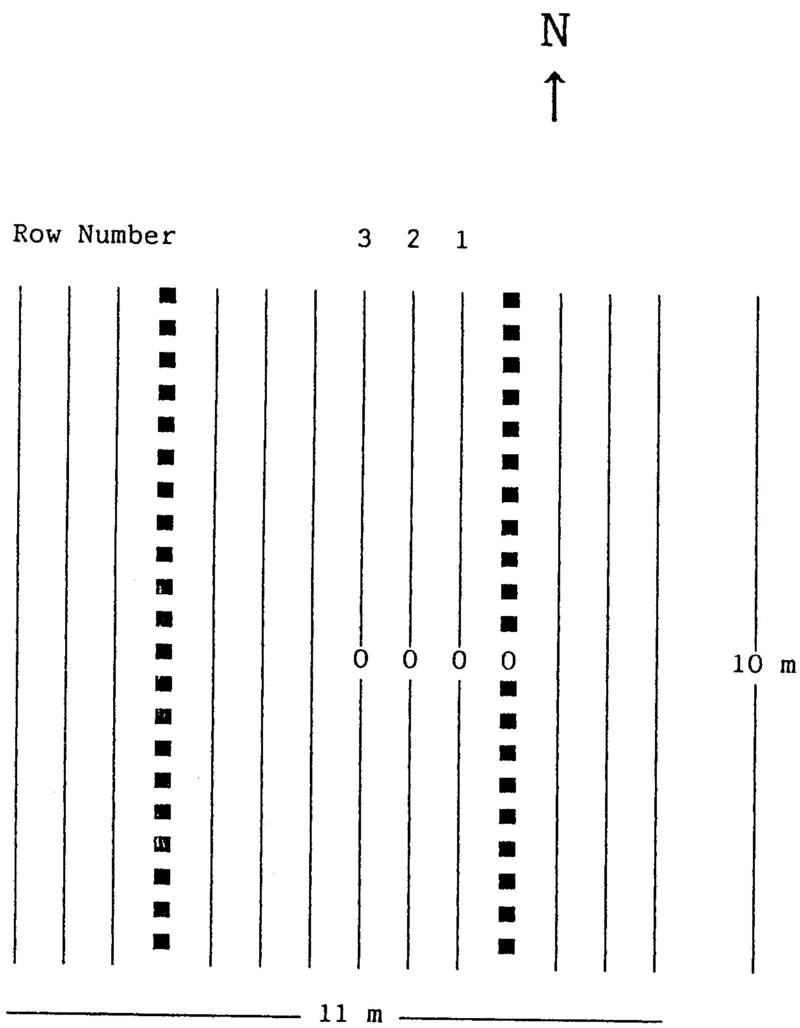
C2 100 cm

F0 UNFERTILIZED

F1 FERTILIZED

C CONTROL

Appendix 5. Schematic diagram of an experimental unit and location of access tubes.



KEY

0 Position of access tube to 120 cm depth

■ Double hedgerow

| Maize row

Appendix 6. Chronological order of field activities in the trial and amounts of total nitrogen (kg/ha) added to the soil in *leucaena* fresh leaves and twigs to the respective plots per pruning.

		Total Nitrogen[1]	
ACTIVITY	DATE	LL+F0	LL+F1
Planting of maize	02.01.1991	--	--
1st pruning of *leucaena*	29.12.1991	298.1	305.6
Basal fertilizer application	02.01.1991	--	--
1st top fertilizer application	07/08.02.1991	--	--
2nd *leucaena* pruning	07.02.1991	55.8	60.1
3rd *leucaena* pruning	04.03.1991	43.3	49.9
2nd top fertilizer application	04.03.1991	--	--
4th *leucaena* pruning	28.03.1991	26.5	26.8
Harvesting	23/24.05.1991	--	--

1 Calcualted according to Mulongoy and Sanginga (1990) finding that *Leucaena* contains 4.1% nitrogen.

2nd and consequent pruning of *leucaena* depended on the rapidity of regeneration due to the earlier pruning

-- Means no prunings added.