EFFECT OF SOIL INCORPORATED LEAF PRUNINGS ON SOIL PRODUCTIVITY IN ALLEY AND SOLE CROPPING SYSTEMS USING *Leucaena leucocephala* (Lam.) de Wit AND *Calliandra calothyrsus* Meissn

BY

JAYNE N. MWANGI

1997

DEDICATION

I dedicate this work to my beloved husband, Simon Mugwe Weru

and

Children; Regina Wanjiru, Marion Wairimu, and Lisa Wangui.

DECLARATION BY THE CANDIDATE

This thesis is my original work and has not been presented for a degree in any other university. No part of this thesis may be reproduced without the prior permission of the author and/or Moi University.

JAYNE N. MWANGI | 10th September, 1997
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This thesis has been submitted for examination with our approval as University Supervisors.

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I need an antidote

LIST OF ACRONYMS AND ABBREVIATIONS

FAO	Food and Agriculture organisation of the United Nations
FURP	Fertilizer Use Recommendation Project
ICRAF	International Centre for Research in Agroforestry
KARI	Kenya Agricultural Research Institute
KEFRI	Kenya Forestry Research Institute
NARL	National Agricultural Research Laboratories
NARP	National Agroforestry Research Project
USDA	United States Department of Agriculture
UNESCO	United States Educational, Scientific and Cultural Organisation

UNITS AND SYMBOLS

g	gram
cm	centimeter
ha	hectare
km	kilometer
m	meter
me/100g	milliequivalent per 100 g soil
mg	milligram
mm	millimeter
pH	Measure of acidity/alkalinity
ppm	Parts per million
$>$	greater than
$<$	less than

ABSTRACT

Crop yields on small-scale farms in the central Kenya highlands continue to decrease due to declining soil fertility, resulting from continous cropping without adequate replenishment of nutrients through addition of fertilizers and/or manure. A study was therefore conducted to investigate the feasibility of using leaf prunings of *Calliandra calothyrsus* Meissn and *Leucaena leucocephala* (Lam.) de Wit for soil fertility and productivity improvement. Alley and sole cropping systems were studied. The experiment was located at KARI's Regional Research Centre's Agroforestry site in Embu District of Kenya. The experimental design was a randomised block with ten treatments. Results of three seasons, namely, 1993 long rainy season (1993 LR), 1993/94 short rainy season (1993/94 SR) and 1994 long rainy season (1994 LR) are reported.

Generally, the sole cropped treatments had consistently higher maize grain yields than alley cropped treatments in all seasons. This was attributed to competition between the trees and the crops for growth resources in alley-cropped treatments. Generally, also, the fertilizer treatments, performed better in terms of maize and bean grain yields than the leaf incorporated and the alley cropping treatments. During 1994 LR, the fertilizer treatments gave significantly ($p=0.05$) higher maize grain yield than all the other treatments. This was ascribed to the readily available nutrients from fertilizer.

Infiltration rate and total nitrogen increased in treatments with leaf prunings incorporation and with tree hedges. Calcium decreased across the seasons in all treatments but generally less in the treatments where prunings were added. Addition of prunings, however, did not cause significant changes in soil pH, phosphorus, potassium, sodium, magnesium, manganese, organic carbon levels, and bulk density among treatments in all seasons. This was attributed mainly to low biomass production by the hedgerows, therefore, low input of nutrients coupled, with removal of nutrients through crop harvests. Insensitivity of conventional soil analysis methods to detect small changes was cited as another reason.

Feasibility of using leaf prunings for soil improvement in an alley cropping system was found to be limited due to low biomass production and possibly competition between the tree hedges. More research on below ground interactions would be useful to provide a better understanding for improving the system. In sole cropping system, incorporation of leaf prunings as source of plant nutrients seem feasible but with fertilizer supplementation. Opportunities of using *Calliandra calothyrsus*, and other promising fodder legumes for soil erosion control and fodder production, and the possibilities of improving soil fertility through recycling of nutrients by manure should be explored.

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CHAPTER ONE

1.0 INTRODUCTION

1.1 Justification

Kenya's population growth rate is among the highest in the world officially at 3.8% per annum (Anonymous, 1989). In 1993, the population of Kenya was estimated at 27.2 million people and is expected to rise to 35 million people by the year 2000 (Anonymous, 1993a). This high population has consequently resulted in the high rainfall areas becoming densely populated, leading to intensive use of land and rapid soil degradation. This is particularly so in the coffee based land use system of the Kenyan highlands, predominantly occupied by small scale farmers. There are 500-700 persons Km^2 in the region (Minae and Nyamai, 1988), and the average land holding is approximately 1.5 ha per household.

The rapidly increasing population, in the coffee based land use system, has resulted in intensification of agriculture with two crops every year (long rains and short rains seasons). This, consequently, has put pressure on the soil resource base. The problem is further aggravated by inadequate replenishment of nutrients through addition of fertilizers and/or manure (Minae and Nyamai, 1988). Majority of farmers apply fertilizer below recommended rates and manure is hardly enough (Kihanda, 1994). As a result, this low-input agriculture has resulted in depletion of major soil nutrients, nitrogen (N), phosphorus (P) and potassium (K) (Stoorvogel *et al.*, 1993) with subsequent low crop yields. High yielding maize varieties have been developed with yield potentials of 7-12 t/ha, but maize yields at the farm level is seldom above 1.5 t/ha (Wokabi, 1994) due to low soil fertility (Schnier, 1993).

With the need to produce more food to meet the ever rising demand, development of appropriate technologies to maintain and improve soil fertility is of paramount importance. These should be low input soil management technologies, capable of reversing the trend of progressively degrading soil, and requiring minimal fertilizer inputs, as the high prices of fertilizers are beyond affordable levels for most small scale farmers. One possible technique is alley cropping, which has been suggested as a potentially promising agroforestry technology (Atta-Krah, 1990; Palada *et al.*, 1992). This is a technique where food crops are cultivated in alleys formed by hedgerows of trees or shrubs (Kang *et al.*, 1981; Kang and Wilson, 1987; Kang, 1993). The hedgerows are cut back and periodically pruned during the cropping season to prevent shading of the companion crops. The prunings of foliage, and young stems, are incorporated into the soil as green manure which upon decomposing release nutrients to the associated crops.

Alley cropping was developed by scientists at the International Institute of Tropical Agriculture (IITA) in 1970s, and to date has generated a lot of data (Young, 1989; Ong, 1994). Despite the fragmentary nature of these data, the hypothesis that alley cropping systems can be designed to maintain soil fertility, as well as being productive remains a distinct possibility (Young, 1989). It is felt that, alley cropping can make a significant contribution to the current soil fertility problem in the region. If leguminous tree species are used, they will be a source of green manure as well as add fixed N to the soil. Use of green manure by farmers in the coffee base land use system is, however, limited and more so alley cropping systems. As such, the performance of this system is largely unknown. The aim of this study, therefore, was to investigate the possibility of using leaf prunings of two leguminous tree species in alley and sole cropping systems for soil fertility improvement with minimal fertilizer inputs.

1.2 Objectives

The general objective of this study, was to evaluate the contribution of soil incorporated leaf prunings to soil fertility improvement in alley and sole cropping systems. The specific objectives were to:

1. Evaluate the effects of soil-incorporated leaf prunings of *Calliandra calothyrsus* Meissn and *Leucaena leucocephala* (Lam.) de Wit, on soil nutrients, and soil physical properties in both alley and sole cropping systems.
2. Assess the contributions of soil-incorporated leaf prunings to crop yields under alley and sole cropping systems.
3. Assess the contributions of leaf prunings plus fertilizer to soil nutrients and crop yields.

1.3. Study hypothesis

(1) Leguminous trees such as *C. calothyrsus* and *L. leucocephala* provide leaf prunings, rich in nutrients, which when incorporated into the soil, increase the amount of nutrients available in the soil.

(2) Incorporation of leaf prunings into the soil improves soil physical properties.

(3) Incorporation of leaf prunings into the soil improves crop yields.

CHAPTER TWO

2.0 LITERATURE REVIEW

2.1 General

The association between trees, and soil fertility, is indicated by the high nutrient status of soils under natural forest, their relatively closed nutrient cycles, the soil fertility restoring power of forest fallow in shifting cultivation, and the success of reclamation forestry. Young (1989) enumerated the following processes by which trees maintain or improve soils:

(1) Augment additions of organic matter and nutrients to the soil.

(2) Reduce losses from the soil, leading to more closed cycling of organic matter and nutrients.

(3) Improve soil physical conditions.

(4) Improve soil chemical conditions.

(5) Affect soil biological processes and conditions.

Agroforestry systems, thus, have potential to improve soil fertility and maintain productivity (Lundgren and Nair, 1989). Nair (1984), postulated the following hypotheses about expected changes under agroforestry systems:

(1) Increase in the organic matter content of the soil through addition of leaf litter and other plant parts.

(2) More efficient nutrient cycling within the system, and consequently more efficient utilization of nutrients, that are either inherently present in the soil or externally

applied.

(3) Biological nitrogen fixation and solubilization of relatively unavailable nutrients, for example phosphate, through the activity of mycorrhizas and phosphate solubilizing bacteria.

(4) An increase in the plant cycling fraction of nutrients, with a resultant reduction in the loss of nutrients beyond nutrient sources among the tree and the crops.

(5) Enhanced nutrient economy because of different nutrient absorbing zones of root systems of component plants.

6) A moderating effect by addition of soil organic matter on extreme soil reactions and consequently, improve nutrient release and availability.

The mechanisms by which trees achieve these beneficial effects include: increase in organic matter through photosynthetic fixation and transfer to the soil as litter and root residues, nitrogen fixation, nutrient cycling through the taking up of nutrients by deep roots and return to the surface, improvement of soil physical conditions and protection from erosion, thereby preventing loss of organic matter and nutrients (Nair, 1984; Young, 1985, 1986).

Incorporation of multipurpose woody species into an alley cropping system, has a potential of creating complementary effects, which may include capture of leached nutrients such as nitrate-N by the roots and improving water infiltration. High root mass associated with agroecosystems including trees, may reduce losses by leaching of soil and applied nutrients through a combination of processes, including sorption and uptake from deeper layers (Jaiyebo and Moore, 1964; Stark and Jordan, 1978; Ewel *et al.*, 1982). Most trees are deep rooted and can exploit subsoil (Nye and Foster, 1987), and their permanence binds the soil and reduces erosion (Lal and Russel 1981; Ludwig, 1987)

When biologically nitrogen-fixing trees or shrubs are used in alley cropping, nitrogen availability to adjacent crops may be enhanced (Young, 1989) through the process of nodule sloughing (Yamoah *et al.*, 1986a), or excretion of nitrogen from actively nodulated roots (Sanginga *et al.*, 1981; Brophy and Heicheil, 1989), although the significance of this process is not well understood (Wacquant *et al.*, 1989). Young (1989) has enumerated the following salient features from hedgerow intercropping studies:

(1) A large biomass production can be obtained from hedgerows, typically 2000-5000 kg dry matter (DM)/ha/year in moist sub-humid climates and up to 10,000 kg DM/ha/year in humid climates.

(2) Large amounts of nitrogen can be fixed by hedgerows, e.g., 75 to 120 kg N /ha in six months by leucaena.

(3) Substantial quantities of nutrients are contained in hedgerow prunings, and can thus be added to the soil if incorporated into soil.

(4) Residues from prunings of most commonly used species decompose rapidly, with corresponding release of nutrients and rapid release of mineral nitrogen. Leucaena

has particularly rapid decomposition rates, releasing 50% of nutrients in the first 25 days.

2.2 Effect of prunings incorporation on soil nutrients

Loppings from fast-growing, and quickly regenerating woody perennials, grown with agricultural crops in mixed cropping systems, could be incorporated into the soil to improve soil fertility. The prunings decompose releasing nutrients into the soil, thus contributing to addition of soil plant nutrients. For example, in Thailand significantly higher pH, organic matter and nutrients (N, P, K, Ca and Mg) were found in paddy rice fields with *Samanea saman* and generally higher soil fertility was found in positions closer to the tree base than in non alley plots (Sae-lee *et al.*, 1992). Kang *et al.*, (1990) in a trial lasting six years in Nigeria, observed higher organic matter in the alley cropping plots where prunings were retained than from where the prunings were removed on a low fertility Entisol/Arenosols (Table 1). Similarly, in Sri Lanka Handawela (1986) reported higher soil organic matter and nitrogen levels under *Gliricidia sepium* (Jacq.) Walp (syn. *Gliricidia maculata*) alley crops than under maize only. Yamoah *et al.*, (1986b) also found an improvement in soil organic levels in *Senna siamea* Lam. (syn. *Cassia siamea*) and *G. sepium* alley crops compared to the control plots.

Table 1: Some chemical properties of the soil (Sandy Entisols) after six years of alley cropping *Leucaena leucocephala* with maize and cowpeas at IITA, Nigeria

Treatments (kg N/ha)	Leucaena prunings	pH H2O	Org. C (%)	Exchangeable (c mole/kg)			P (ppm) Bray No.1
				K	Ca	Mg	
0	removed	6.0	0.65	0.19	2.90	0.35	27.0
0	removed	6.0	1.07	1.28	3.45	0.50	26.2
80	retained	5.8	1.19	1.26	2.80	0.45	25.6
Lsd (0.05)		0.2	0.14	0.05	0.55	0.11	5.3

Source: Kang *et al.*, 1990

A study of the soil chemical and physical properties, in a seven-year old alley cropping trial, containing *L. leucocephala* and *Flemingia congesta* (Willd.) Merril in Northern Zambia by Dallard *et al.* (1993) revealed intriguing results. Under the alley cropped plots, particularly those of leucaena, there were higher levels of organic carbon, magnesium, potassium and exchangeable cation exchange capacity and pH values tha non-alley plots. The higher levels of organic carbon in the alley cropped treatments were responsible for the improvements observed in soil physical properties. Mathews *et al.*, (1992) found similar increases in organic carbon on the same site.

2.3 Effect of prunings incorporation on soil physical properties

Prunings when incorporated into the soil, affect many conditions near the soil/air interface where they are applied. These conditions include soil temperatures, moisture content, physical and chemical properties, microbial activities, mechanical impact and weed growth (Stigter, 1984). The use of green manures by small scale farmers improves soil fertility, thus food crop yields, but also improve soil physical properties (Kang and Ghuman, 1989). This is mainly attributed to the prunings' ability to increase organic matter content, which in turn improves the physical status of the soil (Woomer *et al.*, 1994; Young, 1989). Dallard *et al.*, (1993) reported higher levels of organic carbon in alley crops, and suggested that this could be responsible for the improvements observed in bulk density and infiltration rate. He observed lower bulk density, higher infiltration rate, and pore volume fraction in the alley plots. Similar results have also been observed by Handawela (1986), who measured lower soil compression strengths under a *G. sepium* alley crop in Sri-Lanka and by Yamoah *et al.*, (1986b) who found a decrease in bulk density under alley crops of *G. sepium*, *F. congesta* and *L. leucocephala* in Nigeria.

The effects of improved soil physical properties on crop yields were extensively reviewed by Lal and Greenland (1979). In Nigeria, Lal (1989) observed improved infiltration rates and bulk densities in alley cropped treatments as compared to plow-till and plow systems (Table 2). As Yamoah *et al.*, (1986a) have pointed out, good soil physical properties may be even more important, than the supply of nutrients, because the nutrients released from the prunings become useless, if the soil physical conditions do not favour proper root development to take up these nutrients. This is true for alley cropping system where nutrients supplied by the system are intended to benefit the adjacent crop.

Table 2: Changes in some physical properties of an alfisol under alley cropping and no till systems at IITA, Nigeria

Cropping system	Infiltration rate at 120 min. (cm/hr)			Bulk density (g/cm)		
	year 1	year 3	year 5	year 1	year 3	year 4
Plow-till	24.2	23.2	21.4	1.36	1.51	1.42
plow	18.0	12.4	5.0	1.30	1.47	1.62
Alley-cropping						
leucaena 4 m	39.8	13.0	22.2	1.26	1.44	1.50
leucaena 2 m	13.6	22.4	22.8	1.40	1.39	1.65
gliricidia 4 m	18.8	18.8	16.8	1.30	1.35	1.57
gliricidia 2 m	13.8	21.0	19.61	1.33	1.45	1.55
lsd (0.1)		5.8			0.03	

Source: Lal (1989), adopted from Nair, 1993

2.4 Effect of hedgerows on soil productivity

The use of multipurpose trees and shrubs with agricultural crops in alley cropping has been recommended as an agroforestry approach to improving soil productivity and crop yields in the humid tropics. Alley cropping is a biologically stable, low input production system (Kang and Wilson, 1987). It has been tested with a variety of crops and multipurpose woody species. These include cereals (maize and upland rice), grain legumes (cowpea, soyabean and dry beans), root and tuber crops (cassava and yam), plantain and vegetable crops grown under mono or intercropping systems (Kang *et al.*, 1990; Budelman, 1990; Palada *et al.*, 1992). Examples of multipurpose woody species that have been used successfully with this approach include, *S. siamea*, *Acioa barterii* (Hook. f. ex. Oliv.) Ewgl., *Erythrina poeppigiana* (Walpers) Cook., *L. leucocephala*, *C. calothyrsus*, *Albizia falcataria* (L.) Fosberg. and *G. sepium* (Kang *et al.*, 1981, 1985; Agboola, 1982; Mulongoy, 1986; Wilson *et al.*, 1986; Yamoah, 1986a; Buck, 1986; Szott *et al.*, 1987).

There is increasing information available on the effect of alley cropping with various hedgerow species on crop production in various parts of the tropics. Results obtained thus far have been variable, and differ greatly in different agroecological zones. In semi-arid lowland tropics, results of trials carried out have not been very encouraging (Singh and Saharan, 1989). Singh *et al.*, (1989) reported that the yields of castor, cowpea and sorghum alley cropped with *L. leucocephala* for a period of four years using a wide inter-hedgerow spacing of 10 m were lower than in the control treatment. They attributed much of the yield decline to severe moisture competition. In the humid tropics, where moisture is not limiting, results are likely to be more promising. For example, in an eight year alley cropping trial conducted in Southern Nigeria using *L. leucocephala* prunings only, maize yield could be maintained at a level of 2 t/ha against 0.66 t/ha without leucaena prunings or fertilizer (Kang *et al.*, 1990)

Alley cropping exploits the potential of leguminous trees for maintenance of soil fertility and productivity by supplying additional N. In Hawaii, a maize-leguminous tree alley cropping system was studied on nitrogen deficient soil, and results showed that addition of prunings from hedgerows were able to support maize grain yields at about 800 kg/ha for two consecutive cropping seasons, while control plots yielded an average of less than 600 kg/ha (Rosecrance *et al.*, 1992). The loppings from the hedges provided green manure, which improved the soil fertility. Green manure applied directly to the soil significantly increased yields in maize (Guevara, 1976; Kang 1981; Evensen, 1989). Similarly, alley cropping with *A. baterri* and *L. leucocephala* hedgerows increased maize and cowpea yields compared to the controls consisting of sole crops (Siaw *et al.*, 1991).

Most of the results, however, from alley cropping trials have been negative with yield reductions in the alley plots. Young (1989), Kang (1993) and Ong (1994) have indicated that over 50% of the results on alley cropped maize yields have been negative. For example, in a study on the effect of alley cropping *Zea mays* var. Jeka with *S. siamea* in Gambia, Danso and Morgan (1993b) showed that crop yields, as measured by the number and dry weight of ears, stover, grain and cob weight was significantly different among treatments. The application of prunings plus full recommended fertilizer produced the highest yields.

Inconsistent results have been obtained in different soil types. In an alley cropping trial, with *Inga edulis* Willd and *Cajanus cajan* on a typic Paleudult/Eutric nitisols at Yurimaguas, Peru, Szott (1987) reported extremely low crop yields for the alley crop which was attributed to competition for light and nutrients. Evensen and Yost (1990) reported that results of alley cropping upland rice and cowpea with *Periserianthes falcataria* (L.) Nielsen (syn. *Albizzia falcataria*) on a Tropetic haplorthox/Orthic ferralsols in Western Sumatra were initially positive, particularly with addition of a low lime rate. However, yields declined after four years and were restored only after fertilizer input was increased. They concluded that, there was little build up of nutrient cations due to recycling by the trees, and that, successful alley cropping on acid soils required maintenance of soil fertility through external inputs.

2.5 Nutrient composition of leaf prunings

The potential nutrient contribution by alley shrubs is important particularly if the nutrients could be available to the crops at the amount, time and place (depth) they are most needed. This implies that for a given shrub, knowledge of the nutrient content of prunings, decomposition, nutrient release from the prunings, and the method of incorporation is important. Analysis of prunings nutrient composition of most leguminous tree species like *L. leucocephala* and *G. sepium* show that they contain high levels of nitrogen, phosphorus, calcium, magnesium and zinc (Anonymous, 1980; Agboola *et al.*, 1982; Kang *et al.*, 1981; Yamoah *et al.*, 1986a; Young, 1989).

Biomass production by multipurpose trees and their nutrient composition is variable. An alley cropping trial in Northern Zambia indicated that *L. leucocephala* produced significantly more biomass and its leaves had higher concentration of N, P and K and lower C/N and C/P ratios than did those of *F. congesta* (Dallard *et al.*, 1993). The concentration of N, P and K in January loppings for leucaena was 4.9, 0.32 and 1.8%, while that of flemingia was 3.4, 0.28 and 1.4% respectively. In comparison to *F. congesta*, *L. leucocephala* contributed considerably more N not only by producing higher levels of biomass but also by having a higher level of N content in the biomass.

2.6 Rate of decomposition and mineralization

The term "litter quality" is commonly used in literature about organic matter decomposition to refer to nutrient content and comparative rate of decomposition of plant residues (Anderson and Swift, 1983; Nair, 1993). Plant materials that are high in nutrients, especially nitrogen, are considered to be of high quality and their rates of decomposition and mineralization are generally high (Palm and Sanchez, 1990; Tian *et al.*, 1992). Prunings of many of the leguminous woody species used in agroforestry systems, especially alley cropping are high in nitrogen and when applied to the soil decompose fast releasing N resulting in increased available N levels for the associated crops.

Many leguminous agroforestry trees, produce sufficient pruning biomass and contain enough nutrients to meet crop demand in agroforestry systems, but the N release patterns or quality of the prunings differs greatly, from 100% mineralization to net immobilization during the course of crop growth (Palm, 1995). Leguminous trees such as *L. leucocephala*, *G. sepium* and *Erythrina spp.* decompose relatively fast, releasing a major part of their nutrients (especially nitrogen) within about four weeks under humid tropical conditions (Nair, 1993). Since nutrients are also subject to leaching, fixation and other losses, it is advantageous if this release can be affected at a time coinciding with the major requirements for nutrient uptake by plant roots.

CHAPTER THREE

3.0 MATERIALS AND METHODS

3.1 Experimental site

3.1.1 Location, altitude, rainfall and temperature

The experiment was carried out at the National Agroforestry Research Project's site at the Kenya Agricultural Research Institute's (KARI) Regional Research Centre, Embu District, Eastern Province. The centre is located in the Central highlands of Kenya, on the south-eastern slopes of Mt. Kenya at an altitude of 1480 meters above sea level (Figure 1). Rainfall is moderate with total annual average of 1200 mm to 1500 mm (Jaetzold and Schmidt, 1983). There are two main rainy seasons. The long rains come between mid-March and June, with an average precipitation of 750 mm. The short rains are in mid-October to December with an average rainfall of 350mm. Temperatures are warm, with a mean monthly average between 18 and 21^{0}C.

3.1.2 Soils

The soils are commonly known as "Kikuyu Red Clay loam". They are extremely deep (>2m), well drained, dusky red to dark reddish brown in colour, with moderate soil structure (Table 3). They are derived from rich, basic volcanic rocks and has ben classified as Humic Nitisols (Anonymous, 1975). In the USDA system of classification they fall under Humic Palehumult (Anonymous, 1975). They are deep, well weathered with friable clay texture (Table 3) and moderately high inherent fertility. They are considered good soils agriculturally but have declined in soil fertility due to continuous

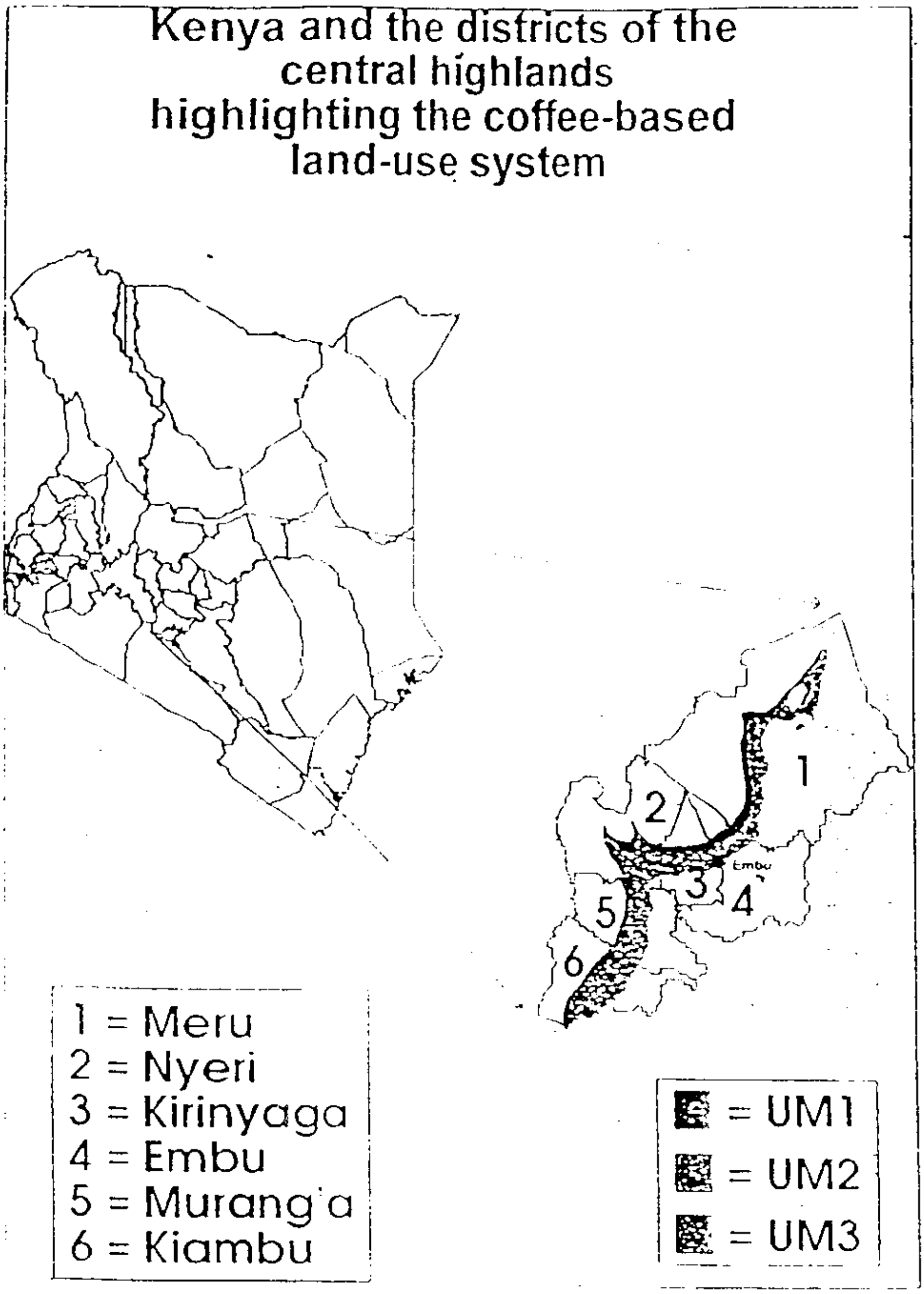


Figure 1: Map of Kenya showing location of Embu and the sorrounding districts highlighting the coffee based land use system (UM1, UM2 and UM3)

Source: O'Niell *et al.*, 1994

cropping and soil erosion arising from steep cultivation (Minae and Nyamai, 1988). Soil profile description and analytical data of a soil profile pit located about 1 km from the site are shown in Table 3 and 4.

Table 3: Profile description of a pit located about 1 km from the experimental site

Genetic horizon	Depth	colour (moist)	consistence	mottling	texture	cutans
Ah1	0-20	2.5YR 2.5R Very dusky red	friable, slightly sticky, slightly plastic	nil	clay	nil
Ah2	20-40	2.5YR 3/2 Dusky red	friable, sticky, plastic	nil	clay	nil
Bt1	40-70	2.5YR 3/4 Dark reddish brown	Friable, sticky, plastic	nil	clay	broken thin clay
Bt2	70-102	10YR 3/4 Dusky red	friable, slightly sticky, slightly plastic	nil	clay	broken moderately thick clay
Bt3	102-150	10R 3/4 Dusky red	broken, modrately thick clay	nil	clay	broken moderately thick clay

Adopted from FURP, 1993

Table 4: Summary of the soil physical and chemical properties of a profile located about 1km from the experimental site.

Depth (cm)	0-20	20-40	40-70	70-102	102-150
Bulk density (g/cm3)	1.02	1.00	1.04	1.04	0.95
Sand (%)	18	16	14	10	8
Silt (%)	18	18	14	14	6
Clay (%)	64	66	72	76	86
pH-H2o (1:2)	5.8	6.1	6.1	6.2	6.2
C (%)	2.59	1.95	1.49	0.91	0.69
N (%)	0.26	0.18	0.13	0.10	0.07
C/N ratio	9.96	10.83	11.46	9.10	9.86
P -Olsen (ppm)	6.50	2.00	nd	nd	nd
CEC (cmol/kg)	25.90	23.80	21.10	18.70	16.60
Ca (cmol/kg)	4.00	3.50	2.90	2.10	2.20
Mg (cmol/kg)	2.10	2.00	1.20	1.50	1.40
K (cmol/kg)	1.35	0.68	0.48	0.26	0.09
Na (cmol/kg)	0.26	0.25	0.28	0.21	0.65
Base saturation (%)	29.76	27.07	23.03	21.76	26.14

nd=not determined

Adopted from FURP, 1993

3.2 Experimental design and treatments

The experimental design was a randomized complete block with ten treatments in four replicates. The tree hedge species were *Calliandra calothyrsus* and *Leucaena leucocephala*. The experimental treatments were as shown in Table 5.

Table 5: Experimental treatments

Trt	Crop	Cropping system	Tree species	Incorporation	Fert (N+P) kg/ha
1	Maize	Intercrop (hedges)	C. calothyrsus	Yes	0
2	Maize	Intercrop (hedges)	L.leucocephala	Yes	0
3	Maize	Intercrop (hedges)	C. calothyrsus	Removed to trt 5	0
4	Maize	Intercrop (hedges)	L. leucocephala	Removed to trt 6	0
5	Maize	Monocrop	C. calothyrsus	Imported from trt 3	0
6	Maize	Monocrop	L. leucocephala	Imported from trt 4	0
7	Maize	Monocrop	C. calothyrsus	Imported from out *a	25
8	Maize	Monocrop	L. leucocephala	Imported from out *b	25
9	Maize	Monocrop	none	none	25
10	Maize	Monocrop	none	none	0

Trt = Treatment

Fert = fertilizer

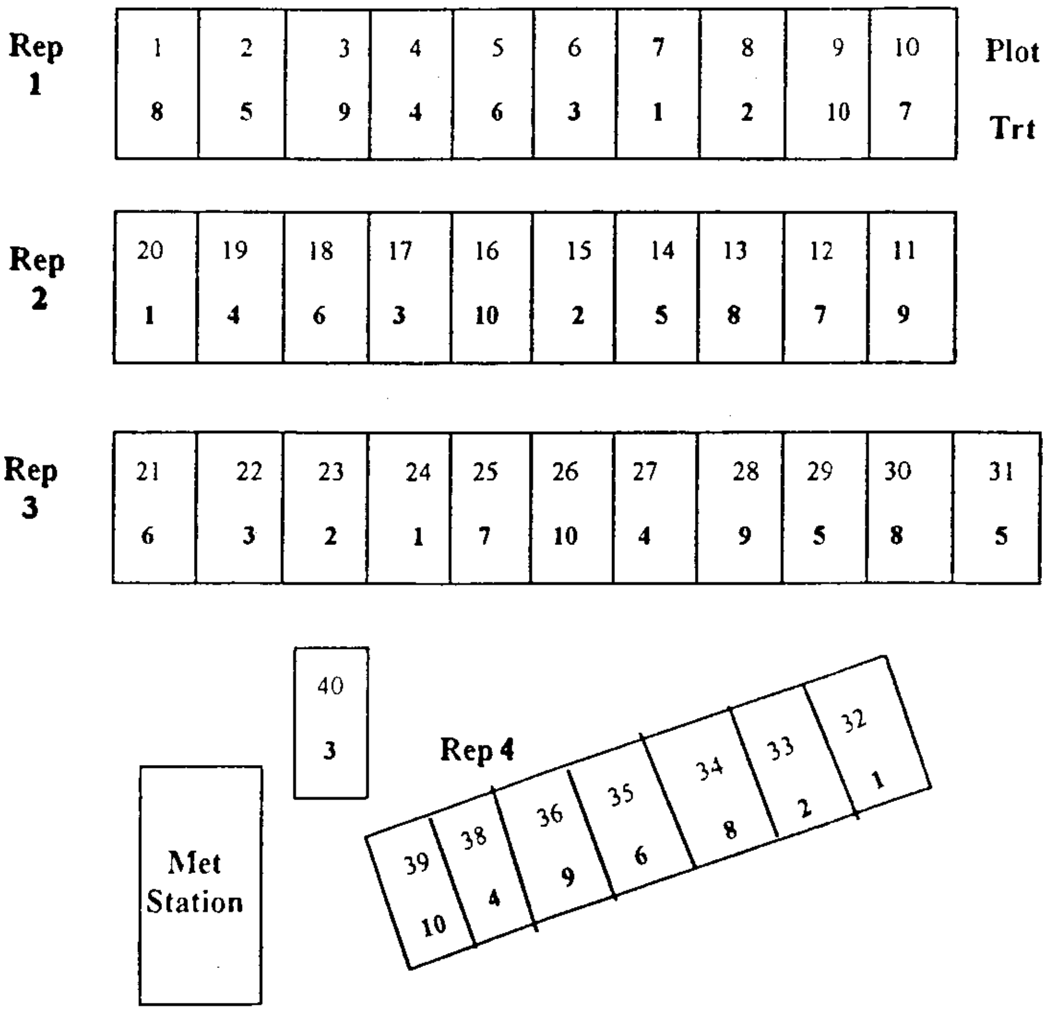
*a = at half rate of treatment 5

*b = at half rate of treatment 6

3.2.1 Experimental layout and Field plan

The replicates consisted of four blocks running across the field (Figure 1). The plot dimensions were 10 m x 9 m with calliandra and leucaena intrarow-spacing of 0.5 m and inter-row spacing of 4.5 m. The net plot dimensions was 4.5 m x 6 m (Figure 2).

Figure 1: Experimental field layout



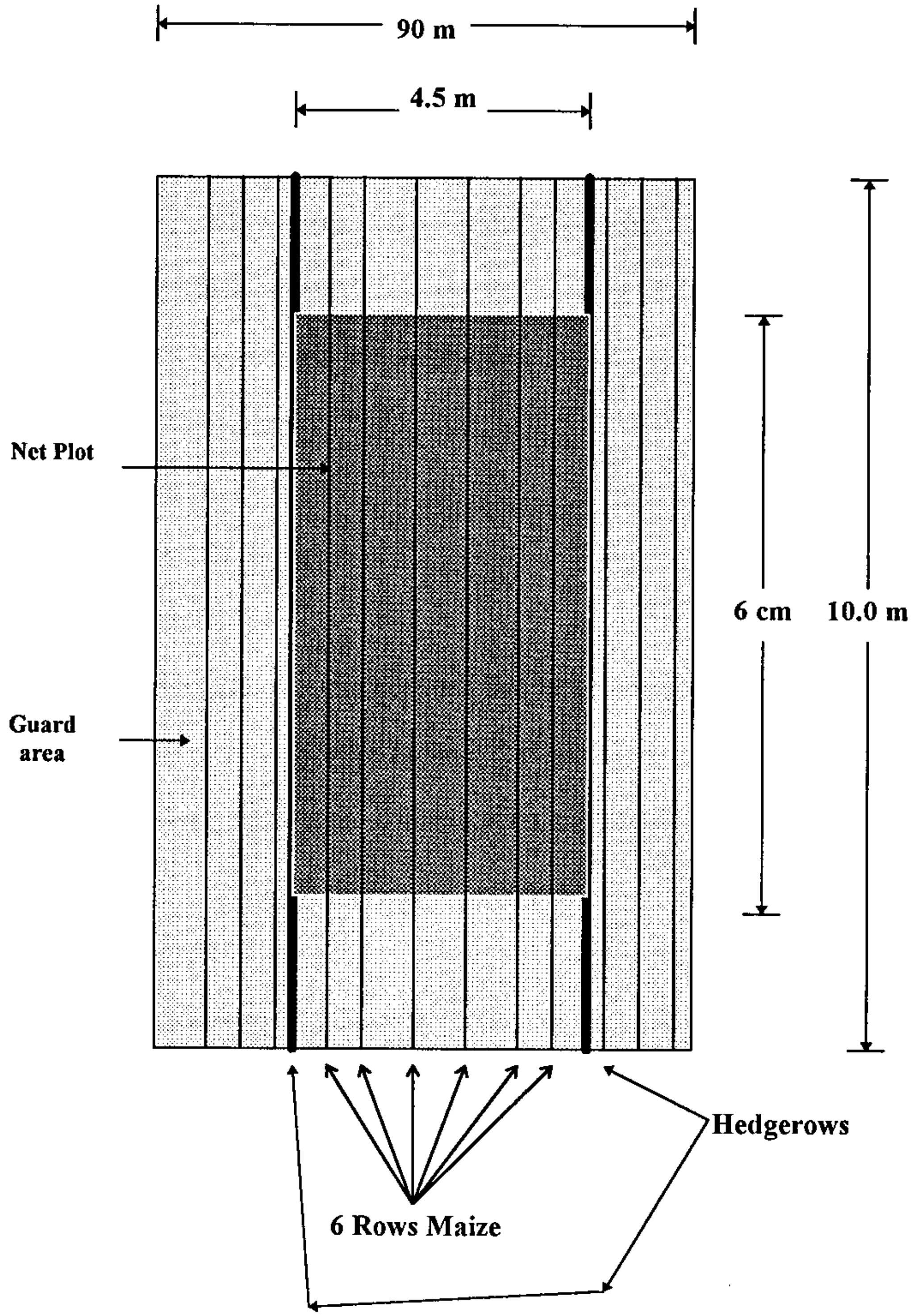


Figure 3: Experimental plot layout

3.3 Cropping history

The area had been cropped for several years, after which was left fallow for two seasons prior to its allocation to the agroforestry project in June 1991. Before setting up the experiment, uniformity trials were carried out without fertilizer during 1991 LR, season and 1992 SR season which revealed the land to be fairly uniform in terms of soil fertility. Soil samples were taken and analyzed at the end of 1991 SR, which also revealed uniformity among blocks.

3.4 Management of the experiment

3.4.1 Planting of tree hedges

The hedge tree species, i.e. *L. leucocephala* and *C. calothyrsus,* were planted as seedlings during 1992 LR. They were allowed two seasons to establish during which crops were grown without treatments. The experimental treatments were applied from 1993 LR.

3.4.2. Lopping of hedges and land preparation

Lopping was done about 3-4 days before planting. The hedges were lopped at a height of 50 cm using secateurs or sharp machetes. During 1993 LR, all the lopped material including woody biomass was chopped up and incorporated. In the following seasons, leafy biomass was separated from the stem and weighed separately before incorporation.

3.4.3 Incorporation of leaf prunings

Incorporation into the soil of the leaf prunings was effected using a hoe. Before incorporation, the leaf prunings were spread evenly over the plot area (10 m x 9 m) for those plots receiving prunings (Refer to Table 3) before incorporation. Prunings for treatment 7 and 8 (which received leaf prunings from outside the experimental plots) were obtained from adjacent areas to the experiment. The weight of leaf prunings applied to Treatments 5 and 7, 6 and 8 was equal to the weight of leaf prunings obtained from Treatments 3 and 4, respectively.

3.4.4 Planting of the test crop

During the long rains, pure maize was grown. Two maize seeds were planted per hill, but later thinned after 3 weeks to one plant per hill. During the short rains season, maize was intercropped with beans. The spacing of maize was 75 cm between rows and 50 cm within rows. This spacing allowed two lines of beans to be planted between maize. The spacing of beans was 25 cm between rows and 15 cm within rows. During this season three maize seeds were sown per hill which were later thinned to 2 per hill three weeks after emergence. In both seasons maize hybrid 511 and bean variety GLP3 (Rosecoco) were grown.

3.4.5 Fertilizer application

Treatments 7, 8 and 9 had Diammoniam Phosphate (DAP) applied at planting at a rate of 25 kg P/ha. Calcium Ammonium Nitrate (CAN) fertilizer was applied later, through top dressing, at the rate of 25 kg N/ha in two equal doses. The first half was applied three weeks after germination and the second half four weeks later.

3.4.3 Weeding

Weeding was done 2 times during the season using a machete. This was necessary to make sure that the plots were free of weeds, which could cause competition. The weeds were retained in the plots.

3.4.3 Root pruning (trenching)

Root pruning was done at the beginning of each growing season to curb roots extending to the neighboring plots. Trenches of approximately 50 cm, deep and 30 cm wide, were dug between plots with hedges and adjacent plots. Roots along these trenches were cut using a sharp machete. The trench was then carefully covered with soil such that the sub-soil was returned first.

3.5 Sampling procedures

3.5.1 Soil sampling

Sampling was carried out prior to setting up the experiment, and samples sent for chemical analysis to National Agricultural Research Laboratories (NARL) Nairobi. The soil was sampled again at the end of every growing season. Sampling was done at 0-20 cm, at four locations using a standard soil auger. The soil was then put in a clean bucket, and mixed, after which a composite sample was taken for chemical analysis at

NARL. Samples were packed in brown (khaki) paper bags with proper labels indicating the plot number and sampling depth.

3.5.2 Foliar sampling and handling

After lopping, random samples were taken from every plot and washed with distilled water, after which they were sun-dried prior to packing in bags. They were clearly labelled before being taken to NARL for chemical analysis.

3.6 Harvesting

The effective (net) plot (Figure 2) which measured 6 m x 4.5 m was harvested first. This comprised of six maize rows in the long rains season and six maize rows and twelve bean lines in the short rains. Harvesting was carried out by cutting the maize plants at the base using a sharp machete. The maize cobs were manually separated from the stover, sun-dried and packed in paper bags before threshing was done. Afterwards, the grain weights were taken and moisture content determined using a moisture meter. Grain yield is therefore expressed at 12.5% moisture content.

3.7 Soil physical analysis

3.7.1 Bulk density

The double cylinder method was used for bulk density determination. The core sampler was driven into the soil to a depth of 15 cm. The sampler was carefully removed so as to obtain the soil with the natural structure. The soil extruding beyond each end of the sampler was trimmed with a knife before placing it in empty cans. The samples were taken to the laboratory where fresh weight was taken and oven dried to constant weight at 105 ^{0}C. The oven dried samples were first cooled before weighing. Weight of the empty sample holders was also taken and the bulk density calculated as follows (Hinga *et al.*, 1980);

BD = M(ds)/V

Where:

BD = Bulk density (g/cm^3)

M(ds) = Mass of dry soil sample (g)

V = Volume of the dry soil sample (cm^3)

3.7.2 Infiltration rate

The double ring method was used to measure infiltration rate (Anderson and Ingram, 1993). The ground was first soaked with water for a few hours before vertically driving the metal rings into the wet soil. Both cylinders were then filled with water to about 15 cm and water level measured every minute. Every time the water level fell to 5 cm the cylinders were refilled and measurements taken until a constant infiltration rate was obtained in cm/min.

3.8 Soil and foliar chemical analysis

3.8.1 Soil samples preparation

At NARL, the soil samples were transferred to special paper bags (soil cartons) and given code numbers. They were later placed in an oven and dried at 45°C for 24 hours. The dry samples were then crushed, ground and sieved through a 2 mm sieve.

3.8.2 Plant samples preparation

C. calothyrsus and *L. leucocephala* prunings were oven dried at 70°C for 48 hours. After drying, the samples were ground using a laboratory mill and passed through a 0.5 mm sieve. The powder-like product was packed in polythene bags, and stored prior to chemical analysis.

3.8.2.1 Dry ashing of plant material

Air dried materials were weighed in crucibles, placed in a muffle furnace at 400-500 °C for three hours. After ashing, the samples were removed from the furnace and allowed to cool. They were then moistened with 5 ml concentrated nitric acid and evaporated on a water bath. The resulting product was ashed again in a muffle furnace at 400 °C for 30 minutes, removed and allowed to cool after which 10 ml of 2.5 N hydrochloric acid was then cautiously added and heated on a water bath. The samples were then filtered through No. 42 filter papers into 50 ml volumetric flasks and the crucibles washed three times with distilled water. The solutions were then used for the determination of P, K, Na, Ca and Mg. Potassium and sodium were determined by flamephotometer, phosphorus by colorimeter, and magnesium and calcium by spectrophotometer.

3.8.3 pH determination

A sample of 20 mg of air dried soil was scooped, transferred to 100 ml plastic bottles and 20 ml of distilled water added to give a soil water ratio of 1:1. The mixture was shaken in a reciprocal shaker for 2 hours. pH buffer solutions of pH 4 and pH 7 were used to calibrate the meter before measurements were taken (Mehlich *et al.*, 1962; Hinga *et al*,. 1980).

3.8.4 Determination of total nitrogen

Both soil and plant nitrogen was determined using Kjedahl method (Black *et al.*, 1965; Hinga *et al.*, 1980). For soil nitrogen, 1 g of air-dried soil, ground to pass through 0.5 mm sieve was weighed and transferred into a Kjeldahl digestion tube. For plant nitrogen, 0.2 g of plant material was used. Selenium mixture (selenium powder, lithium sulphate and hydrogen peroxide) was added followed by concentrated sulphuric acid. The tubes were placed in the digestion apparatus and transferred into a fume chamber. A blank was also treated in a similar manner. The mixture was heated for about 3 hours, removed and allowed to cool. Distilled water was added to make up to the mark. Boric acid (10 ml) of 1% concentration was transferred into 100 ml conical flask and 3 drops of indicator (bromocresol green/blue and methyl red in ethanol) was added. The flask was placed into the distillation apparatus, 10 ml of the digest and 10 ml of sodium hydroxide transferred by pipette into the distillation flask and rinsed with small amounts of distilled water. As the first drops of the distillate reached the indicator, the colour changed from pink to green. Distillation continued for another 2 minutes after which the conical flask was lowered and distillation continued again for another minute. The tip of the condenser was rinsed with distilled water and the solution titrated with 0.01 N sulphuric acid until the colour changed. After a number of determinations a blank and a standard sample were run.

Calculations

$$\% N = (Vs-Vb) * N * 14 * a^{-1} * b^{-1}$$

Where:

Vs = ml sulphuric acid used for titration of the sample

Vb = ml sulphuric acid used for blank titration

N = Normality of H_2SO_4

a = ml digest taken for distillation (ml)

b = mg sample taken for analysis (g)

3.8.5 Determination of soil organic carbon (Walkey-Black, 1934)

A finely ground soil sample of 0.5 g was weighed, transferred to 500 ml conical flask and 10 ml of 1 N potassium dichromate was added using a burette while the flask was gently swirled to disperse the soil in the solution. The resulting suspension was taken to a fume chamber where concentrated sulphuric acid was added. This was gently swirled until soil and reagents were completely mixed, then swirled more vigourosily for another minute. The mixture was allowed to stand for 30 minutes before adding 150 ml distilled water. Five millimeters of phosphoric acid was then added to the suspension followed by ten drops of diphenylamine indicator. The solution was titrated with 0.5N ammonium ferrous sulphate to a pale green end point. Two blank samples containing Potassium dichromate were also titrated against ammonium ferrous sulphate.

Calculations

% organic carbon in the sample = B - T * 0.3 * V * W^{-1} * B^{-1}

Where:

B = Blank titre (ml)

T = Sample titre (ml)

W = weight of oven - dry soil in (g)

V = Volume of potassium dichromate (ml)

0.3 = (1 ml N $K_2Cr_2O_7$ is equivalent to 0.003 g C) X 100

3.8.6 Extraction of available soil P, Mg, Mn, K, Ca, K and Na

Five grams of soil was weighed and transferred into 50 ml bottles. A blank and a standard were also included. To the soil, 0.5 ml of activated charcoal and 2 ml of extracting solution (0.1 N hydrochloric acid and 0.25 N sulphuric acid) were added and mixed. The mixture was allowed to stand for one hour before shaking in a mechanical shaker for ten minutes. This was followed by filtering through the whatman filter paper No.2 and the resulting extract used in the determination of the above nutrients (Mehlich *et al.*, 1962)

3.8.7 Determination of P, Mg and Mn (calorimetrically)

Five milliliters of P standard solution and soil extract was pipetted into test tubes and one ml of ammonium vanadate - ammonium molybdate added and mixed. The optical density was read on the calorimeter after one hour at 430 μ. The results were expressed in ppm from the standard curve (Mehlich *et al.*, 1962).

One milliliter each of Mg standard and soil extract were pippeted into 50 ml volumetric flasks and 1 ml of lanthanum chrolide solution added and made to the mark with distilled water. After mixing the density of the mixture was read after one hour at 540 μ and the concentration expressed in percent milliequivalent % (m.e%) from the standard curve (Mehlich *et al.*, 1962).

One milliliter of manganese standard solution and soil extract were measured into a test tube and 4 ml of phosphoric acid-potassium periodate and 2ml of sodium hydroxide added. The density of the mixture was read after one hour at 520 μ and the concentration expressed in percent milliequivalent (m.e.%) from the standard curve (Mehlich *et al.*, 1962).

3.8.8 Determination of Calcium, potassium and sodium (flamephotometrically)

Twenty milliliters of the standard and 5 ml of anion exchange resin and 150 ml of distilled water were measured into 200 ml flasks. The mixture was shaken for 30 minutes and allowed to settle overnight after which the clear solution was decanted. The concentrations were read on the flame photometer using the appropriate filter lamps and expressed in percentage milliequivalent (Mehlich *et al.*, 1962).

3.9 Statistical analysis

All data was subjected to analysis of variance (ANOVA) using the general linear model (GLM) procedures of the Statistical Analysis System (SAS) package (Anonymous, 1985). Differences between treatment means were declared significant at $p=0.05$. Separation of means was done using Duncan's multiple range test in the same programme. Contrasts were also analysed to compare some treatments and only significant ones are shown in the text. The rest are presented in Appendix III

Only the statistical means are presented in the tables that follow. The analysis of variance (ANOVA) tables are contained in Appendix I. The f-probability shown in the anova tables is the actual probability as calculated by the SAS programme at 0.05 level of significance. The raw data is contained in Appendix II.

CHAPTER FOUR

4.0 RESULTS

4.1 General concept

After a uniformity study in 1992, the experiment was continued for three seasons, namely, 1993 long rainy season (1993 LR), 1993/94 short rainy season (1993/94 SR) and 1994 long rainy season (1994 LR). The 1992/93 SR soil data was before treatment application and thus acts as the baseline data.

4.2 Nutrients composition for *C. calothyrsus* and *L. leucocephala* prunings

The mean nitrogen, phosphorus, potassium, calcium and magnesium concentrations in the leaf prunings (leaves and tender twigs) of *C. calothyrsus* and *L. leucocephala* are shown in Table 6. The concentration of N in both leucaena and calliandra was variable, ranging from an average of 1.7% during 1993 LR to 3.1% during 1994 LR. In both species, N concentration in the material incorporated during 1993 LR season was significantly lower than that incorporated in the following seasons (1993/94 SR and 1994 LR). This was due to the high woody material incorporated during 1993 LR (see section 3.4.2.1). K was observed to be significantly higher in *L. leucocephala* prunings than *C. calothyrsus* during 1993 LR and 1994 LR. Calcium was highly variable across seasons ranging from 0.4 to 1.2%. P and Mg were more or less constant across seasons with an average of 0.2 and 0.4%, respectively.

Table 6: Mean nutrient concentration (%) of leaf prunings incorporated at the beginning of the 1993 LR, the 1993/94 SR and 1994 LR season.

Nutrient	1993 LR		1993/94 SR		1994 LR	
	Calliandra	Leucaena	Calliandra	Leucaena	Calliandra	Leucaena
Nitrogen (N)	1.7 b	2.1 b	2.9 a	3.1 a	2.8 a	3.0 a
Phosphorus (P)	0.2 a	0.2 a	0.1 a	0.2 a	0.1 a	0.2 a
Potassium (K)	1.2 b	1.6 a	0.9 b	1.2 b	1.2 b	1.7 a
Calcium (Ca)	0.8 b	0.9 b	0.6 b	0.7 b	1.0 a	1.2 a
Magnesium (Mg)	0.4 a	0.4 a	0.5 a	0.4 a	0.3 a	0.4 a

Means in the same row followed by the same letter are not significantly different according to Duncan's multiple range test ($p=0.05$).

4.3 Tree leafy biomass production and their nutrient contribution

Biomass production by *C. calothyrsus* and *L. leucocephala* is shown in Figure 3. Biomass production from both species was variable across the seasons ranging from 1.2 t/ha to 6.5 t/ha dry matter (DM). The biomass produced and incorporated during 1993 LR was significantly higher with an average of 6.4 t/ha than for the following seasons with an average of 1.7 t/ha. There were no clear differences in biomass production between the two species except 1993 LR when *L. leucocephala* produced more biomass than *C. calothyrsus*.

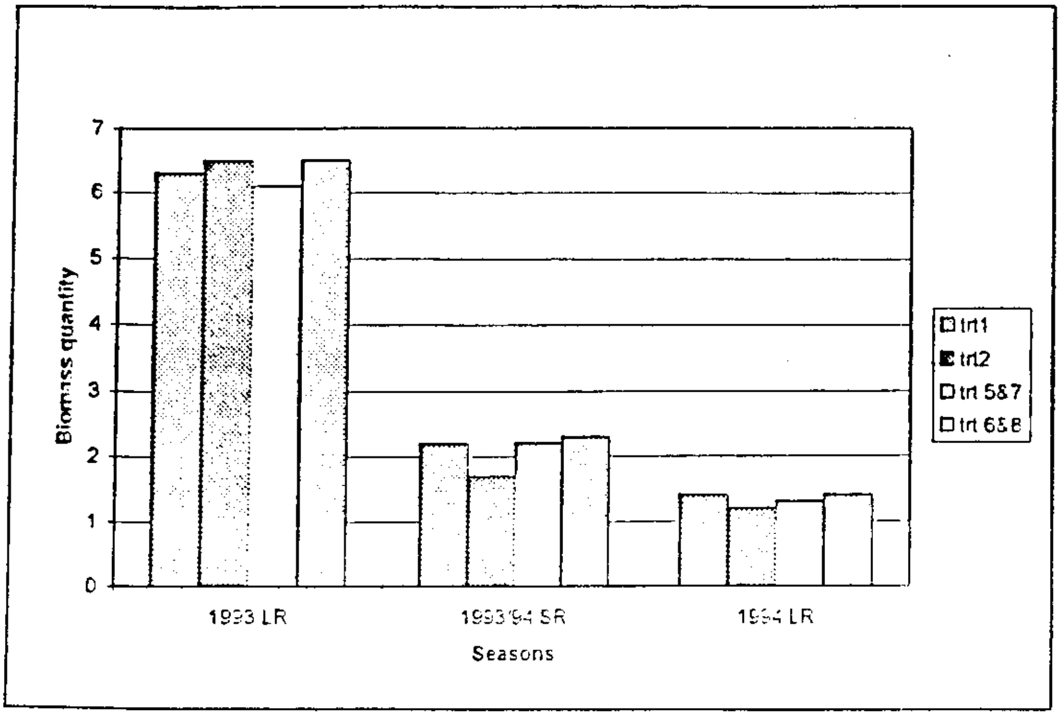


Figure 4: Biomass production over the study period

The contribution of each nutrient to the soil can be estimated from the mean biomass produced and the nutrient concentration in the prunings using the formular below;

Nutrient contribution = Quantity of prunings * Nutrient content in the prunings

The high biomass produced and incorporated into the soil at the beginning of the 1993 LR contributed to the high amounts of nutrients reflected in Table 7. During the (1993/94 SR and the 1994 LR, the biomass production was significantly low, resulting in very small amounts of nutrients supplied to the soil. *L. leucocephala* prunings contributed significantly higher levels of nutrients, especially N and K, than *C. calothyrsus*. This was mainly because of the relatively higher biomass production and higher nutrient concentration in the prunings of the former (Figure 3).

Table 7: Leafy biomass incorporated (t/ha) and nutrients (kg/ha) contribution to the soil at the beginning of 1993 LR, 1993/94 SR and 1994 LR

	TRT	Tree spp.	N	P	K	Ca	Mg
1993 LR	1	Calliandra	83 b	9.5 b	57 b	38 b	19 b
	2	Leucaena	139 a	13 a	106 a	58 a	26 a
	5 & 7	Calliandra	87 b	10 b	59 b	39 b	19 b
	6 & 8	Leucaena	142 a	14 a	108 a	61 a	27 a
1993/94 SR	1	Calliandra	30 b	1 b	13 b	6 a	8 a
	2	Leucaena	44 a	3 a	24 a	11 a	7 a
	5 & 7	Calliandra	32 b	1 b	13 b	18 a	8 a
	6 & 8	Leucaena	48 a	3 a	24 a	10 a	6 a
1994 LR	1	Calliandra	25 b	1 b	10 b	6 b	6 a
	2	Leucaena	32 a b	2 a	17 a	10 a	6 a
	5 & 7	Calliandra	24 b	1 b	10 b	4 b	6a
	6 & 8	Leucaena	41 a	3 a	21 a	11a	6a

Means followed by the same letter down the column in each season are not significantly different according to Duncan's multiple range test (P=0.05).

NB: Refer to Table 8 for simplified treatments

Table 8: Experimental treatments (Adopted from pg 18)

Treatments	Description
1	Alley crop, *C. calothyrsus* hedge, prunings incorporated
2	Alley crop, *L. leucocephala* hedge, prunings incorporated
3	Alley crop, *C. calothyrsus* hedge, prunings removed
4	Alley crop, *L. leucocephala* hedge, prunings removed
5	Monocrop, *C. calothyrsus* prunings incorporated
6	Monocrop, *L. leucocephala* prunings incorporated
7	Monocrop, *C. calothrysus* prunings + fertilizer
8	Monocrop, *L. leucocephala* prunings + fertilizer
9	Monocrop, no prunings, fertilizer
10	ontrol, monocrop, no hedge, no prunings and fertilizer

4.4 Soil status

Baseline soil samples were taken at the end of 1992/93 SR and the results are shown in Table 9. The soil was generally acidic with pH range between 5.1-5.6 (Table 9). The trend across seasons is not clear. Organic C was low (appendix Vc) ranged from 2.2 to 2.4% (Table 9) and was more or less constant during the three seasons. K and Mg levels were high (appendix Vb) and also did not change across seasons.

Table 9: Soil status at the end of 1992/93 SR

Trt	pH	Na	K	Ca	Mg	Mn	P pmm	N %	C %
1	5.6	0.5	1.1	3.8	1.2	0.6	13	0.2	2.2
2	5.4	0.5	1.1	3.3	1.2	0.7	13	0.2	2.3
3	5.6	0.5	1.1	3.6	1.5	0.5	15	0.2	2.2
4	5.6	0.5	1.2	3.3	1.4	0.9	13	0.2	2.1
5	5.1	0.4	0.7	2.1	1.0	0.8	11	0.2	2.1
6	5.5	0.5	1.3	3.4	1.5	0.6	12	0.2	2.2
7	5.6	0.5	1.3	4.1	1.1	0.6	15	0.2	2.3
8	5.4	0.4	0.7	2.4	1.6	1.3	13	0.2	2.2
9	5.5	0.4	1.0	3.4	1.3	0.8	14	0.2	2.0
10	5.5	0.4	1.1	3.5	1.2	0.4	15	0.2	2.2
f-prob	0.75	0.94	0.79	0.79	0.60	0.15	0.49	0.92	0.71
CV%	6	32	47	47	32	17	22	10	10

F-prob = f-probability at p=0.05

Trt = Treatment

Na, K, Ca, Mg, Mn in m.e %

Analysis of variance (ANOVA) for soil sampled taken at the end of 1993 LR, 1993/94 SR and 1994 LR, revealed no significant differences among treatments, except for nitrogen and infiltration rates, thus the results are presented in APPENDIX I . Nitrogen and infiltration rate was significantly higher in treatments with leaf prunings incorporated and with tree hedges during 1994 LR (Table 10).

Table 10: Infiltration rate (cm/min) for soil sampled at the end of 1993 LR, 1993/94 SR and 1994 LR

Treatment	1993 LR	1993/94 SR	1994 LR
1	0.9 a	1.0 a	1.3 abc
2	0.9 a	0.9 a	1.2 abc
3	0.7 a	0.7 a	0.9 de
4	0.8 a	0.8 a	0.8 cd
5	1.0 a	1.0 a	1.4 a
6	1.1 a	1.1 a	1.3 ab
7	1.0 a	1.0 a	1.6 a
8	1.1 a	1.1 a	1.3 ab
9	0.7 a	0.7 a	0.8 d
10	0.7 a	0.7 a	0.8 d

Means followed by the same letter down the column in each season are not significantly different according to Duncan's multiple range test (P=0.05).

The C:N ratios and N% for soil sampled at the end of 1992/93 SR were similar in all treatments in the range of 10:1 (Table 11). During the following seasons, the trends were not clear but major differences were observed between C:N ratios of 1992/93 SR and 1994 LR. In treatments 1 and 2 (hedge + prunings incorporation), and 7 and 8 (fertilizer + prunings incorporation), C:N ratios decreased by 30% wherease in the other treatments C:N ratios remained more or less constant with small changes (Table 11). The decrease in C:N values in the forementioned treatments was mainly due to increase in N% in the soil.

Table 11: C:N ratios and Nitrogen (%) in soil changes across seasons

TRT	1992/93 SR		1993 LR		1993 SR		1994 LR		% change from 1992 SR-1994 LR	
	C:N	N	C:N	N	C:N	N	C:N	N	C:N	N
1&2	12	0.2	12	0.2	10	0.24	8	0.3	-30%	+50%
3&4	11	0.2	12	0.2	11	0.21	11	0.2	0	0
5&6	11	0.2	11	0.2	10	0.23	10	0.3	-9%	+50%
7&8	12	0.2	9	0.2	8	0.25	8	0.3	-30%	+50%
9	10	0.2	12	0.2	11	0.19	11	0.2	+9%	0
10	11	0.2	11	0.2	10	0.22	12	0.2	+8%	0

NB: For ease of comparison similar treatments (Table 8) are combined and means reported.

Phosphorus deficiency was realised in all seasons except during 1994 LR which showed drastic increase (Table 12). This drastic increase was due to single superphosphate (SSP) fertilizer applied at the rate of 25 kg/ha at the beginning of 1994 LR. The critical Mehlich P level in these soils is 20 ppm (Irambu, personal communication, 1994 and

Appendix 5b. P is also observed to decrease from an average of 13 ppm in 1992/93 SR to an average of 10 ppm in 1993/94 SR (Table 12).

Ca generally decreased in all treatments across seasons from an average of 3.4 m.e% in 1992/93 SR to 2.4 m.e.% in 1994 LR. Calcium levels in the treatments with leaf prunings incorporated (1&2, 5&6 and 7&8), were observed to have a smaller percentage decrease, in the range of 11% to 19% than those without leaf prunings incorporation in the range of 24% to 50% (Table 12).

Table 12: Calcium levels in m.e% and Phosphorus (ppm) changes across seasons

TRT	1992/93 SR		1993 LR		1993/94 SR		1994 LR		% change (1992 SR-1994 LR)	
	Ca	P	Ca	P	Ca	P	Ca	P	Ca	P
1&2	3.6	13	3.8	10	3.3	10	2.9	65	-19%	400%
3&4	3.5	14	3.3	7	2.3	8	2.1	62	-40%	343%
5&6	2.8	12	3.2	7	2.6	9	2.5	65	-11%	440%
7&8	3.3	14	3.8	10	4.2	10	2.3	70	-21%	400%
9	3.4	11	3.9	10	3.3	14	2.6	69	-24%	527%
10	3.5	15	3.5	8	2.9	10	1.8	64	-50%	326%
Mean	3.4	13	3.6	9	3.1	10	2.4	66		

TRT= Treatment

NB: Similar treatments (Table 8) have been combined and mean reported for ease of comparison

4.5 Crop yields

During 1993 LR, there were no significant differences (P=0.05) in maize grain yield among the treatments, but generally treatments with leaf prunings incorporated had higher maize grain yield than treatments without leaf prunings incorporated (Table 13). The lowest yields were obtained from the control (treatment 10), and the treatment with leucaena hedge and leaf prunings removed (Treatment 4), while the highest were obtained from calliandra tree hedge intercrop with leaf prunings incorporated (Treatment 1) and the maize monocrop with calliandra leaf prunings incorporated (Treatment 5).

The maize yield during the 1993/94 SR (Table 13) was generally low compared to the previous seasons because of drought (Figure 4). The crop yields (maize and beans) were slightly higher in non-tree hedge treatments than the tree hedge treatments although not significantly. The hedge treatments (Treatments 1, 2, 3 and 4) had the lowest maize grain yield with means of 174 kg/ha and 93 kg/ha for hedge with prunings incorporated treatments (1&2) and hedge with prunings removed (3&4) respectively (Table 14). Means maize grain yield of all the non hedge treatments (5, 6, 7, 8 and 9) yielded more than the control treatment. The percentage difference over the control ranged from 40-57% (Table 14).

The best treatments in terms of mean bean yield during 1993/94 SR, was 7 and 8 followed by 5, 6, 9, 10 and lastly the tree-hedge treatments in a descending order 1, 4, 3, and 2 (Table 13). Significant differences (P=0.05) were observed between treatment

7 and 2. Generally, leaf prunings incorporated plus fertilizer treatments performed better than fertilizer alone treatment. The yield differences over the control for prunings plus fertilizer treatments was 25% compared to 5% and 12% for prunings alone and fertilizer treatment respectively (Table 13).

The maize grain yield for 1994 LR (Table 13), was generally low with a mean yield of 1013 kg/ha due to a serious attack by chafer grubs during germination, and possibly P deficiency. The fertilizer treatments performed better in terms of maize grain yield than all the other treatments. Treatments, i.e., 7, 8 and 9 had significantly higher yields than all the other treatments ($p=0.05$).

During 1993 LR, the contrast between 1 and 2 (prunings incorporated) versus 3 and 4 (prunings removed) was found to be significant (Table 15). This is an indication that in alley cropping, the associated crop would benefit from prunings incorporation. During 1993 SR, it was only treatment 5 and 7 which showed significant contrast with the ccontrol. However, there were many significant contrasts during 1994 LR as shown in Table 15.

Table 13: Grain yields in kg/ha during 1993 LR, 1993/94 SR and 1994 LR

Treatment	1993 LR	1993/94		1994 LR
	maize	maize	bean	maize
1	2350 a	143 b	310 ab	279 cd
2	2167 a	204 ab	165 b	150 d
3	1659 a	95 b	231 ab	383 cd
4	1466 a	190 ab	306 ab	464 cd
5	1854 a	561 a	414 ab	307 cd
6	1617 a	257 ab	350 ab	938 cd
7	2120 a	567 a	518 a	2059 b
8	1840 a	297 ab	453 ab	2539 ab
9	1622 a	309 ab	413 ab	3008 a
10	1417 a	186 ab	364 ab	1139 c

Means followed by the same letter down the column are not statistically different according to Duncan's multiple range test (P=0.05).

Table: 14 Grain yield (kg/ha) differences in % over the control during 1993/94 SR and 1994 LR

Treatments	1993/94 SR Maize		1993/94 SR Bean		1994 LR Maize	
	Mean	Diff. (%)	Mean	Diff. (%)	Mean	Diff.(%)
Hedge+Prunings	174	-7% NS	237	-35% NS	214	-81% *
Hedge-prunings	93	-23% NS	267	-26% NS	423	-63% *
Prunings alone	409	+54% NS	382	+5% NS	623	-49% NS
Prunings+fertilizer	432	+57% *	485	+25% NS	2299	50% *
Fertilizer	309	+40% NS	413	+12% NS	3008	62% *
control	186		364		1139	

Diff. = Difference

* contrast significant (p=0.05)

NS contrast not significant (0.05)

NB: Similar treatments (Table 8) have been combined and means reported for ease of comparison

Table 15: Other Significant contrasts for crop yields

Season	contrast
1993 long rains	1 and 2** vs 3 and 4
1993 short rains *	7** vs 10 5** vs 10
1994 long rains	1 vs 10** 2 vs 10** 7** vs 10 9** vs 10 7 and 8 vs 9** 5 vs 10** 3 and 4 vs 10** 7 and 8 vs 10**

* = Maize crop only

** = significantly higher (P=0.05)

4.6 Rainfall distribution

Rainfall distribution during the study period is shown in Figure 5. Distribution was observed to be variable, both monthly and seasonally. During 1994 SR (September to October 1994), rainfall was below normal causing drought during this season.

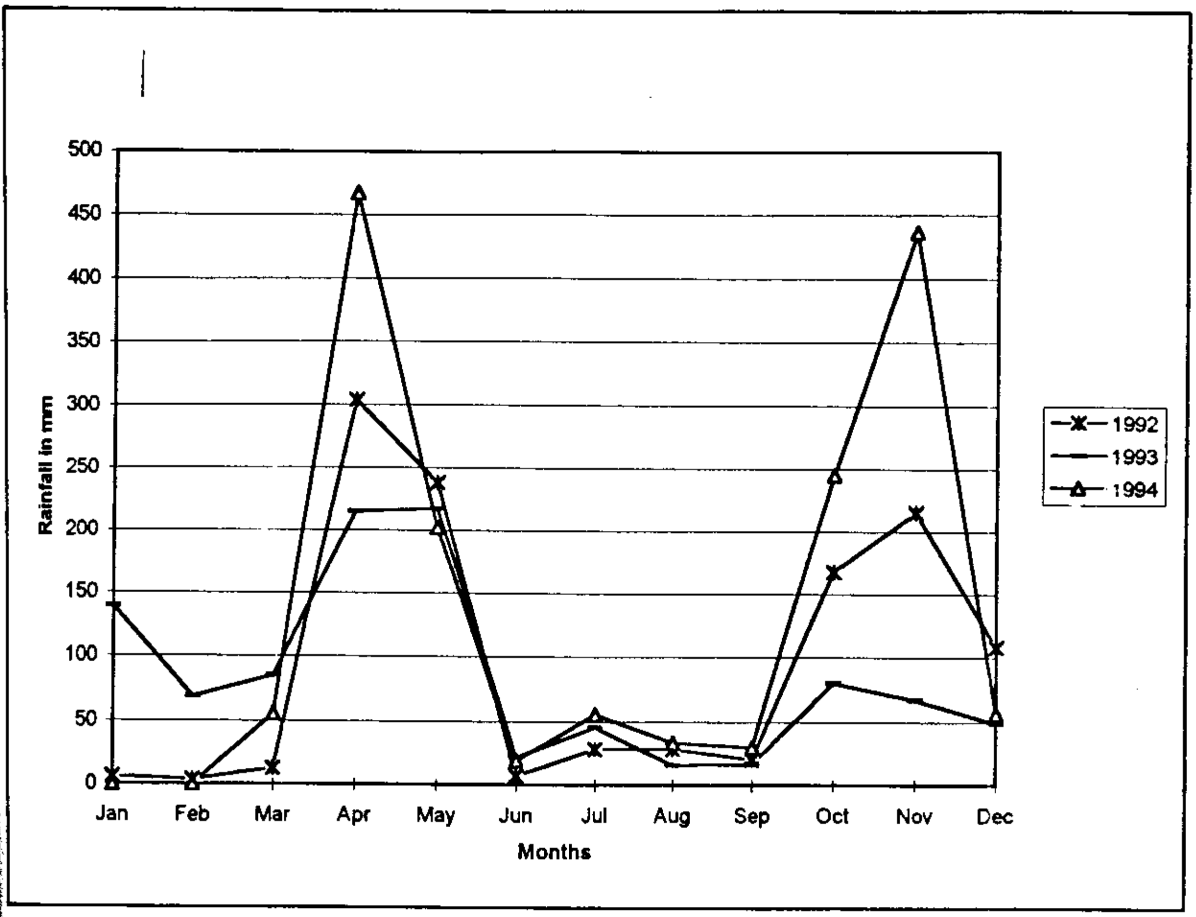


Figure 5: Rainfall distribution over the study period

CHAPTER FIVE

5.0 DISCUSSION AND CONCLUSIONS

5.1 Quantity and quality of biomass production

The amount of leaf prunings applied in this experiment was low. Apart from the beginning of 1993 LR season where an average of 6.4 t/ha and 6.2 t/ha of biomass (leucaena and calliandra) were applied, respectively, the following seasons biomass production was very low (Figure 3). This meant that, the nutrient contribution of the leaf prunings to the soil was small and this may explain why incorporation of leaf prunings did not cause significant changes in soil nutrient status among treatments. In studies where soil incorporated prunings from alley cropping have been found to improve soil nutrient status and crop yields, the tree biomass production in those particular instances were large, in the order of 6-8 DM t/ha/yr using species like *L. leucocephala* (Duguma, 1988; Kang *et al.*,1985). Indeed, Mathews *et al.*, (1992) and Yadvinder *et al.*, (1992) suggested that, one of the factors determining contribution of nutrients made to the soil by the prunings depends on quantity thus plays a major role in alley cropping where the prunings act as a source of nutrients for the associated crop.

The nutrient content of the prunings depends on many factors, including tree species and the nutrient concentrations of the incorporated material (Budelman, 1989; Palm, 1995). In this study, *L. leucocephala* contributed more nutrients to the soil than *C. calothyrsus* mainly because the former contained higher nutrient concentration, and produced relatively higher biomass. Generally, the quality of prunings applied was low, with an average of 2.6% N, 0.2% P, 1.0% K, 0.85 Ca and 0.4% Mg compared to other studies where nutrient concentrations of 4.2% N, 2.5% K, 1.49% Ca have been realised (Wilson *et al.*, 1986; Kang *et al.*, 1984). The low amount of nutrients, especially N, in this study especially during 1993 LR, could be attributed to large amounts of woody material incorporated during this season. The amount of nutrients provided by the prunings are determined by the relative proportions of leaves and stems (Palm, 1995).

The decrease in biomass production across seasons observed in this experiment limits the amount of nutrients being supplied to the soil. During 1993 LR, when biomass production was relatively high, with an average of 6.2 and 6.3 t/ha for *C. calothyrsus* and *L. leucocephala* respectively, nutrient supply was large in the range of 85-141 kg/ha N as compared to 1994 LR where N supplied was in the range of 36-42 kg/ha (Figure 3). This is below the recommended rate (50 kg/ha) of N application in these areas. This could have contributed to the differences in crop response observed during the two seasons. Since in alley cropping nutrients are availed to the soil by prunings (green manure) harvested from the hedgerows (Kang *et al.*, 1985), this technology is likely to be limited by the low biomass production.

5.2 Effect of leaf prunings on soil nutrients

The results of this study show that, application of leaf prunings of *L. leucocephala* or *C. calothyrsus* did not significantly affect soil pH levels, C, P, K, Ca, Mg and Mn among the treatments. This could have been due to insufficient biomass quantities as formerly explained. In similar studies, values in kg/ha/yr of as high as 358 N, 28 P, 232 K, 144 K and 60 Mg have been recorded (Young, 1989; Szott *et al.*, 1991). Kang *et al.*, (1985), Tomar *et al.*, (1992) and Tian *et al.*, (1993) reported significant increases in soil organic matter as well as K, Ca, Mg levels from additions of high rates of leguminous shrubs in the range of 7-10 t/ha. Onim *et al.*, (1990) realised increased soil organic matter (SOM), and total N, when they applied 16 t/ha of leucaena leaf mulch in deep red soil (Nitisols) in six applications spread over a 12-month period in Kenya. This is almost twice the amount applied in the present experiment for a period of one and a half years. However, as studies by Palm (1988) suggest, differences between sites, soils and mulch species could confound the effects of high rates of mulch application on soil organic carbon.

The C added in prunings in the present experiment, about 45% of the prunings (appendix IIId) could have been oxidized into carbon dioxide during the season. The warm temperatures in the range of 18-24^{0}C centigrade (see 3.1) could have enhanced the oxidation, thus no increase in C was realised even after relatively high quantities of prunings in the range of 6.4 t/ha during 1993 LR. The changes in soil C could also have been small, not detectable by the conventional soil analysis methods used in the study. For example, the wet oxidation method (section 3.8.5) used for determination of organic carbon could not have been sensitive enough to detect small changes. Barrios *et al.*, 1996 realised changes in C and N in several soil organic matter (SOM) fractions, but not with total organic carbon. They recommended use of these different SOM fractions as sensitive measure of differences in SOM.

Another possible explanation for the lack of any treatment related differences in the soil C and the major plant nutrients in the present study could have been due to plant uptake of nutrients during the growing season and loss of nutrients from the soil by volatilization, leaching and also by surface runoff after the release of the nutrients following mineralization. The soil C:N ratio of less than 20 (Table 11) indicates that mineralization is dominant. In addition, prunings of *C.calothyrsus* and *L. leucocephala* applied had high decomposition rates (Mugendi, 1995; O'Neill *et al.*, 1993) as they had a narrow C:N ratios (Appendix V) which was necessary for mineralization. Lack of significant changes in nutrients following leguminous prunings application compares well with those of Rosecrance *et al.*, (1992), who after 4 years of alley cropping on vertic Haplustoll/Haplic kastanozems, observed no improvement in N, P, K, Ca, Mg and organic C in alley cropped plots compared to the control, despite the fact that at least 15 t/ha dry weight prunings were applied to the soils each year. This, however, differs from results found by Weeraratna and Ashgar (1992), who found significant improvement in soil nutrient status in an Inceptisol/Cambisols after one year of prunings application as mulch. They, however, cut and carried the mulch onto the plots and applied substantially larger quantities of 30-60 t/ha.

In this study there is a possibility that, some N could also have been lost through leaching and volatilization. High quality materials (low in polyphenols and having narrow C:N ratios) like *L. leucocephala* and *C. calothyrsus* that release N rapidly are known to lose more N via volatilization (Glasener, 1991).

The slight N-build up and the corresponding decrease of C:N (Table 11) in soil observed in treatments with leaf prunings incorporated could be explained by the prunings supplying N into the soil (Table 3). Danso and Morgan (1993) also realised increased N content in a sandy loam soil where prunings were applied. This N could have been contained in the soil organic matter inorganic N (Brady, 1984). Haggar *et al.*, (1993), based on a detailed labelling study of *E. poeppigiana* and *G. sepium*, concluded that the majority of the N ends up in some readily mineralized fraction of the soil organic matter. Ladd *et al.*, (1981) found for a legume-wheat rotation that the first crop recovered only 11-17% of the N added as legume and that 72-78% was found in the soil organic matter. The benefits of the leaf prunings incorporation to the crop may be through the long term build up of N rather than the direct use of N, from the decomposing prunings (Palm, 1995)

In other studies results have been inconsistent, for example Lal (1989) in an Oxic Paleustalf/Dystric planosols in Nigeria, reported a decrease in organic carbon from an average of 2.37% to 0.73% over four year period in all treatments including the hedgerow intercropping plots and attributed this to rapid oxidation and soil erosion. Murethi *et al.*, (1994) reported a decline in soil organic carbon at the Kenyan coast with soils classified as Orthox (USDA) and Orthic Ferralsols/Ferric Acrisols (FAO/UNESCO) Yamoah *et al.*, (1986c) and Kang and Wilson (1987) reported increased organic carbon in long term alley cropping treatments. It then appears that changes in organic carbon might be influenced by soil type, climate and duration of the experiment.

The available P deficiency realised at the end of all seasons except 1994 LR, could have been mainly due to plant uptake during the growing seasons combined with some P fixation. These soils (Nitisols), rich in iron and aluminium oxides are known to be high fixers of P (Brady, 1984). Another possible explanation for the decreasing P levels across seasons could be that the prunings incorporated could not supply sufficient quantities of P possibly because of the low P concentration in the prunings (Table 3). Similarly, results where available P declined at the end of each growing season in alley cropping trials were obtained with *G. sepium* (Yamoah, 1986a), *L. leucocephala* and *F. macrophylla* (Danso and Morgan, 1993a) and with *S. siamea* (Danso and Morgan, 1993b), although these declines were not significant among treatments. Nutrient budgets accounting for nutrients added in prunings show insufficient amount of P in prunings in most tree species (Palm *et al.*, 1991; Salazari *et al.*, 1993). With high concentrations of P in prunings, nutrient contributions can be large. For example, Jama (1993) in semi-arid area of Machakos observed increased concentrations of soil P in *S. siamea* green leaf applied plots and attributed it to high levels of P in *S. siamea* leaves.

Another possible explanation for lack of change in P among the treatments is insensitivity of the conventional soil analysis used to pick small changes. For instance, work at Western Kenya, Maroko *et al.*, 1996), found none of the conventional measures of extractable inorganic P detected differences among treatments involving continous maize cropping, natural fallow and sesbania fallow. However, considerable differences were found in P associated with SOM fractions and microbial biomass P.

5.3 Effect of leaf prunings on soil physical properties

Treatments with leaf prunings incorporated, and with tree hedges, tended to have significant increases in soil infiltration rates compared to treatments without prunings incorporation at the end of 1994 LR (Table 10). This could be due to the organic material supplied to the soil by the leaf prunings and the influence of the tree roots. According to Brady (1984), organic materials are known to increase soil aggregation and porosity thus increasing the amount of space between the soil for water to infiltrate through. The tree roots are also known to contribute to increased porosity in the soil. These results are similar to those of Rosecrance *et al.* (1992) who, after four years of mulch application, found measurably greater soil water holding capacity and bulk density in the mulch treated plots in comparison with treatments without mulch. There were also significant increases in pore volume fraction and infiltration rate in *L. leucocephala* plots (Dallard *et al.*, 1993)

The differences in infiltration rate observed are associated with changes in physical properties, the major one being bulk density. In this study, bulk density remained constant, so it is surprising that infiltration rate changed. The explanation for this could have been errors during field measurements of infiltration rate. Indeed, Anderson and Ingram, 1993 have mentioned that errors can be encountered duriing field measurements.

The lack of change in bulk density was attributed to the constant soil organic C levels ranging between 2.2-2.4% (Appendix I) over the study period. Like many other properties, soil bulk density is influenced by changes in soil organic matter (Allison, 1973). Another possible explanation of the constant bulk density, could be the low biomass production due to sub-humid climatic conditions coupled with short duration of this study. Several workers have noted significant improvements in soil bulk density in the humid lowlands of Nigeria, where mulch yields as high as 8-10 t/ha/yr (dry matter) were obtained from hedgerows, in studies spanning four years (Yamoah *et al.*, 1986c). In the current study, biomass production was lower than those obtained by Yamoah and colleagues.

5.4 Effect of hedgerows on crop performance

The alley cropped treatments performed poorly in terms of crop yields during the 1993/94 SR and 1994 LR seasons when significant differences ($p=0.05$) among treatments were realised (Table 13). These yield reductions could be attributed to competition between the tree hedges with the crops for the same growth resources; mainly light, nutrients and possibly water. Kang (1993) stated that in the humid zone, competition between hedgerows and crops for nutrients could be very severe because both woody species and crops have the tendency to concentrate their roots in the surface soil. Research at ICRAF station, Machakos, Kenya has shown that the root systems of *L. leucocephala* tends to be more superficial when managed as hedges leading to severe competition with crops particularly in soils depleted of nutrients (Anonymous, 1993). In the present study, such competition could have occured in the alley cropped plots, thereby contributing to the consistently low and declining yields in these plots.

Analysis of alley cropping system using tree crop interaction equation (Sanchez, 1995) has shown that the negative effects of competition frequently outweigh the benefits of improved fertility provided by the trees. In the semi-arid areas, competition for moisture is the most limiting factor to improved production (Coulson *et al.*, 1989; Mittal and Singh, 1989). In the humid and sub-humid tropics, where moisture is not expected to be limiting but fertility may be, trials still show a major competition effect because of competition for nutrients, light and water (Anonymous, 1993). In the present study, rainfall during 1993/94 SR was below normal (Figure 3) and could have resulted to severe moisture competition especially in the hedge treatments.

Yield reductions in the alley cropped plots compared with the controls have been found in acid soils (Typic Ustropepts/Humic cambisols) in Indonesia (Evensen, 1989; Szott, 1987) and in many other parts of the world (Basri *et al.*, 1990; Evensen and Yost, 1990; Fernades, 1990). In the present study, rows next to the tree hedges were observed to be stunted during the growing season, and always yielded less than the middle rows, and this contributed to the overall lower yields in the alley plots in comparison to the monocrops. Similarly, rows closest to the hedge have been reported to have the lowest yields in rice (Evensen, 1989) castor and sorghum (Matta-Machado and Jordan, 1995; Singh *et al.*, 1989), sweet potatoes (Yamoah and Getahum, 1990) and in maize yields (Jama, 1993; Rosecrance, *et al.*, 1992).

The lack of significant maize grain yield differences during the 1992/93 SR and 1993 LR could be attributed to lack of competition during the initial stages of hedge establishment when nutrient demand for the tree species was low. Similarly, Fernandes (1990) noted that reduced crop yield due to root competition between hedgerows and the crops in the alleys were detected eleven months after hedgerows establishment and that competition increased with the age of the hedgerows as measured by the steadily declining crop yields close to the hedgerows. However, beneficial aspects of superficial root systems are that, they may reduce loss of nutrients by leaching and soil erosion while at the same time improving porosity, infiltration and aeration (Lundgren, 1979).

5.5 Effect of leaf prunings and fertilization on crop performance

The consistently higher yields observed during all seasons in the fertilizer treatments than the others could be attributed to readily available nutrients from the fertilizers. Nutrients from the leaf prunings must undergo microbial decomposition before they are available for crop uptake. Similar results were obtained by Danso and Morgan (1993a) in alley cropping trials with cassia, where application of fertilizer at full recommended rate plus prunings produced the highest maize yields. Lal (1989), concluded that high yields could not be sustained with prunings alone thus the importance of fertilizer supplementation. A study by Chirwa *et al.*, (1994) found better maize growth and dry matter production in fertilized alleys than in unfertilized alleys. In fact, fertilized alleys produced twice as much grain as in the unfertilized alleys and suggested that the prunings alone were not an efficient source of nutrients.

The importance of fertilizer in this alley cropping study is not surprising as this has been mentioned by several authors. For example, Yamoah et al., (1986c) indicated that N-supplementation was necessary in alley cropping systems to optimize yields and Bashir (1988) found benefits of the use of chemical fertilizers in supplementing the advantages of green manure. This is an indication that, nutrients from prunings alone may not be sufficient for crop establishment, and growth, and inorganic fertilizers are needed as supplements. Use of organic materials (green manure/mulch), may however, be beneficial because one of the main agronomic effects of adding organic materials to the soil is that of enhancing lateral growth and abundance of roots (Allmaras and Nelson, 1971; Chaudhary and Prihar, 1974) which may result in high nutrient use efficiency in the surface soil (Russel, 1977).

The low maize grain yield during 1994 LR, could have partly been to P deficiency during the growing season though the soil sampled indicates high quantities of P. The single superphosphate fertilizer (SSP) applied at the beginning of the 1994 LR season seemed not to have been utilized during the growing season. A mid-season general assessment of all the plots indicated deficiency symptoms for phosphorus, and nitrogen, which included yellow and purple colouration and many stunted maize plants. The stunted maize plants when uprooted showed poor root development, while white crystals of the phosphate fertilizer applied at the beginning of the season were still visible in the soil. Lack of efficient utilization of this phosphate fertilizer could have been due to low solubility and high phosphorus fixing capacity of these soils.

The hedgerow treatments and prunings alone incorporated treatments had very low yields during 1994 LR as compared to fertilizer and control treatments. This could have been attributed to the attack of the germinating seedlings by chafer grubs at the beginning of the season. They (chafer grubs) are known to prefer areas with organic materials (Sutherland and Ouma, 1995), thus the attack was more prevalent in treatments where leaf prunings were incorporated.

In this experiment, there were no consistent or clear differences in soil characteristics observed over the three seasons under investigation except N and Ca, and infiltration rate. The significant differences in crop yields during 1993/94 SR and 1994 LR observed among treatments may indicate differences in the soil status at some time during the growing season, more available nutrients in some treatments which could not be detected at the end of the growing season. The soil was always sampled at the end of the growing season and there is a possibility that the nutrients available were used up during the growing season. This can further be explained by the fact that *L. leucocephala* and *C. calothyrsus* leaf prunings have been reported to decompose relatively fast releasing nutrients into the soil within a very short period (Young, 1989; O'Neill *et al.*, 1994). These nutrients may have been immediately taken up by the crop.

Addition of prunings alone to sole crops, seemed to benefit the maize crop during 1993/94 SR where yields increased by 54% over the control treatment. These high yields during 1993/94 SR could have been due to the combined effect of leaf prunings applied during 1993 LR and 1993/94 SR (note the high tree leaf biomass production during 1994 LR (Figure 3). Similarly, Rosecrance *et al.*, (1992) observed a linear response of maize yields in alley cropping to N applied as green manure. The yield of beans during this season was higher with addition of prunings and fertilizer than with addition of either prunings alone or fertilizer alone (Table 13). This may suggest a beneficial effect of combining prunings with fertilizer. Mathews *et al.*, (1992) in a similar study realised net benefit of N supplied by *L. leucocephala* prunings and suggested that *L. leucocephala* was compensating the crop with a net equivalent of between 60 and 120 N kg/ha. They also observed increased grain quality with applications of prunings.

Although this study did not demonstrate clearly the benefits of combining fertilizer with prunings of the leguminous trees for the short term period, there was evidence of increased soil N as shown by the steady build up of N following prunings application. In other similar studies the advantages of combining prunings with fertilizer has been realised, e.g. Tian *et al.*, (1993) found that nutrient uptake was higher when N was partially applied as prunings, indicating the importance of the combined addition of plant residues and fertilizer for improving crop production.

CHAPTER 6

6.0 Conclusions and recommendations

During the three seasons under investigation, the addition of leaf prunings did not cause any significant changes in soil pH levels and macro nutrients except N and Ca. In the prunings incorporated treatments, there was slight build up of N by about 50%. Ca levels decreased in all plots from an average of 3.4 to 2.4 m.e.%, but decreased less in the treatments with leaf prunings. This was attributed to the prunings supplying nutrients to the soil after decomposition.

Lack of significant changes in soil status was ascribed to low biomass incorporated from the hedgerows, and inability of conventional soil analysis methods employed to detect small changes. Other contributing factors could have been due to nutrient uptake by the crop and subsequent nutrient removal via crop harvests (maize grain and stover). Other losses could have through volatilization, leaching and surface runoff.

Soil infiltration rate increased significantly in treatments with addition of prunings both in the alley cropped plots and the solecrop plots. This was attributed to added organic materials increasing soil pore volume and aggregation and also the influence of the tree roots. Bulk density remained constant ranging from 1.1-1.2 cm/g3. This was due to lack of change in organic carbon which remained constant in the range of 2.1-2.4%.

During the three seasons under consideration, yields declined substantially and was attributable to depletion of nutrients due to removal of nutrients in crop harvests without adequate soil nutrient replenishment. Biomass production was low, thus nutrients supplied into the soil via incorporated nutrients was low. The fertilizer applied treatments, tended to have consistently higher yields than either leaf prunings alone, or the alley cropping treatments, because fertilizer was supplying additional available nutrients for the crops to utilize.

From the results of this study, the feasibility of using leaf prunings (direct incorporation) for soil improvement, or yield sustainability in an alley cropping system is limited with the tree species used. This was mainly attributed to low biomass production, and possibly competition between the tree-hedges and the crops for growth resources. In sole cropping system, incorporation of leguminous leaf prunings as source of plant nutrient seem feasible but with fertilizer supplementation.

Due to the beneficial effect of the alley cropping system on soil, a very important agricultural resource, reported else where, the contribution of leaf prunings as green manure both in alley and sole cropping systems need to be considered more critically in future. The following recommendations emerge from this experiment:

(i) More research is needed on the interactions between crops and hedgerows, particularly below ground interactions, to provide a better understanding for improving the system.

(ii) Nutrient dynamics, especially phosphorus and nitrogen, following prunings application need to be studied to determine the actual contribution of prunings to, and the efficiency of nutrient utilization by the associated crop.

(iii) Long term effects on soil chemical and physical properties of prunings application should be compared with the use of fertilizer.

(iv) Time of nutrient release from prunings requires further study.

(v) Opportunities of using *Calliandra calothyrsus*, and other promising fodder legumes for soil erosion control and fodder production, and the possibilities of improving soil fertility through recycling of nutrients by manure should be explored.

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8.0 APPENDICES

APPENDIX 1: **Data for soil sampled at the end of 1993 LR, 1993 SR and 1994 LR**

Appendix 1a: **Soil status at the end of 1993 LR**

Treatment	pH	Na m.e%	K m.e%	Ca m.e%	Mg m.e%	Mn m.e%	P pmm	N %	C %	Infil (cm/min)	B.D. cm/g^3
1	5.5 (0.1)	0.7 (0.2)	1.4 (0.4)	3.8 (0.8)	2.8 (0.5)	1.5 (0.1)	10 (5)	0.2 (0.02)	2.3 (0.1)	0.9 (0.5)	1.1 (0.1)
2	5.4 (0.2)	1.0 (0.3)	1.3 (0.5)	3.7 (1.2)	3.0 (1.0)	1.6 (0.3)	9 (3)	0.2 (0.03)	2.3 (0.3)	0.9 (0.5)	1.1 (0.1)
3	5.4 (0.2)	0.6 (0.2)	1.2 (0.4)	3.1 (0.9)	2.4 (0.9)	1.2 (0.3)	7 (2)	0.2 (0.02)	2.2 (0.3)	0.7 (0.2)	1.1 (0.1)
4	5.3 (0.2)	0.6 (0.2)	1.0 (0.5)	3.5 (1.0)	2.3 (1.0)	1.3 (0.3)	6 (3)	0.2 (0.03)	2.1 (0.2)	0.8 (0.2)	1.1 (0.1)
5	5.1 (0.2)	0.4 (0.2)	0.7 (0.5)	2.9 (0.9)	2.2 (0.6)	1.3 (0.3)	5 (3)	0.2 (0.02)	2.1 (0.2)	1.0 (0.4)	1.1 (0.1)
6	5.4 (0.2)	0.6 (0.2)	1.0 (0.4)	3.5 (0.7)	2.5 (0.3)	1.3 (0.3)	8 (3)	0.2 (0.05)	2.3 (0.2)	1.1 (0.4)	1.1 (0.1)
7	5.5 (0.2)	0.7 (0.1)	1.3 (0.4)	3.9 (1.5)	2.6 (0.9)	1.4 (0.4)	9 (3)	0.2 (0.04)	2.2 (0.4)	1.0 (0.3)	1.1 (0.10
8	5.3 (0.2)	0.5 (0.2)	1.0 (0.5)	3.6 (1.5)	2.9 (0.9)	1.3 (0.4)	11 (4)	0.2 (0.02)	2.2 (0.4)	1.1 (0.3)	1.1 (0.1)
9	5.3 (0.2)	0.6 (0.2)	1.1 (0.4)	3.9 (1.0)	2.3 (0.6)	1.2 (0.3)	10 (5)	0.2 (0.02)	2.2 (0.4)	0.7 (0.2)	1.1 (0.1)
10	5.5 (0.3)	0.6 (0.2)	1.1 (0.3)	3.5(0.9)	1.2(0.3)	1.4 (0.6)	8 (3)	0.2 0.03	2.2 (0.1)	0.7 (0.3)	1.1 (0.1)
f-prob	0.11	0.29	0.62	0.91	0.44	0.87	0.08	0.26	0.71	0.46	0.88
CV%	10	41	42	28	21	23	35	14	10	7	13

F-prob= f-probability at p=0.05 Infil=infiltration rate B.D. - bulk density

Standard deviation is shown in parenthesis

Appendix 1b: **Soil status at the end of 1993/94 SR**

Treatment.	pH	Na m.e%	K m.e%	Ca m.e%	Mg m.e%	Mn m.e%	P ppm	N %	C %	infil (cm/min)	B.D. gm^3
1	5.4 (0.2)	0.5 (0.2)	0.8 (0.4)	3.3 (0.8)	2.1 (0.3)	1.4(0.3)	9 (3)	0.25 (0.02)	2.3 (0.2)	1.0 (0.6)	1.1 (0.1
2	5.4 (0.3)	0.6 (0.3)	0.9 (0.6)	3.2 (1.0)	2.2 (0.4)	1.1(0.4)	10 (2)	0.23 (0.04)	2.3 (0.3)	0.9 (0.5)	1.1 (0.1)
3	5.3 (0.1)	0.6 (0.3)	1.0 (0.6)	2.3 (0.6)	1.9 (0.2)	1.6(0.4)	10 (2)	0.20 (0.03)	2.3 (0.30	0.7 (0.2)	1.1 (0.1)
4	5.4 (0.1)	1.0 (0.5)	1.1 (0.2)	2.3 (0.2)	1.9 (0.2	1.4(0.5)	7 (2)	0.18 (0.04)	2.3 (0.2)	0.8 (0.4)	1.1 (0.1)
5	5.2 (0.2)	0.4 (0.1)	0.9 (0.3)	2.0 (3.2)	2.3 (0.8)	1.4(0.2)	9 (3)	0.22 (0.04)	2.2 (0.1	1.0 (0.3)	1.1 (0.1)
6	5.4 (0.2)	0.6 (0.2)	0.9 (0.2)	3.2 (0.8)	2.0 (0.1)	1.4(0.2)	8 (3)	0.21 (0.04)	2.3 (0.1)	1.1 (0.4)	1.1 (0.1)
7	5.6 (0.2)	0.6 (0.1)	0.9 (0.5)	4.2 (0.3)	2.0 (0.1)	1.5(0.2)	10 (4)	0.24 (0.03)	2.3 (0.3)	1.0 (0.3)	1.1 (0.1)
8	5.4 (0.30	0.5 (0.1)	1.0 (0.2)	4.2 (0.7)	1.6 (0.3)	1.2(0.3)	11 (4)	0.25 (0.04)	2.2 (0.2)	1.1 (0.3)	1.1 (0.1)
9	5.4 (0.2)	0.8 (0.1)	0.8 (0.2)	3.3 (1.4)	1.8 (0.2)	1.7(0.6)	14 (6)	0.19 (0.06)	2.2 (0.3)	0.7 (0.2)	1.1 (0.1)
10	5.3 (0.2)	0.6 (0.1)	0.9 (0.2)	2.9 (0.9)	1.9 (0.1)	1.4(0.2)	10 (2)	0.22 (0.02)	2.3 (0.3)	0.7 (0.3)	1.1 (0.1)
f-prob	0.14	0.16	0.98	0.07	0.20	0.77	0.06	0.03	0.99	0.40	0.88
CV%	6	39	40	24	16	30	24	15	9	36	7

f-prob=f-probability Infil=infiltration rate B.D.=bulk density

Standard deviation is shown in parenthesis

Appendix 1c: Soil status at the end of 1994 LR

Treatment	pH	Na m.e%	K m.e%	Ca m.e%	Mg m.e%	Mn m.e%	P ppm	N%	C%	infil cm/min	B.D. gm^3
1	5.5 (0.3)	1.1 (0.5)	1.5 (0.7)	2.9 (1.0)	1.9 (0.3)	1.4 (0.3)	67 (2)	0.3 (0.04)	2.3 (0.18)	1.3 (0.2) abc	1.2 (0.1)
2	5.3 (0.3)	0.9 (0.3)	1.3 (0.6)	2.9 (1.1)	2.0 (0.1)	1.5 (0.1)	63 (2)	0.3 (0.04)	2.3 (0.08)	1.2 (0.3) abc	1.1 (0.1)
3	5.6 (0.3)	0.9 (0.4)	1.4 (0.6)	2.4 (1.1)	2.1 (0.2)	1.5 (0.3)	62 (12)	0.2 (0.03)	2.4 (0.09)	0.9 (0.1) de	1.1 (0.1)
4	5.3 (0.3)	1.2 (0.4)	1.3 (0.2)	1.7 (0.3)	2.1 (0.1)	1.4 (0.3)	62 (11)	0.2 (0.04)	1.8 (0.98)	0.8 (0.2) cd	1.2 (0.2)
5	5.2 (0.5)	0.6 (0.2)	0.8 (0.3)	2.2 (0.4)	2.0 (0.5)	1.6 (0.3)	62 (1)	0.3 (0.01)	2.2 (0.29)	1.4 (0.4) a	1.1 (0.1)
6	5.4 (0.2)	0.9 (0.2)	1.4 (0.4)	2.7 (0.9)	1.9 (0.2)	1.4 (0.2)	68 (2)	0.3 (0.02)	2.3 (0.19)	1.3 (0.5) ab	1.2 (0.2)
7	5.6 (0.2)	0.9 (0.4)	1.6 (0.6)	2.4 (0.7)	2.1 (0.1)	1.4 (0.1)	72 (15)	0.3 (0.06)	2.3 (0.11)	1.6 (0.4) a	1.2 (0.1)
8	5.3 (0.4)	0.7 (0.2)	1.3 (0.4)	2.2 (0.6)	2.0 (0.2)	1.5 (0.2)	65 (6)	0.2 (0.05)	2.4 (0.23)	1.3 (0.2) ab	1.1 (0.10
9	5.3 (0.4)	0.9 (0.2)	1.2 (0.7)	2.6 (1.1)	2.0 (0.4)	1.4 (0.3)	69 (10)	0.2 (0.02)	2.2 (0.12)	0.8 (0.2) d	1.0 (0.3)
10	5.3 (0.2)	0.8 (0.1)	1.2 (0.3)	1.8 (1.3)	2.0 (0.9)	1.6 (0.1)	64 (2)	0.2 (0.01)	2.3 (0.20)	0.8 (0.2) d	1.0 (0.3)
f-prob	0.68	0.30	0.77	0.30	0.96	0.44	0.67	0.04	0.81	0.001	0.43
CV%	8	32	41	32	11	12	12	12	8	24	9

f-prob= f-probability Infil=infiltration rate B.D. =bulk density
Standard deviation is shown in parenthesis

APPENDIX 2: ANOVA TABLES

F-tabular for Replicates is 2.30

F-tabular for Treatments is 2.81

NS =Not significant (p=0.05)

* =Significant (P=0.05)

Appendix 2a: Soil data at the end of 1992/93 SR

Dependent Variable: pH

Source	DF	SS	MS	F	P
REPS	3	0.17	0.06	0.3	0.6946 NS
TREAT	9	0.68	0.08	0.4	0.7524 NS
Error	27	3.16	0.18		

Dependent Variable: Na

Source	DF	SS	MS	F	P
REPS	3	1.08	0.36	15	0.0001 *
TREATS	9	0.08	0.01	0.4	0.9366 NS
Error	7	0.64	0.024		

Dependent Variable: K

Source	DF	SS	MS	P	P
REPS	30	0.19	0.06	0.2	0.8606 NS
TREATS	9	1.37	0.15	0.5	0.7926 NS
Error	27	6.94	0.26		

Dependent Variable: Ca

Source	DF	SS	MS	F	P
REPS	3	5.76	1.92	0.8	0.5064 NS
TREATS	9	12.80	1.42	0.6	0.7930 NS
Error	27	64.70	2.41		

Dependent Variable: Mg

Source	DF	SS	MS	F	P
REPS	3	1.21	0.40	2.35	0.0907 NS
TREATS	9	1.27	0.14	0.8	0.6035 NS
Error	27	4.67	0.17		

Dependent Variable: Mn

Source	DF	SS	MS	F	P
REPS	3	11.62	3.88	29.85	0.0001 *
TREATS	9	1.97	0.22	1.69	0.1521 NS
Error	27	3.59	0.13		

Dependent Variable: P

Source	DF	SS	MS	F	P
REPS	3	378	126	15.75	0.0001 *
TREATS	9	70	7.7	1.0	0.4879 NS
Error	27	216	8		

Dependent Variable: N

Source	DF	SS	MS	F	P
REPS	3	0.002	0.001	1.0	0.3509 NS
TREATS	9	0.002	0.001	1.0	0.9210 NS
Error	27	0.012	0.001		

Dependent Variable: C

Source	DF	SS	MS	F	P
REPS	3	0.06	0.02	0.4	0.7487 NS
TREATS	9	0.30	0.03	0.6	0.7121 NS
Error	27	1.30	0.05		

Appendix 2b: Soil data at the end of 1993 LR

Dependant variable PH

Source	DF	SS	MS	F	P
REPS	3	0.075	0.03	1.0	0.4899 NS
TREATS	9	0.489	0.03	1.0	0.1147 NS
Error	27	0.815	0.03		

Dependent Variable: Na

Source	DF	SS	MS	F	P
REPS	3	0.15	0.05	0.7	0.5681 NS
TREATS	9	0.83	0.09	1.25	0.2934 NS
Error	27	1.95	0.072		

Dependent Variable: K

Source	DF	SS	MS	F	P
REPS	3	0.70	0.23	1.05	0.3799 NS
TREATS	9	1.56	0.17	0.77	0.6261 NS
Error	27	5.90	0.22		

Dependent Variable: Ca

Source	DF	SS	MS	F	P
REPS	3	7.97	2.66	13.30	0.0681 *
TREATS	9	3.69	0.41	2.05	0.9181 NS
Error	27	26.92	0.20		

Dependent Variable: Mg

Source	DF	SS	MS	F	P
REPS	3	11.40	3.80	13.10	0.0001 *
TREATS	9	2.68	0.30	1.03	0.4444 NS
Error	27	7.83	0.29		

Dependent Variable: Mn

Source	DF	SS	MS	F	P
REPS	3	0.60	0.20	2.0	0.1507 NS
TREATS	9	0.46	0.05	0.5	0.8722 NS
Error	27	2.82	0.10		

Dependent Variable: P

Source	DF	SS	MS	F	P
REPS	3	202.28	67.43	10.5	0.0001 *
TREATS	9	113.125	12.57	1.9	0.0850 NS
Error	27	172.975	6.41		

Dependent Variable: N

Source	DF	SS	MS	F	P
REPS	3	0.002	0.0008	0.8	0.5005 NS
TREATS	9	0.012	0.001	0.4	0.9302 NS
Error	27	0.026	0.002		

Dependent Variable: C

Source	DF	SS	MS	F	P
REPS	3	0.38	0.13	2.6	0.0820 NS
TREATS	9	0.32	0.04	0.8	0.7187 NS
Error	27	1.39	0.05		

Dependent Variable: INFILTRATION RATE

Source	DF	SS	MS	F	P
REPS	3	0.76	0.25	1.25	0.0737 NS
TREATS	9	0.88	0.20	1.0	0.4652 NS
Error	27	2.65	0.20		

Dependent Variable: BULK DENSITY

Source	DF	SS	MS	F	P
REPS	3	0.11	0.037	5.98	0.0029 *
TREATS	9	0.03	0.003	0.47	0.8804 NS
Error	27	0.17	0.006		

Appendix 2c: Soil data for 1993/94 SR

Dependent Variable: pH

Source	DF	SS	MS	F	P
REPS	3	0.38	0.13	4.3	0.0173 NS
TREATS	9	0.47	0.05	1.7	0.1439 NS
Error	27	0.84	0.03		

Dependent Variable: Na

Source	DF	SS	MS	F	P
REPS	3	0.09	0.03	0.3	0.6765 NS
TREATS	9	0.83	0.09	1.5	0.1610 NS
Error	27	1.55	0.06		

Dependent Variable: K

Source	DF	SS	MS	F	P
REPS	3	0.81	0.27	1.8	0.1584 NS
TREATS	9	0.31	0.2	0.03	0.9853 NS
Error	27	3.92	0.15		

Dependent Variable: Ca

Source	DF	SS	MS	F	P
REPS	3	4.57	1.52	2.7	0.0650 NS
TREATS	9	11.17	1.24	2.2	0.075 NS
Error	27	15.19	0.56		

Dependent Variable: Mg

Source	DF	SS	MS	F	P
REPS	3	0.68	0.23	2.3	0.1142 NS
TREATS	9	1.38	0.15	1.5	0.2094 NS
Error	27	2.81	0.10		

Dependent Variable: Mn

Source	DF	SS	MS	F	P
REPS	3	0.38	0.13	0.7	0.5706 NS
TREATS	9	1.02	0.11	0.6	0.7743 NS
Error	27	5.02	0.19		

Dependent Variable: P

Source	DF	SS	MS	F	P
REPS	3	155	52	10	0.0002 NS
TREATS	9	102	11	2.1	0.0602 NS
Error	27	142	5.2		

Dependent Variable: N

Source	DF	SS	MS	F	P
REPS	3	0.02	0.007	7	0.0019 *
TREATS	9	0.02	0.003	3	0.0381 *
Error	27	0.03	0.001		

Dependent Variable: C

Source	DF	SS	MS	F	P
REPS	3	0.53	0.18	4.5	0.0096 NS
TREATS	9	0.06	0.01	0.25	0.9928 NS
Error	27	1.03	0.04		

Dependent Variable: INFILTRATION RATE

Source	DF	SS	MS	F	P
REPS	3	0.74	0.25	2.30	0.0997 NS
TREATS	9	1.04	0.12	1.08	0.4069 NS
Error	27	2.89	0.12		

Dependent Variable: BULK DENSITY

Source	DF	SS	MS	F	P
REPS	3	0.11	0.04	5.98	0.0029 *
TREATS	9	0.03	0.003	0.47	0.8804 NS
Error	27	0.17	0.006		

Appendix 2d: Soil data for 1994 LR

Dependent Variable: pH

Source	DF	SS	MS	F	P
REPS	3	0.39	0.13	1.4	0.2727 NS
TREATS	9	0.63	0.07	0.7	0.6751 NS
Error	27	2.56	0.09		

Dependent Variable: Na

Source	DF	SS	MS	F	P
REPS	3	0.34	0.11	1.4	0.2820 NS
TREATS	9	0.96	0.11	1.4	0.3054 NS
Error	27	2.28	0.08		

Dependent Variable: K

Source	DF	SS	MS	F	P
REPS	3	0.68	0.23	0.8	0.5178 NS
TREATS	9	1.62	0.18	0.6	0.7738 NS
Error	27	7.89	0.29		

Dependent Variable: Ca

Source	DF	SS	MS	F	P
REPS	3	4.30	1.43	2.6	0.0767 NS
TREATS	9	6.40	0.71	1.3	0.3003 NS
Error	27	15.19	0.56		

Dependent Variable: Mg

Source	DF	SS	MS	F	P
REPS	3	0.45	0.15	2.5	0.0715 NS
TREATS	9	0.16	0.02	0.3	0.9652 NS
Error	27	1.53	0.06		

Dependent Variable: Mn

Source	DF	SS	MS	F	P
REPS	3	0.58	0.19	6.3	0.0033 *
TREATS	9	0.31	0.03	1.0	0.4410 NS
Error	27	0.89	0.03		

Dependent Variable: P

Source	DF	SS	MS	F	P
REPS	3	58	19	0.4	0.8234 NS
TREATS	9	424	47	0.7	0.6705 NS
Error	27	1720	63		

Dependent Variable: N

Source	DF	SS	MS	F	P
REPS	3	0.01	0.004	4.0	0.0099 *
TREATS	9	0.01	0.003	3.0	0.0486 *
Error	27	0.03	0.001		

Dependent Variable: C

Source	DF	SS	MS	F	P
REPS	3	0.13	0.04	1.3	0.2956 NS
TREATS	9	0.17	0.02	0.6	0.8197 NS
Error	27	0.92	0.03		

Dependent Variable: INFILTRATION RATE

Source	DF	SS	MS	F	P
REPS	3	0.75	0.25	3.2	0.0395 *
TREATS	9	3.20	0.34	4.4	0.0013 *
Error	27	2.115	0.078		

Dependent Variable: BULK DENSITY

Source	DF	SS	MS	F	P
REPS	3	0.47	0.16	14.5	0.0001 *
TREATS	9	0.11	0.012	1.1	0.4310 NS
Error	27	0.30	0.011		

Appendix 2e: Maize grain yield for 1993 long rains

Dependent Variable: GRAIN

Source	DF	SS	MS	F	P
REPS	3	17356865.30	5785621.77	13.63	0.0001
TREATS	9	3546444.00	394049.33	0.93	0.5167
Error	27	5327932.01			

Appendix 2f: Bean grain yield during 1993 SR

Dependent Variable: BEAN

Source	DF	SS	MS	F	P
REPS	3	473539.40	157846.47	4.5	0.0102 *
TREATS	9	396207.10	44023.01	1.3	0.2939 NS
Error	27	930993.10	34481.23		

Appendix 2g: Maize grain yield during 1993/94 SR

Dependent Variable: MAIZE

Source	DF	SS	MS	F	P
REPS	3	1083510.9	361170.3	6.8	0.0015 *
TREATS	9	921433.5	102381.5	1.9	0.0908 NS
Error	27	1434920.4	53145.2		

Appendix 2h: Maize grain yield during 1994 LR

Dependant Variable: MAIZE

Source	DF	SS	MS	F	P
REPS	3	1408942	469647	1.63	0.207 NS
TREATS	9	38093192	4232577	14.67	0.0001*
Error	26	75020441	288540		

REPS= Replicates

TREATS= Treatments

APPENDIX 3: CONTRASTS

Appendix 3a: Maize grain yield for 1993 long rains

Contrast	DF	Contrast SS	Mean Square	F Value	Pr > F
1vs2	1	66430	66430	0.16	0.6955
1vs3	1	954962	954962	2.25	0.1452
1&2 vs 3 &4	1	4539752	1939752	4.57	0.0417
2vs4	1	984906	984906	2.32	0.1393
1vs10	1	1741911	1741911	4.10	0.0528
2vs10	1	1128002	1128002	2.66	0.1147
7vs10	1	987715	987715	2.33	0.1388
9vs10	1	84460	84460	0.20	0.6591
8vs9	1	95048	95048	0.22	0.6398
7 & 8vs91	1	341055	341055	0.80	0.3779
5vs10	1	382812	382812	0.90	0.3507
5 and 6vs10	1	543305	543305	1.28	0.2678
1 & 2vs3 &4	1	1939752	1939752	4.57	0.0417
3 and 4vs10	1	56648	56648	0.13	0.7177
1 and 2vs10	1	1891132	1891132	4.46	0.0442
3 and 4vs10	1	56648	56648	0.13	0.7177
5vs6	1	112812	112812	0.27	0.6103

Appendix 3b: Bean grain yield for 1993 short rains

Contrast	DF	Contrast SS	Mean Square	F Value	Pr>F
1vs2	1	5408.00	5408.00	0.10	0.7522
1vs3	1	6612.50	6612.50	0.12	0.7270
1&2 vs 3&4	1	5076.56	5076.56	0.10	0.7596
2vs4	1	378.13	378.13	0.01	0.9334
1vs10	1	2312.00	2312.00	0.04	0.8363
2vs10	1	648.00	648.00	0.01	0.9129

7vs10	1	274911	274911.12	5.17	0.0311
9vs10	1	30258.00	30258.00	0.57	0.4571
8vs9	1	312.50	312	0.01	0.9394
7and8 vs 9	1	36895	36895.04	0.69	0.4120
5 vs 10	1	280500	280500	5.28	0.0296
5 & 6 vs 10	1	130242.67	130242	2.45	0.1291
1&2 vs 3&4	1	5076	5076.56	0.10	0.7596
3&4 vs 10	1	5075.04	5075.04	0.10	0.7597
1 & 2 vs 10	1	171	171	0.01	0.9552
3 & 4 vs 10	1	5075	5075	0.10	0.7597
5 vs 6	1	183921	183921	3.46	0.0738
5&6 vs 10	1	132462	132462	2.49	0.1260
7&8 vs 10	1	154401	154401	2.91	0.0998
5&6 vs 7&8	1	1260	1260	0.02	0.8788

(c) Maize grain yield 1993 short rains

Contrast	DF	Contrast SS	Mean Square	F Value	Pr > F
1vs2	1	5408	5408	0.10	0.7522
1vs3	1	6612	6612	0.12	0.7270
1&2 vs 3&4	1	5076	5076	0.01	0.7596
2vs4	1	378	378	0.01	0.9334
1vs10	1	2312	2312	0.04	0.8363
2vs10	1	648.00	648	0.01	0.9129
7vs10	1	274911	274911	5.17	0.0311
9vs10	1	30258	30258	0.57	0.4571
8vs9	1	312	312	0.01	0.9394
7 and 8vs9	1	36895	36895	0.69	0.4120
5vs10	1	280500	280500	5.28	0.0296
5 and 6vs10	1	130242	130242	2.45	0.1291
1&2 vs 3&4	1	5076	5076	0.10	0.7596

3 and 4vs10	1	5075	5075	0.10	0.7597
1 and 2vs10	1	170	170	0.10	0.9552
3 and 4vs10	1	5075	5075	0.10	0.7597
5vs6	1	183921	183921	3.46	0.0738
5 and 6vs10	1	132462	132462	2.49	0.1260
7 and 8vs10	1	154401	154401	2.91	0.0998
5&6 vs 7&8	1	1260	1260	0.02	0.8788

Appendix 3d: Maize grain for 1994 long rains

Contrast	DF	Contrast SS	Mean Square	F Value	Pr > F
1vs2	1	33282	33282	0.12	0.7369
1vs3	1	21528	21528	0.07	0.7869
1 &2vs 3& 4	1	174306	174306	0.60	0.4440
2vs4	1	196878	196878	0.68	0.4163
1vs10	1	1480060	1480060	5.13	0.0321
2vs10	1	1957231	1957231	6.78	0.0150
7vs10	1	1691880	1691880	5.86	0.0227
9vs10	1	6988191	6988191	24.22	0.0001
8vs9	1	441330	441330	1.53	0.2272
7 and 8vs9	1	1342847	1342847	4.65	0.0404
5vs10	1	1015517	1015517	3.52	0.0719
5 and 6vs10	1	344640	344640	1.19	0.2845
1 and 2vs3and 4	1	174306	174306	0.60	0.4440
3 and 4vs10	1	1367082	1367082	4.74	0.0388
1 and 2vs10	1	2280433	2280433	7.90	0.0093
3 and 4vs10	1	1367082	1367082	4.74	0.0388
5vs6	1	557929	557929	1.93	0.1762
7and8vs10	1	3585947	3585947	12.43	0.0016
5 and 6vs10	1	598742	598742	2.08	0.1617

APPENDIX 4: RAW DATA

Appendix 4a: **Nutrient concentration (%) of leaf prunings incoporated at the beginning of 1993 LR**

	Plot	N	P	K	Ca	Mg
CALLIANDRA						
	6	1.75	0.15	0.94	0.81	0.36
	7	1.83	0.15	1.04	0.91	0.42
	10	2.14	0.18	1.52	0.77	0.45
	12	1.72	0.18	1.20	1.00	0.34
	17	1.58	0.15	1.12	0.80	0.48
	20	1.97	0.15	1.33	0.90	0.45
	22	1.45	0.14	1.07	0.83	0.38
	24	1.60	0.12	1.39	0.74	0.39
	25	1.90	0.16	1.19	0.66	0.46
	32	1.42	0.13	0.98	0.93	0.44
	37	1.82	0.18	1.11	0.80	0.52
	40	1.97	0.06	0.88	0.55	0.31
LEUCAENA						
	1	1.90	0.15	1.90	0.80	0.34
	4	2.06	0.15	1.37	0.93	0.38
	8	2.04	0.16	1.46	0.83	0.59
	13	1.89	0.15	1.58	0.77	0.46
	15	1.87	0.16	1.30	0.95	0.44
	19	2.11	0.18	1.65	0.88	0.48
	23	2.16	0.15	1.63	0.92	0.32
	27	2.37	0.14	1.24	0.87	0.38
	30	2.28	0.17	1.92	0.53	0.40
	33	2.27	0.17	1.62	1.09	0.37
	34	2.24	0.17	1.74	0.82	0.42
	38	1.93	0.17	1.55	0.91	0.31

Appendix 4b: **Nutrient concentration (%) of leaf prunings incoporated at the beginning of 1993/94 SR**

CALLIANDRA

Plot	N	P	K	Ca	Mg
6	2.60	0.08	0.94	0.50	0.48
7	2.72	0.12	0.99	0.46	0.36
10	2.80	0.08	0.92	0.43	0.43
12	3.31	0.09	0.86	0.40	0.59
17	2.61	0.08	0.86	0.38	0.58
20	3.05	0.12	0.87	0.41	0.37
22	3.00	0.06	0.85	0.39	0.44
24	3.07	0.07	0.94	0.53	0.40
25	3.00	0.13	0.89	0.43	0.43
32	3.10	0.08	0.89	0.33	0.44
37	3.30	0.08	0.89	0.39	0.52
40	2.72	0.06	0.88	0.55	0.31

LEUCAENA

1	3.40	0.09	1.54	0.51	0.34
4	2.80	0.09	1.12	0.94	0.34
8	3.60	0.09	1.12	0.94	0.34
13	3.40	0.10	1.56	0.46	0.38
15	3.20	0.10	0.97	0.90	0.42
19	2.70	0.09	1.10	1.20	0.24
23	2.80	0.09	1.19	0.86	0.59
27	2.90	0.08	1.14	0.59	0.45
30	2.90	1.01	1.23	0.34	0.44
33	3.00	0.07	0.93	0.52	0.48
34	2.80	0.07	1.04	0.51	0.36
38	3.20	0.07	1.24	0.49	0.43

(c) Nutrient concentration (%) of leaf prunings incoporated at the beginning of 1994 LR

	Plot	N	P	K	Ca	Mg
CALLIANDRA						
	6	2.90	0.13	1.45	1.29	0.36
	7	2.80	0.11	1.00	1.10	0.38
	10	3.00	0.14	1.04	1.27	0.39
	12	2.90	0.13	1.09	1.15	0.35
	17	2.60	0.11	0.96	0.91	0.32
	20	2.80	0.11	1.59	1.23	0.32
	22	2.90	0.11	0.88	0.89	0.32
	24	2.80	0.13	0.92	0.71	0.28
	25	2.80	0.14	1.15	1.04	0.35
	32	2.90	0.08	1.43	0.87	0.35
	37	3.00	0.14	1.13	0.72	0.39
	40	2.70	0.12	0.96	0.96	0.35
LEUCAENA						
	1	3.10	0.11	2.18	1.20	0.44
	4	3.00	0.12	1.40	1.22	0.34
	8	2.90	0.11	1.93	1.18	0.38
	13	2.80	0.11	1.24	1.28	0.44
	15	2.70	0.10	1.06	1.22	0.48
	19	3.10	0.12	2.02	0.86	0.33
	23	3.20	0.10	2.02	1.91	0.35
	27	3.00	0.09	1.40	1.09	0.57
	30	2.80	1.07	1.38	1.15	0.25
	33	3.10	0.09	1.22	1.23	0.42
	34	3.00	0.11	2.02	1.05	0.42
	38	2.90	0.11	2.60	1.14	0.41

Appendix 4d: Soil data at the end of 1992/93 SR

BL	TRT	PH	Na	K	Ca	Mg	Mn	P	N	C
1	1	5.4	0.62	1.18	3.6	1.2	0.20	14	0.229	2.46
1	2	5.6	0.62	1.18	4.0	1.0	0.10	16	0.234	2.34
1	3	5.3	0.62	1.24	3.2	1.2	0.28	18	0.216	2.31
1	4	5.6	0.54	1.00	2.4	2.0	1.13	14	0.189	2.01
1	5	5.4	0.50	0.84	2.8	1.6	1.25	10	0.228	2.30
1	6	5.4	0.50	0.84	2.8	1.6	1.25	10	0.228	2.30
1	7	5.2	0.44	0.70	2.4	0.9	0.40	16	0.196	2.17
1	8	5.9	0.78	1.50	5.0	2.5	1.31	12	0.238	2.39
1	9	5.8	0.66	1.28	4.0	2.0	1.25	22	0.222	2.12
1	10	5.4	0.62	1.12	3.0	1.1	0.20	16	0.174	1.94
2	1	5.8	0.66	1.38	5.0	1.6	0.12	16	0.224	2.24
2	2	5.1	0.50	1.00	2.2	1.3	0.40	18	0.212	2.14
2	3	5.2	0.36	0.66	2.0	1.3	0.34	18	0.212	2.25
2	4	5.7	0.66	1.50	4.0	1.4	0.12	16	0.209	2.15
2	5	5.1	0.36	0.54	2.0	1.3	0.26	16	0.200	2.19
2	6	5.3	0.62	1.46	3.0	1.4	0.12	16	0.208	2.12
2	7	5.4	0.50	0.92	3.0	1.3	0.22	16	0.209	2.08
2	8	5.4	0.54	1.18	2.4	1.2	0.26	18	0.197	2.13
2	9	5.6	0.62	1.06	4.4	1.1	0.10	14	0.191	2.10
2	10	5.2	0.36	0.70	2.0	1.5	0.20	16	0.212	2.21
3	1	5.9	0.70	1.38	5.0	1.2	0.16	14	0.210	2.18
3	2	5.9	0.88	2.00	6.0	1.3	0.22	12	0.236	2.45
3	3	5.7	0.66	1.38	5.0	1.6	0.16	16	0.196	1.91
3	4	5.3	0.44	0.70	2.2	0.6	0.22	10	0.178	1.88
3	5	5.0	0.62	1.18	2.2	0.2	0.34	10	0.206	2.07
3	6	5.8	0.70	1.62	5.8	1.7	0.12	16	0.222	2.20
3	7	5.9	0.78	1.54	6.0	0.9	0.12	16	0.217	2.46
3	8	5.1	0.16	0.08	0.8	1.4	1.84	8	0.201	2.01
3	9	4.9	0.26	0.44	1.6	0.6	0.22	12	0.200	2.04
3	10	5.5	0.62	1.18	4.0	0.8	0.04	16	0.200	2.16
4	1	5.3	0.18	0.52	1.4	0.7	1.72	6	0.172	1.71
4	2	5.0	0.10	0.16	0.8	1.0	1.96	4	0.217	2.20
4	3	6.0	0.18	1.18	4.0	2.0	1.36	8	0.252	2.42
4	4	5.9	0.26	1.42	4.4	1.4	1.51	12	0.251	2.52
4	5	5.2	0.16	0.40	1.4	0.9	1.66	6	0.188	1.88
4	6	5.4	0.18	1.12	1.8	1.1	1.64	6	0.220	2.08
4	7	5.9	0.32	2.00	5.0	1.4	1.60	10	0.240	2.38
4	8	5.1	0.16	0.06	1.4	1.2	1.60	12	0.218	2.20
4	9	5.8	0.18	1.28	3.6	1.3	1.64	8	0.213	1.59
4	10	6.0	0.18	1.46	5.0	1.4	1.25	10	0.245	2.48

Appendix 4e: Soil data at the end of 1993 LR

BL	TRT	PH	Na	K	Ca	Mg	Mn	P	N	C
1	1	5.5	0.62	1.06	4.6	3.2	1.51	12	0.213	2.16
1	2	5.4	1.88	1.10	4.0	3.1	1.34	12	0.225	2.34
1	3	5.4	0.44	0.70	3.0	3.0	1.46	9	0.201	2.10
1	4	5.3	0.62	1.06	4.0	3.1	1.74	8	0.212	2.13
1	5	5.4	0.78	1.50	5.2	3.9	1.20	8	0.212	2.41
1	6	5.4	0.50	0.54	3.0	2.9	1.42	10	0.196	2.05
1	7	5.5	0.62	0.96	3.4	2.2	1.48	6	0.205	2.12
1	8	5.6	0.70	1.24	5.0	3.2	1.31	10	0.230	2.61
1	9	5.2	0.70	1.38	4.8	3.7	1.13	3	0.215	2.04
1	10	5.4	0.40	0.88	4.0	2.7	1.78	10	0.227	2.28
2	1	5.5	0.78	1.50	2.8	2.2	1.40	12	0.213	2.34
2	2	5.2	0.40	0.62	2.0	1.8	1.78	10	0.214	2.09
2	3	5.2	0.44	0.70	2.0	1.0	1.57	8	0.204	1.90
2	4	5.4	0.78	1.46	4.0	1.6	1.22	8	0.234	2.07
2	5	5.0	0.40	0.54	2.0	1.5	1.48	8	0.209	1.99
2	6	5.3	0.62	1.06	3.6	1.5	1.46	8	0.204	1.92
2	7	5.2	0.62	0.96	4.4	2.5	1.74	8	0.202	2.20
2	8	5.2	0.54	0.84	2.6	2.0	1.69	6	0.209	2.21
2	9	5.4	0.66	1.18	4.0	2.8	1.69	12	0.214	2.14
2	10	5.5	0.54	0.88	2.2	1.5	1.20	10	0.208	2.03
3	1	5.5	0.96	1.96	3.6	2.8	1.48	14	0.243	2.25
3	2	5.6	0.84	1.74	4.3	2.7	1.42	10	0.252	2.10
3	3	5.6	0.78	1.50	4.2	2.3	1.25	8	0.240	2.26
3	4	5.0	0.32	0.44	2.0	2.0	1.20	4	0.176	1.79
3	5	5.0	0.22	0.26	2.0	1.9	0.98	2	0.186	1.76
3	6	5.6	0.84	1.62	4.8	2.4	1.51	10	0.238	2.47
3	7	5.6	0.84	1.50	3.0	2.5	1.46	11	0.210	2.27
3	8	5.1	0.26	0.28	2.0	1.8	0.84	2	0.165	1.60
3	9	5.1	0.32	0.50	2.4	1.7	0.98	2	0.218	2.20
3	10	5.4	0.62	1.18	4.0	1.9	2.07	10	0.200	2.02
4	1	5.4	0.62	1.06	4.0	3.1	1.46	2	0.260	2.29
4	2	5.4	0.88	1.74	4.6	4.3	1.87	4	0.274	2.63
4	3	5.5	0.84	1.74	3.0	3.2	0.82	4	0.230	2.62
4	4	5.5	0.70	1.28	4.0	3.4	1.07	4	0.258	2.30
4	5	5.0	0.36	0.50	2.4	1.9	1.66	2	0.167	1.80
4	6	5.1	0.50	0.78	2.6	1.9	0.95	4	0.229	2.10
4	7	5.5	0.88	1.88	4.6	2.9	0.98	4	0.101	2.46
4	8	5.3	0.70	1.28	4.6	3.3	1.46	2	0.271	2.41
4	9	5.4	0.70	1.38	4.2	3.2	1.02	4	0.248	2.22
4	10	5.6	0.70	1.62	3.7	2.9	0.69	4	0.262	2.26

Appndix 4f: Soil data at the end of 1993/94 SR

BL	TRT	pH	Na	K	Ca	Mg	Mn	P	N	C
1	1	5.4	0.55	0.86	3.6	1.84	1.12	6	0.25	2.48
1	2	5.5	0.68	1.20	4.0	2.17	1.07	7	0.25	2.55
1	3	5.3	0.36	0.58	3.6	1.83	1.53	6	0.23	2.44
1	4	5.5	0.64	0.84	3.0	1.58	0.97	5	0.22	2.04
1	5	5.3	0.57	0.50	3.0	1.79	1.29	6	0.23	2.44
1	6	5.6	0.75	0.95	4.2	1.98	1.43	7	0.23	2.36
1	7	5.8	0.44	0.74	4.0	1.94	1.26	5	0.25	2.22
1	8	5.8	0.74	0.96	3.6	1.70	2.20	7	0.26	2.45
1	9	5.6	0.74	0.92	3.0	1.76	2.49	8	0.21	2.50
1	10	5.2	0.54	0.88	4.0	1.80	1.18	10	0.23	2.31
2	1	5.5	0.78	1.39	4.0	2.10	1.30	10	0.24	2.37
2	2	5.1	0.44	0.68	3.0	1.79	1.51	9	0.25	2.29
2	3	5.2	0.44	0.62	2.8	1.80	1.85	11	0.20	2.26
2	4	5.3	0.75	1.22	2.6	2.10	1.03	10	0.21	2.27
2	5	5.2	0.36	0.44	2.0	1.60	1.39	9	0.21	2.21
2	6	5.3	0.66	1.06	3.0	2.06	1.22	7	0.22	2.21
2	7	5.3	0.52	0.76	4.0	2.12	1.81	14	0.26	2.08
2	8	5.2	0.44	0.62	2.6	1.53	1.19	12	0.26	2.17
2	9	5.5	0.64	0.96	5.0	1.98	1.69	14	0.24	2.08
2	10	5.1	0.42	0.62	2.0	1.87	1.30	12	0.23	2.33
3	1	5.7	0.46	0.68	3.6	1.84	1.25	7	0.22	2.40
3	2	5.7	0.86	1.50	4.0	1.94	1.12	11	0.16	1.94
3	3	5.5	0.94	1.62	2.2	1.94	1.12	11	0.16	1.94
3	4	5.4	0.84	1.28	2.8	1.99	1.43	7	0.12	2.21
3	5	5.2	0.26	1.28	1.4	3.34	1.27	12	0.16	2.14
3	6	5.5	0.72	1.14	3.0	2.00	1.57	7	0.14	2.42
3	7	5.6	0.68	1.02	4.0	1.78	1.68	8	0.25	2.27
3	8	5.5	0.53	1.68	4.2	1.25	0.19	8	0.29	1.96
3	9	5.1	0.74	0.44	1.6	1.50	1.36	11	0.11	1.84
3	10	5.4	0.72	1.20	3.0	2.00	1.51	8	0.19	1.97
4	1	5.1	0.40	0.57	2.0	2.50	1.88	12	0.27	2.06
4	2	5.2	0.26	0.22	1.9	2.70	0.60	12	0.24	2.45
4	3	5.2	0.74	1.50	2.4	2.19	1.74	10	0.17	2.57
4	4	5.5	1.73	1.08	2.6	2.02	2.02	6	0.16	2.49
4	5	5.1	0.38	1.42	1.6	2.60	1.77	10	0.26	2.13
4	6	5.3	0.32	0.44	2.4	1.80	1.53	12	0.23	2.14
4	7	5.8	0.76	1.22	4.6	2.00	1.34	12	0.18	2.67
4	8	5.2	0.42	0.64	3.1	1.90	1.35	15	0.19	2.39
4	9	5.3	0.57	0.86	3.6	2.00	1.19	21	0.19	2.36
4	10	5.4	0.70	1.02	2.4	2.11	1.69	9	0.21	2.61

Appendix 4g: Soil data at the end of 1994 LR

BL	TRT	pH	Na	K	Ca	Mg	Mn	P	N	C
1	1	5.5	0.64	0.84	1.6	2.00	1.40	68	0.23	2.47
1	2	5.3	0.91	1.62	2.8	2.00	1.57	65	0.25	2.36
1	3	5.4	0.80	1.13	1.6	2.10	1.53	64	0.25	2.36
1	4	5.5	0.71	0.84	1.6	2.20	1.70	58	0.25	2.37
1	5	5.8	0.84	1.17	2.6	2.70	1.80	62	0.30	2.53
1	6	5.6	0.78	1.12	2.4	1.90	1.53	69	0.22	2.27
1	7	5.6	0.71	1.08	2.0	2.10	1.53	63	0.25	2.27
1	8	5.8	0.74	1.00	2.0	2.30	1.70	66	0.30	2.57
1	9	5.6	0.78	1.00	1.7	2.50	1.80	84	0.20	2.32
1	10	5.2	0.78	1.28	1.8	2.00	1.67	65	0.26	2.27
2	1	5.7	1.17	2.20	3.0	2.10	1.30	68	0.21	2.33
2	2	5.1	0.62	0.87	2.0	1.90	1.53	62	0.24	2.28
2	3	5.2	0.68	0.97	1.6	1.90	1.34	70	0.30	2.26
2	4	5.6	1.12	2.02	1.6	2.10	1.49	68	0.30	2.28
2	5	5.1	0.62	0.87	1.8	1.90	1.53	62	0.26	2.28
2	6	5.3	1.00	1.75	2.3	1.80	1.33	68	0.26	2.16
2	7	5.3	0.80	1.04	2.0	2.00	1.39	65	0.14	2.13
2	8	5.1	0.64	0.84	1.6	1.80	1.43	62	0.27	2.21
2	9	5.5	0.97	1.62	3.0	2.10	1.42	64	0.24	2.09
2	10	5.1	0.68	0.84	2.0	1.90	1.67	65	0.25	2.15
3	1	5.7	1.70	1.95	4.0	2.10	1.12	67	0.27	2.43
3	2	5.7	1.28	1.95	4.4	2.10	1.25	66	0.29	2.46
3	3	5.9	1.50	2.10	4.0	2.20	1.27	68	0.31	2.47
3	4	5.0	1.50	0.56	2.0	1.90	1.24	61	0.22	2.08
3	5	4.8	0.44	0.44	2.0	1.70	1.25	61	0.28	2.11
3	6	5.5	1.08	1.88	4.0	2.20	1.04	70	0.23	2.55
3	7	5.5	0.52	2.02	2.1	2.10	1.30	67	0.28	2.39
3	8	4.9	0.53	1.68	2.0	1.80	1.55	74	0.29	2.09
3	9	4.8	0.74	0.44	1.6	1.50	1.36	62	0.27	2.07
3	10	5.4	0.80	1.39	2.0	2.00	1.51	75	0.30	2.29
4	1	5.0	0.80	1.08	2.8	1.50	1.88	64	0.26	2.05
4	2	5.2	0.64	0.84	2.4	1.80	1.56	61	0.32	2.27
4	3	5.7	0.80	1.50	2.4	2.19	1.74	45	0.29	2.44
4	4	5.0	1.39	1.95	1.4	2.20	1.00	65	0.30	2.63
4	5	4.9	0.56	0.74	2.4	1.60	1.77	63	0.27	1.83
4	6	5.2	0.74	1.00	2.2	1.80	1.53	66	0.26	2.13
4	7	5.8	1.46	2.10	3.4	2.00	1.34	94	0.28	2.34
4	8	5.2	1.00	1.59	3.0	1.90	1.35	61	0.22	2.53
4	9	5.3	1.08	1.91	4.0	2.00	1.19	67	0.21	2.23
4	10	5.6	0.84	1.39	1.4	2.11	1.69	53	0.24	2.61

Appendix 4h: Bean and maize grain yield during 1993/94 SR

BL	TRT	Bean	Maize
1	1	492	37
1	2	222	12
1	3	309	113
1	4	227	106
1	5	707	771
1	6	530	295
1	7	340	206
1	8	1013	496
1	9	560	297
1	10	157	218
2	1	560	43
2	2	233	12
2	3	213	0
2	4	389	92
2	5	415	0
2	6	550	12
2	7	544	169
2	8	427	2
2	9	387	189
2	10	570	382
3	1	121	75
3	2	107	146
3	3	97	432
3	4	69	498
3	5	150	934
3	6	112	627
3	7	534	3
3	8	200	129
3	9	206	339
3	10	172	410
4	1	68	190
4	2	98	410
4	3	306	190
4	4	538	417
4	5	385	1039
4	6	208	224
4	7	653	1060
4	8	174	63
4	9	502	767
4	10	559	395

Appendix 4i: Maize grain yield (kg) during 1994 long rains

Bl	TRT	GRAIN
1	1	62
1	1	25
1	3	400
1	4	759
1	6	1014
1	7	1210
1	8	3593
1	9	3381
1	10	2041
2	1	681
2	2	220
2	3	379
2	4	120
2	5	293
2	6	126
2	7	1869
2	8	2168
2	9	2220
2	10	614
3	1	127
3	2	198
3	3	574
3	4	129
3	5	220
3	6	1935
3	7	3095
3	8	2329
3	9	2695
3	10	1210
4	1	245
4	2	156
4	3	159
4	4	846
4	5	407
4	6	678
4	7	2061
4	8	2064
4	9	3737
4	10	691

Appendix 4j: Infiltration rate and bulk density at the end of 1993/94 SR and 1994 LR

BL	TRT	Inf-1993	BD-1993	Inf-1994	BD-1994
1	1	1.5	1.2	1.2	1.2
1	2	1.0	1.2	1.5	1.2
1	3	0.7	1.1	0.9	1.3
1	4	0.5	1.1	1.0	1.4
1	5	1.0	1.1	1.2	1.3
1	6	0.7	1.1	1.0	1.4
1	7	0.6	1.1	1.7	1.3
1	8	1.5	1.0	1.5	1.2
1	9	0.5	1.1	0.8	1.3
1	10	0.5	1.0	0.6	1.3
2	1	0.9	1.1	1.3	1.2
2	2	0.4	0.9	0.9	1.1
2	3	0.5	1.1	0.7	1.1
2	4	0.8	0.9	0.5	1.1
2	5	0.6	0.9	1.5	1.0
2	6	0.8	1.1	1.1	1.1
2	7	1.2	1.1	1.6	1.1
2	8	1.0	0.9	1.3	1.1
2	9	0.7	0.9	0.6	1.0
2	10	1.0	1.1	0.7	1.1
3	1	0.3	1.1	1.5	1.1
3	2	0.5	1.1	1.5	1.2
3	3	0.9	1.1	1.0	1.1
3	4	1.0	1.1	0.8	1.1
3	5	0.9	1.2	1.0	1.1
3	6	1.5	1.1	1.0	1.1
3	7	1.0	1.1	1.0	1.1
3	8	1.0	1.1	1.0	1.0
3	9	0.5	1.1	0.7	1.1
3	10	0.6	1.1	0.6	1.1
4	1	1.4	1.0	1.0	1.1
4	2	1.5	1.2	1.0	1.0
4	3	0.7	1.2	1.0	1.0
4	4	0.7	1.1	1.0	1.1
4	5	1.5	1.1	2.0	1.1
4	6	1.5	1.2	2.0	1.1
4	7	1.0	1.1	2.0	1.1
4	8	1.0	1.2	1.4	1.1
4	9	1.0	1.2	1.0	0.7
4	10	1.0	1.1	1.1	0.6

Appendix 4k: Infiltration rate and bulk density at the end of 1993/94 SR

BL	TRT	INF	BD
1	1	1.0	1.2
1	2	1.0	1.2
1	3	1.0	1.1
1	4	0.5	1.1
1	5	1.0	1.1
1	6	0.7	1.1
1	7	0.6	1.1
1	8	1.5	1.0
1	9	0.5	1.1
1	10	0.5	1.0
2	1	0.9	1.1
2	2	0.4	0.9
2	3	0.5	1.1
2	4	0.8	0.9
2	5	0.6	0.9
2	6	0.8	1.1
2	7	1.2	1.1
2	8	1.0	0.9
2	9	0.7	0.9
2	10	1.0	1.1
3	1	0.3	1.1
3	2	0.5	1.1
3	3	0.9	1.1
3	4	1.0	1.1
3	5	0.9	1.2
3	6	1.5	1.1
3	7	1.0	1.1
3	8	1.0	1.1
3	9	0.5	1.1
3	10	0.6	1.1
4	1	1.4	1.0
4	2	1.5	1.2
4	3	0.7	1.2
4	4	0.7	1.1
4	5	1.5	1.1
4	6	1.5	1.2
4	7	1.0	1.1
4	8	1.0	1.2
4	9	1.0	1.2
4	10	1.0	1.1

BL- Block
TRT- Treatment
INF- Infiltration
BD- Bulk density

APPENDIX 5: PH LEVELS AND NUTRIENT RATINGS

Appendix 5a: Ratings for pH

Range	Rating	Interpretation
> 8.5	very high	alkaline soils
7.0-8.5	high	alkaline to neutral
5.5-7.0	medium	acid to neutral
< 5.5	low	acid soils

Appendix 5b: Ratings for exchangeable K, Mg and P

Ratings	K (m.e/100g)	Mg (m.e/100g)	P (ppm) (Mehlich)
low	0.03-0.2	< 0.2	1-20
medium	0.2-0.4	0.2-0.5	20-40
high	0.4-0.8	> 0.5	> 40
very high	> 0.8		

Appndix 5c: Ratings for C and N

Rating	Organic C content Walkey-Black method (% of soil by weight)	N content Kjeldahl method (% of soil by weight)
Very low	< 2	< 0.1
Low	2-4	0.1-0.2
Medium	4-10	0.2-0.5
high	10-20	0.5-1.0
Very high	> 40	> 1.0

Adopted from Landon, 1991.

Appendix 5d: Chemical composition of *L. leucocephala* and *C. calothyrsus*

Plant residue	Lignin	ADF	Polyphenols	C	N	C/N
L. leucocephala	17.56	32.35	1.65	45.08	3.94	11.44
C. calothyrsus	29.05	58.08	2.89	45.23	3.64	12.45

Adopted from Mugendi, 1995.