

ROOT DISTRIBUTION AND BELOW GROUND INTERACTIONS IN ALLEY
CROPPING OF *CALLIANDRA CALOTHYRSUS* AND *LEUCAENA*
LEUCOCEPHALA WITH MAIZE AT EMBU, KENYA.

BY

MARGARET W. NJUKI, BSc.(AGRICULTURE)

A DISSERTATION SUBMITTED IN PARTIAL FULFILMENT OF THE
REQUIREMENTS FOR THE DEGREE OF MASTER OF SCIENCE IN
AGRICULTURE, SOKOINE UNIVERSITY OF AGRICULTURE.

1998

ABSTRACT

A study was conducted to assess the root distribution of *Leucaena leucocephala*, *Calliandra calothyrsus* and *Zea mays* (maize) when intercropped and that of maize when monocropped. The effect of leucaena and calliandra prunings on maize was also evaluated both under monocropping and intercropping. The prunings were applied at a rate of 6.7 tons/ha in two splits. Measurements were made of soil moisture, fine root biomass, plant height, stem diameter, number of leaves, above ground dry matter yield, leaf area index and maize grain yield.

The hedge trees were found to have a considerable amount of fine root biomass in the zone occupied by the maize roots with leucaena being more superficially rooted than calliandra. The maize fine root biomass was higher in alley cropping compared to monocropping. Addition of prunings reduced the maize fine root biomass. Comparing the maize and tree fine root biomass at both depths, the maize plants had more biomass at both depths than the trees.

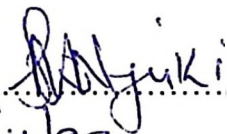
Trenching slightly improved grain yields though this was not significant. Application of prunings improved maize crop yields as compared to the control and fertilizer treatment. Soil moisture competition did not feature in the experiment since there was plenty of rainfall during the growing season.

iii

Based on the fine root distribution, calliandra emerged a better alley cropping tree than leucaena in this experiment.

DECLARATION

I MARGARET W. NJUKI do hereby declare to the Senate of Sokoine University of Agriculture that this dissertation is the result of my own original work and has not been submitted for a degree award in any other University.

Signature 

Date.. 27/11/98

COPYRIGHT

No part of this dissertation should be reproduced, stored in any retrieval system or transmitted in any form or by any means: electronic, mechanical, photocopying or otherwise without prior written permission of the author or Sokoine university of Agriculture.

ACKNOWLEDGEMENTS

The preparation of this dissertation would not have been possible without the help and cooperation of my associates and friends. I am especially indebted to my supervisors Prof. A.N. Minjas and Prof. S.A.O. Chamshama for their valuable advice, guidance and patience during the preparation of this dissertation. I am also sincerely grateful to Dr. M. O'Neill of ICRAF who advised and guided me during my field work at Embu, Kenya.

Many thanks also go to Mr. S.P. Gachanja, Director, Regional Research Centre, Embu for his assistance, and the National Agroforestry Research staff for their cooperation during data collection.

I am also grateful to ICRAF for sponsoring my MSc. studies. Lastly, I wish to thank my beloved husband and daughter for the understanding, patience and encouragement extended to me even at times of extreme difficulties and my sister Jemimah for her help during our stay together.

vii

DEDICATION

This work is dedicated to my husband Anastasio Gichimu and our lovely daughter Rita Wangechi.

TABLE OF CONTENTS

CONTENT	Page No.
ABSTRACT	ii
DECLARATION	iv
COPYRIGHT	v
ACKNOWLEDGEMENTS	vi
DEDICATION	vii
LIST OF TABLESxiii
LIST OF FIGURESxvi
LIST OF APPENDICES	xviii
LIST OF ABBREVIATIONS	xxi
CHAPTER ONE	1
1. INTRODUCTION	1
CHAPTER TWO	4
2. LITERATURE REVIEW	4
2.1 General overview	4
2.2 Effects of hedgerows on crop yields	5
2.3 Effects of prunings on crop yields	8
2.4 Root distribution and below ground interactions	10
2.5 The role of roots	12

	Page No.
CHAPTER THREE	15
3. MATERIALS AND METHODS	15
3.1 Experimental site	15
3.2 Cropping history	15
3.3 Experimental design and treatments	16
3.4 Management of the experiment	17
3.4.1 Land preparation	17
3.4.2 Planting of the test crop	17
3.4.3 Fertilizer application, weed and pest control	19
3.4.4 Lopping of hedges and prunings incorporation.	19
3.5 Measurements and sampling procedures	20
3.5.1 Soil sampling and analysis	20
3.5.2 Nutrient analysis of the prunings	20
3.5.3 Soil moisture content	21
3.5.4 Fine root biomass	21
3.5.5 Measurements on the maize plant	22
3.5.5.1 Plant height, stem diameter and number of leaves	22
3.5.5.2 Above ground dry matter yield	22
3.5.5.3 Leaf area index (LAI)	22

	Page No.
3.5.5.4 Maize grain yield	23
3.6 Data analysis	23
 CHAPTER FOUR	 24
4. RESULTS	24
4.1 Nutrient composition and contribution of the prunings	24
4.2 Some selected physical and chemical properties of soil	25
4.3 Soil moisture	26
4.4 Rainfall	28
4.5 Plant height, stem diameter and number of leaves	28
4.6 Maize leaf area index and above ground dry matter yield	34
4.7 Fine root biomass	36
4.7.1 Maize fine root biomass	36
4.7.2 Tree fine root biomass	37
4.8 Maize crop grain yield	38
4.9 Distribution and interaction of maize and tree roots at different depths	44

	Page No.
CHAPTER FIVE	47
5. DISCUSSION	47
5.1 Soil and prunings nutrient status	47
5.2 Soil moisture	48
5.3 Plant height, Stem diameter and number of leaves	49
5.4 Maize leaf area index and above ground dry matter yield	49
5.5 Fine root biomass	50
5.5.1 Maize fine root biomass	50
5.5.2 Tree fine root biomass	51
5.6 Maize crop grain yield	53
5.7 Distribution and interaction of maize and tree roots at different depths	56
CHAPTER SIX	58
6. CONCLUSION AND RECOMMENDATIONS	58
6.1 Conclusion	58
6.2 Recommendations	59
REFERENCES	61

APPENDICES 72

LIST OF TABLES

	Page No.
Table 1: Crop yields (kg/ha) in sole and alley cropping systems in the first two years (1984-85 and 1985-86) of a four year study on alfisols at ICRISAT centre, India.	7
Table 2: Plant nutrients supplied by calliandra prunings during the growing season of maize in an alley cropping system at Ibadan, Nigeria.	9
Table 3: Alley cropping trial: Intercropping maize with <i>Leucaena leucocephala</i> and <i>Calliandra calothyrsus</i> at Embu, Kenya.	18
Table 4: Nutrient concentrations of leaf prunings of <i>L. leucocephala</i> and <i>C. calothyrsus</i> incorporated into the soil in an alley cropping trial at Embu, Kenya.	24

Table 5:	Amounts of nutrients that can be supplied by the prunings of <i>L. leucocephala</i> and <i>C. calothyrsus</i> assuming total decomposition in an alley cropping trial at Embu, Kenya.	25
Table 6:	Some selected physical and chemical properties of the soil at the experimental site at the beginning of the season in an alley cropping trial at Embu, Kenya	27
Table 7:	Rainfall data (mm) at the alley cropping trial at Embu, Kenya.	29
Table 8:	Leaf area index, plant height, stem diameter and number of leaves in an alley cropping trial at Embu, Kenya.	35
Table 9:	Maize root biomass, above ground dry matter yield and maize grain yield (tons/ha) in an alley cropping trial at Embu, Kenya	43

Table 10:	Tree fine root biomass (tons/ha) at various depths in an alley cropping trial at Embu, Kenya	45
-----------	--	----

LIST OF FIGURES

	Page No.
Fig. 1: Percent volumetric moisture content (VMC) 14 days after planting in an alley cropping trial at Embu, Kenya.	30
Fig. 2: Percent volumetric moisture content (VMC) at 50 % tasselling in an alley cropping trial at Embu, Kenya.	31
Fig. 3: Percent volumetric moisture content (VMC) at milk stage in an alley cropping trial at Embu, Kenya.	32
Fig.4: Percent volumetric moisture content (VMC) at harvesting in an alley cropping trial at Embu, Kenya.	33
Fig. 5: Maize root biomass (tons/ha) at various depths in an alley cropping trial at Embu, Kenya.	39

Fig. 6:	Maize root biomass (tons/ha) variation with distance (cm) from the plant in an alley cropping trial at Embu, Kenya.	40
Fig. 7:	Maize root biomass (tons/ha) and tree root biomass (tons/ha) in an alley cropping trial at Embu, Kenya.	41
Fig. 8:	<i>L. leucocephala</i> and <i>C. calothyrsus</i> fine root biomass (tons/ha) variation with distance (cm) from the hedge in an alley cropping trial at Embu, Kenya.	42
Fig. 9:	Maize root biomass (tons/ha) and tree root biomass (tons/ha) at various depths in an alley cropping trial at Embu, Kenya.	46

LIST OF APPENDICES

	Page No.
Appendix 1: pH levels and nutrient ratings in an alley cropping trial at Embu, Kenya	72
Appendix 1a: pH ratings in an alley cropping trial at Embu, Kenya	72
Appendix 1b: Ratings for exchangeable K, Mg, and Ca in an alley cropping trial at Embu, Kenya	73
Appendix 1c: Ratings for C, N, P and Al in an alley cropping trial at Embu, Kenya	74
Appendix 2 : ANOVA tables	75
Appendix 2a: ANOVA for some selected physical and chemical properties of soil in an alley cropping trial at Embu, Kenya	75

		Page No.
Appendix 2b:	ANOVA for % volumetric moisture content in an alley cropping trial at Embu, Kenya.	78
Appendix 2c:	ANOVA for % volumetric Moisture Content for the Treatments with Hedges in an alley cropping trial at Embu, Kenya	80
Appendix 2d:	ANOVA for plant height in an alley cropping trial at Embu, Kenya	82
Appendix 2e:	ANOVA for stem diameter in an alley cropping trial at Embu, Kenya	82
Appendix 2f:	ANOVA for the number of leaves in an alley cropping trial at Embu, Kenya.	83
Appendix 2g:	ANOVA for leaf area index (LAI) in an alley cropping trial at Embu, Kenya	83

Appendix 2h:	ANOVA for above ground dry matter yield in an alley cropping trial at Embu, Kenya	84
Appendix 2i:	ANOVA for maize fine root biomass in an alley cropping trial at Embu, Kenya	84
Appendix 2j:	ANOVA for tree fine root biomass in an alley cropping trial at Embu, Kenya	85
Appendix 2k:	ANOVA for maize grain yield in an alley cropping trial at Embu, Kenya	85
Appendix 3:	Partial correlation coefficients of variables in an alley cropping trial at Embu, Kenya	86
Appendix 4:	Diagrammatic plan of the experiment	87

LIST OF ABBREVIATIONS

ANOVA	Analysis of variance
Al	Aluminium
BD	Bulk density
cm	Centimetre
CV	Coefficient of variation
Ca	Calcium
C	Carbon
g	Gram
GLM	General linear model
ha	Hectare
ICRAF	International Centre for Research in Agroforestry
K	Potassium
kg	Kilogram
KARI	Kenya Agricultural Research Institute
LAI	Leaf Area Index
m	Metre
Mg	Magnesium
m.e	Milliequivalents
N	Nitrogen
NS	Not significant
No.	Number

°C	Degrees centigrade
OC	Organic carbon
$P < 0.05$	Significant at 5% level of significance
$P > 0.05$	Not significant at 5% level of significance
P_2O_5	Phosphorus pentoxide
P	Phosphorus
ppm	Parts per million
RCBD	Randomised complete block design
SAS	Statistical analysis system
tons	Tonnes
TN	Total nitrogen
%	Percent

CHAPTER ONE

1. INTRODUCTION

The coffee growing zones in Kenya are some of the highly populated parts of the country with 450 - 700 inhabitants per km² and an average farm size of 1.5 ha (Minae and Nyamae, 1988). The high population has led to land pressure and as a consequence there is shortening of the fallow period used to restore soil fertility in traditional farming systems (Torres, 1983; Atta-Krah, 1990). This has resulted in a decline in soil productivity and crop yields (Kang *et al.*, 1989; Atta-krah, 1990; Young, 1997). An alternative to the traditional fallow is the use of inorganic fertilizers in crop production. Attempts to improve the productivity by introducing inorganic fertilizers have not been widely adopted mainly due to capital scarcity among small scale resource poor farmers. Due to the low ion exchange and buffering capacities of the soils in the humid and sub-humid tropics, it is also not completely possible to sustain crop production using inorganic fertilizers (Kang and Wilson, 1987). Therefore there is a great need to develop a more productive, yet capital and labour efficient cropping system.

Agroforestry has been identified as one of such systems. According to ICRAF (1997), agroforestry is a dynamic, ecologically based, natural resources management system that, through the integration of trees/shrubs on farms and in the agricultural landscape, diversifies and sustains production for increased social, economic and

environmental benefits. To solve the specific problem of declining soil fertility, scientists at the International Institute of Tropical Agriculture (IITA), Ibadan, Nigeria have developed the alley cropping technology (Ssekabembe and Henderlong, 1991).

Alley cropping is an agroforestry technology in which food crops are grown in alleys formed by hedgerows of trees or shrubs preferably leguminous nitrogen fixing species (Kang *et al.*, 1989; Nair, 1993). Examples of these trees are *Faidherbia albida*, *Acacia tortilis*, *Calliandra calothyrsus*, *Casuarina equisetifolia*, *Erythrina poeppigiana*, *Gliricidia sepium*, and *Inga jinicuil* (Young, 1997). The trees/shrubs are periodically pruned during the crops growth to provide biomass which when returned to the soil enhances its nutrient status and physical properties and prevents shading of the growing crops. For this system to function properly, tree/shrub species are needed which tolerate regular pruning, have a good biomass production and a deep root system with few roots in the top layer in the zone occupied by the food crops (Van Noordwijk *et al.*, 1991). Alley cropping is considered a promising technology for the humid and sub-humid tropics. Several trials have been carried out on alley cropping. Success in this system has in some locations been limited. In some trials, crop yield reductions associated with excessive competition with the hedgerows especially in semi-arid areas have been reported (Singh *et al.*, 1989 ; Jama *et al.*, 1995). As most small scale farmers in the tropics give importance to food crops, alley cropping will not be favoured unless it maintains or increases crop yields over traditional cropping systems (Jama *et al.*, 1995). To make it more adaptable to farmers the reductions in yield in alley cropping have to be minimized.

In the humid and sub-humid tropics some of the yield reductions have been attributed to shading (Gichuru and Kang, 1989; Lal, 1989; Ssekabembe and Henderlong, 1991; Hagger and Beer, 1993). Below ground competition has partly been responsible for yield reductions but has in most cases not been quantified. This study was therefore carried out with the following objectives:

- (i) Determine the distribution of maize and tree roots under intercropping and monocropping.
- (ii) Evaluate the yield of maize as influenced by the root distribution of trees.
- (iii) Determine the yield of maize with and without trees under inputs of prunings and fertilizers.

CHAPTER TWO

2. LITERATURE REVIEW

2.1 General overview

When leguminous trees and shrubs are integrated in farming systems, they may be beneficial by:

- exploiting growth resources better thus resulting in greater biomass production;
- improving the soil fertility due to nutrient recycling and biological nitrogen fixation;
- improving soil physical properties due to root activity;
- improving the microclimate due to mulching of the biomass and shelter by hedgerows.

On the negative side, hedgerows may compete with crops for common growth resources and reduce yields of crops (Jama *et al.*, 1995). So the suitability of trees for hedgerow cropping depends on a number of above and below ground

characteristics of the trees such as biomass production, nitrogen content of the prunings, rooting depth, presence of horizontal branch roots, nodulation, mycorrhizal infection and pruning tolerance (Hariah *et al.*, 1992). Also production of useful products such as firewood and browse for goats. According to van Noordwijk *et al.* (1996) without competition between plants, environmental resources would not be used efficiently. Competition between plant species is only a problem if its effects are more pronounced than those of intra-specific competition and especially when this affects the plant component which is most highly valued.

In alley cropping, the prunings from the hedgerows supply nutrients to the crops and organic materials for soil enrichment. Weed and erosion control as well as provision of fuelwood and livestock feed are also important attributes of alley cropping (Yamoah *et al.*, 1986a).

2.2 Effects of hedgerows on crop yields.

The use of multipurpose trees and shrubs in combination with agricultural crops in alley cropping has been recommended as an agroforestry approach to improving crop productivity through addition of nutrient rich organic mulch and providing a favourable effect on the physical and chemical properties of soil (Nair, 1993). Studies in the tropics indicate that both yield increases and reductions can be expected from alley cropping depending on several factors (Ssekabembe and Henderlong, 1991). These factors include the ecological compatibility of the different

species used, soil and crop management systems used for food crop production, the proportion of land area allocated to food crops versus trees/shrubs, previous soil properties and the climate (Lal, 1989).

Yield increases have been reported in alley cropping of maize with various agroforestry species as opposed to the sole maize crop (Yamoah *et al.*, 1986b; Jama *et al.*, 1986; Kang *et al.*, 1989; Jama *et al.*, 1991; Hauser and Kang, 1993; Shannon *et al.*, 1994). On the other hand, yield reductions have been reported when different trees/shrubs have been intercropped with a variety of food crops (Garrity *et al.*, 1992; Salazar *et al.*, 1993; Mureithi *et al.*, 1994; Chamshama *et al.*, 1995; Akonde *et al.*, 1996; Chamshama *et al.*, 1998). In an alley cropping of *Leucaena* with pigeon pea, castor and pearl millet at two alley widths, 3 metres and 5.4 metres in India, the yields shown in Table 1 were reported. The data show yield reductions in alley cropping as compared to sole cropping with narrow alleys having less yield compared to wider alleys.

Possible causes of crop yield reductions are competition for light, available nutrients and water between the hedge and the alley crop (Rosecrane *et al.*, 1992). In the semi-arid tropics, competition for moisture is mainly responsible for the negative interactions reported in alley cropping (Singh *et al.*, 1989; Rao *et al.*, 1991; Ong *et al.*, 1991; Rosecrane *et al.*, 1992). In the humid tropics, most of the yield reductions have been attributed to shading (Lal, 1989; Ssekabembe and Henderlong 1991; Hagger and Beer, 1993). In contrast Leihner *et al.* (1996) found no

Table 1: Crop yields (kg/ha) in sole and alley cropping systems in the first two years (1984-85 and 1985-86) of a four year study on alfisols at ICRISAT centre, India.

	1984-85		1985-86		
	Pearl millet		Pigeon pea		Castor
	Grain	Fodder	Grains	Stalks	beans
Sole cropping					
No mulch	955	1305	460	1175	1350
With mulch	725	1420	455	1150	1180
Alley cropping 3 m alleys					
No mulch	535	910	310	850	300
With mulch	530	925	396	870	330
Alley cropping 5.4 m alley					
No mulch	640	1045	415	1010	570
With mulch	650	1065	385	1120	585

Source (Rao *et al.*, 1991)

conclusive shading effect of *Leucaena leucocephala* and *Cajanus cajan* on maize and cassava in sub-humid Benin.

2.3 Effects of prunings on crop yields

When prunings from hedgerows are incorporated into the soil they improve the soil fertility on decomposition and hence crop yields. Mureithi *et al.* (1994) reported a significant increase in maize grain and stover yields when leucaena mulches were used. The maize grain yield was increased by 44% over the sole maize. The improved maize performance can be attributed to the increased availability of plant nutrients, especially nitrogen and potassium contributed by the mulch. Similarly, Salazar *et al.* (1993) reported maize yield increases when mulches of *Erythrina species*, *Leucaena leucocephala* and *Inga edulis* were used.

Apart from improving the soil nutrient status the prunings also increase the organic matter content of the soil (Yamoah *et al.*, 1986b). This in turn improves the physical properties of the soil, creating favourable conditions for plants growth. In alley cropping of nine leguminous trees with maize in Hawaii, Rosecrane *et al.* (1992) reported an increase in maize yields with addition of mulches. For every kilogram of nitrogen applied in form of mulch, approximately 12 kg of maize grain yield was produced. Increased maize yields were also reported by Mwangi *et al.* (1997) when prunings of *Leucaena leucocephala* and *Calliandra calothyrsus* were used. Gichuru and Kang (1989) reported an average maize yield of 3.1 tons/ha per year when 6

tons/ha per year of fresh calliandra prunings were added. The amount of nutrients produced from the prunings in this experiment are presented in Table 2.

Table 2: Plant nutrients supplied by calliandra prunings during the growing season of maize in an alley cropping system at Ibadan, Nigeria.

Year	Nutrients Kg/ha				
	N	P	K	Ca	Mg
1986	163	8	83	42	26
1987	135	11	112	32	18

Source (Gichuru and Kang, 1989)

In the case of leucaena, Chamshama et al. (1998) reported that application of fresh prunings at the rate of 6.18 tons/ha produced a yield of 0.18-1.94 tons/ha in maize at Gairo located in the central arid areas of Tanzania.

For nutrients to be available to the plants during the growing season, the decomposition and release of the nutrients by the prunings has to be synchronized with when nutrients are needed by plants. In an experiment to determine the decomposition of prunings of three agroforestry species, Yamoah *et al.* (1986a) reported that the decomposition rate of *Gliricidia sepium* was the highest when

compared to *Flemingia congesta* and *Senna siamea*. In this experiment, *Gliricidia sepium* was able to release all or most of its nitrogen for crops use within 120 days by a dry matter loss of 96%, compared to 58% and 46% for *Flemingia congesta* and *Senna siamea* respectively.

2.4 Root distribution and below ground interactions

Competition between trees/shrubs and crops for below ground resources are often as important as those for light and above ground space (van Noordwijk *et al.*, 1996). It is the general apprehension of farmers that trees/shrubs in association with crops in agroforestry compete strongly for available nutrients and water. Generally trees/shrubs are believed to have deeper rooting systems than most crops. This is very desirable in agroforestry since there would be spatial sharing of below ground resources resulting in their greater utilization. In addition, the trees/shrubs could exploit deep soil water reserves, intercept leaching water and nutrients on their way down below the crop root zone. Contrary to this popular belief, not all trees/shrubs have a deep rooting system in reality. A study by Dhyani *et al.* (1990) showed that five tree species *Bauhinia purpurea*, *Grewia optiva*, *Eucalyptus tereticornis*, *Leucaena leucocephala* and *Ougeinia oojeinensis* have tap and lateral roots which reach deep soil levels (90-120 cm) but the bulk of their roots are found near the surface.

According to Rocheleau *et al.* (1988) a good alley cropping tree or shrub should have a deep tap root system with few lateral root branches near the surface so as to reduce competition with crops. Reports on tree-root distribution especially for multipurpose tree species suitable for agroforestry are scanty (Dhyani *et al.*, 1990). Available information on the root distribution is mostly concentrated on the total root biomass, though it is the finest part of the root system which is most dynamic and most actively involved in nutrient and water uptake, hence of great interest in agroforestry. It is the fine roots that are involved in mycorrhizal transfer and nutrient incorporation through their extremely rapid turnover (Berish, 1982).

In an experiment to determine the vertical root distribution of five agroforestry species, Jonsson *et al.* (1988) reported similar root distribution of *Senna siamea*, *Leucaena leucocephala* and *Prosopis chilensis* to that of maize with the trees having twice the density of fine roots as that of maize. Thus, intense root competition would be expected between the crop and the tree species when they are intercropped. In another experiment in semi-arid India, Ong *et al.* (1991) reported that the maximum root density of *Leucaena leucocephala* which was intercropped with millet was highest in the top 30 cm. This is the same zone where most of the millet roots would be found. Intense competition is, therefore, expected between the trees and the crop. Agroforestry being a relatively complex land use system where environmental resources are shared between species, knowledge of root distribution is crucial in selection of species, design of the agroforestry system and its management.

Van Noordwijk *et al.* (1996) reported that the actual distribution pattern of a species is based on the genotype and environmental interactions such as nutrient levels, soil compaction and oxygen concentration. Therefore, a certain species may have different root distributions in different environments. For most species root densities decrease with depth and with increasing distance from the plant in the horizontal direction.

Management practices on trees/shrubs also have an effect on the distribution of roots. Pruning, pollarding, or lopping reduces the carbohydrate supply to the roots and this may cause dieback of the fine roots (van Noordwijk *et al.*, 1996). Fownes and Anderson (1991) found the fine root biomass of *Leucaena leucocephala* to decrease by 10% following coppicing. The height at which these practices are done also affect root distribution. Hairiah *et al.* (1992) reported that reducing the pruning height from 100-50 cm led to more fine root branches and less thick ones being formed. For agroforestry systems such as alley cropping to be successful, there has to be complementarity in root distribution as is the case of *Grevillea robusta* and maize systems in Kenya (Huxley *et al.*, 1994).

2.5 The role of roots

The root biomass of trees is usually 20-30 % of the total plant biomass and consist of structural roots, fine roots and associated mycorrhizae (Nair, 1993). The principle functions of roots are anchorage, absorption of water and minerals and production

of growth regulators (Kramer and Boyer, 1995). Roots are an important component in primary production and are of great significance in soil fertility maintenance (Young, 1997). Net primary production is through exudation and sloughing off of fine roots especially during adverse conditions. Decomposition of these tree roots and the substances they exude greatly and positively affect soil organic matter (Groot and Soumare, 1995). The carbon inputs from the roots play an important role in the soil environment by regulating the decay rate of senesced plant tissues by sustaining the microbial populations that are involved in litter decay and nutrient mineralization. The organic matter also increase the capacity of the soil to hold and carry water and also increase their capacity of cation exchange both of which help improve soil fertility. Apart from improving soil fertility, they also increase the efficiency of nutrient use as organic matter has a positive effect on the water holding capacity, hence increasing nutrient diffusion.

Roots help in the improvement of soil physical characteristics (Ong *et al.*, 1991), thus creating a favourable environment for plants growth. Roots may also help in the transfer of assimilates from one plant to another through mycorrhizal bridges in root systems. Mycorrhizae also expand the plants root system assisting in the extraction of nutrients from the soil. Of particular importance for the tropics is improving plant access to phosphorus.

Trees with lateral roots may reduce loss of nutrients from the soil by recycling nutrients that would have been leached out from the system. Their tap roots may also

take up nutrients released by weathering in deeper soil layers. Possible problems of tree root systems in alley cropping and other agroforestry systems is competition with herbaceous plants. Under conditions where soil moisture is not a limiting factor, growth of the tree roots into the alleys may actually be desirable (Ssekabembe and Henderlong, 1991). In case of nitrogen fixing trees, the roots that grow into the alleys carry nodules that fix atmospheric nitrogen. Part of this nitrogen can be used by the herbaceous crop when the nodules undergo senescence. This source of nitrogen can be very important in farming situations where no nitrogen fertilizer is used.

CHAPTER THREE

3. MATERIALS AND METHODS

3.1 Experimental site

The experimental work was carried out at the Embu Regional Research Centre (KARI), Eastern Province, Kenya. It is located on the central highlands of Kenya on the south eastern slopes of Mt. Kenya at an altitude of 1480 m and latitude of 0°30'S and longitude 37°27'E. The average rainfall at the Research Station ranges between 1100 mm to 1500 mm received in two distinct rainy seasons. The long rains come between mid March and June with an average precipitation of 750 mm and the short rains between mid October and December with an average of 350 mm. The temperatures are warm with a monthly average of 18 to 21°C. The soils are mainly nitosols (red kikuyu loams) derived from basic volcanic rocks. They are deep, well weathered with friable clay texture and moderate to high inherent fertility.

3.2 Cropping history

The area under the experiment had been previously cropped for several years after which it was left fallow for two years prior to its allocation to the experiment in June 1991. Before setting up the experiment, uniformity trials were carried out without fertilizer during the 1991 long rain season and 1992 short rain season which revealed

the land to be fairly uniform in terms of soil fertility. Soil samples were taken and analyzed at the end of the 1991 short rains which also revealed uniformity among blocks. The hedge trees *L. leucocephala* and *C. calothyrsus* were planted as seedlings during 1992 long rains and allowed two seasons to establish after which treatments were applied from 1993 long rains. During the long rains, maize has been used as the test crop while an intercrop of maize and beans have been used in the short rains. Root pruning has been done at the beginning of each growing season to curb tree roots extending to the neighbouring plots which do not have trees. The experimental site was used for the present study starting October 1997 for one cropping season. It would have been desirable to repeat the experiment for the second season, but resources and fixed MSc. research period were the constraints.

3.3 Experimental design and treatments

The experimental design was a randomized complete block design (RCBD) with 4 replicates (Appendix 4). The plots had dimensions of 10 m x 9 m. The tree hedge species were *Calliandra calothyrsus* and *Leucaena leucocephala* spaced at 10 m inter row and 0.5 m intra row. The experimental treatments are shown in Table 3.

3.4 Management of the experiment

3.4.1 Land preparation

The land was prepared at the beginning of the month of October 1997 using a hand hoe. For some treatments trenches which were 0.5 m deep were dug to act as barriers at a distance of 37.5 cm from the hedge (Table 3). Barriers were also dug between plots with hedges and the adjacent plots.

3.4.2 Planting of the test crop

Planting of maize was carried out in mid-October 1997 at a spacing of 75 cm between rows and 50 cm between plants. To avoid planting over the disturbed soil, in treatments three and four, maize was grown 75 cm from the trenches. Three seeds were planted per hole and later thinned to two plants per hill as recommended for Embu, three weeks after emergence.

Table 3: Alley cropping trial: Intercropping maize with *Leucaena leucocephala* and *Calliandra calothyrsus* at Embu, Kenya.

Treatment	Crop	Trenches	Cropping system	Mulches incorporated	Fertilizer added
1	Maize	Absent	Intercrop	C.c mulches	50 kg P ₂ O ₅ /ha
2	Maize	Absent	Intercrop	L.l mulches	50 kg P ₂ O ₅ /ha
3	Maize	Present	Intercrop	C.c mulches	50 kg P ₂ O ₅ /ha
4	Maize	Present	Intercrop	L.l mulches	50 kg P ₂ O ₅ /ha
5	Maize	Absent	Monocrop	C.c mulches	50 kg P ₂ O ₅ /ha
6	Maize	Absent	Monocrop	L.l mulches	50 kg P ₂ O ₅ /ha
7	Maize	Absent	Monocrop	None	50 kg P ₂ O ₅ /ha 25 kg N/ha
8	Maize	Absent	Monocrop	None	50 kg P ₂ O ₅ /ha

C.c - *Calliandra calothyrsus*

L.l - *Leucaena leucocephala*

3.4.3 Fertilizer application, weed and pest control

For treatment seven, calcium ammonium nitrate (CAN) fertilizer was applied at a rate of 25 kg N/ha. For all plots there was a uniform application of 50 Kg P₂O₅/ha in form of triple super phosphate (TSP).

The first weed control was done three weeks after crop emergence. More weed controls were carried out as required to ensure that the field was weed free.

Maize stalk borer is a common pest of maize in Embu. This was controlled using Trichlorophon 2.5% (Dipterex) in granular form at a rate of 3.5 kg/ha when the maize plants were knee high.

3.4.4 Lopping of hedges and prunings incorporation.

Lopping of the hedgerows in both calliandra and leucaena was done one week before planting. The hedges were lopped to a height of 50 cm using secateurs. The woody biomass was separated from the leafy biomass. The leafy biomass of both species were weighed separately to obtain fresh weights. The weighed prunings were evenly spread over the soil surface and incorporated using a hoe. This was the first incorporation. The long term procedure of the alley cropping experiment did not permit second lopping of the hedgerows. Also the prunings were not adequate for the required amounts to be applied in the plots. Hence, at three weeks before

tasselling, fresh prunings from outside sources were obtained and weighed fresh according to the amounts required for each plot to make up to the adequate amounts of 6.7 tons/ha. Hence in total the prunings for both species were applied at a rate of 6.7 tons/ha when fresh in two splits. The rates were based on Gichuru and Kang (1989) for calliandra and Chamshama *et al.* (1998) for leucaena.

3.5 Measurements and sampling procedures

3.5.1 Soil sampling and analysis

Soil sampling was done before the experiment was laid out. Soil was sampled at a depth of 0 - 20 cm using a soil auger at five randomly selected points in every plot. The soil was bulked, mixed thoroughly and a sub-sample taken for both physical and chemical analysis. The analysis was done to determine the soil pH, bulk density, available P, exchangeable cations (Ca^{2+} , Mg^{2+} , K^{+}), total N and C using the method by Walsh (1971) and Wilde *et al.* (1979).

3.5.2 Nutrient analysis of the prunings

Before incorporation into the soil, a sample of the leaf prunings was chopped, thoroughly mixed and oven dried using a forced air oven at 70°C to avoid loss of some nitrogen. The material was then ground in a Wiley mill in preparation for nutrient analysis. The sample was analyzed for nitrogen, potassium, phosphorus,

calcium and magnesium using the method by Wilde *et al.* (1979). The percent of nutrient concentrations present in the prunings and the amounts applied (6.7tons/ha) were used to calculate the total amount of nutrients that can be supplied by the prunings assuming total decomposition.

3.5.3 Soil moisture content

The soil moisture content was determined volumetrically at 0-30 and 30-60 cm depths from the surface at a distance of one and two metres from the hedge 14 days after maize planting, at 50% anthesis, milk stage and at harvesting time. The soil was weighed, oven dried at 105 °C to constant weight, cooled and weighed again. The difference is the amount of water that was present before drying.

3.5.4 Fine root biomass

The fine root biomass (roots < 2 mm in diameter) of both the hedge and maize were determined at 0-15 and 15-30 cm, depths and at 37.5 cm, 112.5 cm and 187.5 cm from the hedge. A 7.3 cm auger was used. The roots were washed off the soil over sieves of different sizes with tap water and the fine roots collected, freshly weighed and then oven dried at 70°C for 48 hours for dry weight determination.

3.5.5 Measurements on the maize plant

At 50% anthesis 15 plants were randomly selected from every plot and the following measurements made: plant height, stem diameter, number of leaves, above ground dry matter yield and leaf area index (LAI).

3.5.5.1 Plant height, stem diameter and number of leaves

The above ground plant height of the sampled plants was measured using an ordinary tape measure starting from the ground level to the tip of the tassel. The stem diameter was measured at the third internode from the ground of every plant using a vernier calliper while the number of leaves were physically counted.

3.5.5.2 Above ground dry matter yield

The sampled plants were finely chopped, thoroughly mixed, weighed and a sub sample taken and freshly weighed. The sub-sample was oven dried at 70°C for 48 hours and then weighed.

3.5.5.3 Leaf Area Index (LAI)

For determination of LAI, the lengths of the leaves from sampled plants (the leaf sheath excluded) and width were measured using an ordinary tape measure. The

width was taken at the widest point of the leaf. From the figures, the LAI was calculated using the formula by Daughtry and Hollinger (1984), that is

$$\text{LAI} = 0.75 (L \times W) / \text{Ground area}$$

Where LAI = Leaf Area Index

L = Length

W = Width

3.5.5.4 Maize grain yield

On drying, maize was harvested from a net plot which measured 6 x 4.5 m. The cobs were separated from the stover manually and sun dried. The maize was shelled, the grains weighed and a sample taken to determine their moisture content using a moisture meter. This was used to express grain yield at 12.5% moisture content.

3.6 Data analysis

All data except that on the nutrient composition of the prunings was subjected to analysis of variance (ANOVA) using the general linear model (GLM) procedures of the statistical analysis system (SAS) package. Differences between treatment means were declared significant at $P < 0.05$. Separation of means was done using Duncan's multiple range test.

CHAPTER FOUR

4. RESULTS

4.1 Nutrient composition and contribution of the prunings

The concentrations of nitrogen, phosphorus, potassium, calcium, and magnesium in the leaf prunings of *Leucaena leucocephala* and *Calliandra calothyrsus* are shown in Table 4.

Table 4: Nutrient concentrations of leaf prunings of *L. leucocephala* and *C. calothyrsus* incorporated fresh into the soil in an alley cropping trial at Embu, Kenya.

Species	% Nutrient concentrations				
	N	P	K	Ca	Mg
<i>L. leucocephala</i>	1.57	0.24	1.33	0.33	0.19
<i>C. calothyrsus</i>	2.17	0.24	1.66	0.99	0.52

Table 4 shows that calliandra prunings contained more nitrogen, potassium, calcium, and magnesium compared to leucaena prunings. Calliandra prunings had about three times the amounts of calcium and magnesium contained in leucaena prunings while potassium and phosphorus levels were almost equal. The amounts of

nutrients which can be provided by the prunings assuming total decomposition are shown in Table 5 (see section 3.5.2).

Table 5: Amounts of nutrients that can be supplied by fresh prunings of *L. leucocephala* and *C. calothyrsus* assuming total decomposition in an alley cropping trial at Embu, Kenya.

Species	Nutrients Kg/ha				
	N	P	K	Ca	Mg
<i>L. leucocephala</i>	105.19	16.08	89.11	22.11	12.73
<i>C. calothyrsus</i>	145.39	16.08	111.22	66.33	34.84

The trend of the amount of nutrients was similar to that of the nutrient concentrations of the prunings (Table 4).

4.2 Some selected physical and chemical properties of soil

Soil samples were taken at the beginning of the season before applying treatments and the data on their chemical and physical characteristics is shown in Table 6. The soil was generally acidic with a pH range between 5.0-5.5 (Appendix 1a). Organic carbon was low and ranged between 2.69% and 2.89%. Calcium, magnesium and

potassium levels ranged between 1.39-1.63, 1.69-2.00 and 1.08-4.02 Me/100 g respectively.

These levels of nutrients are considered high for magnesium and potassium but low for calcium (Appendix 1b). Phosphorus and aluminium levels were low ranging between 6.04-10.09 ppm and 0.04-0.12 Me/100 g respectively. Nitrogen levels were medium (Appendix 1c) and ranged between 0.31 and 0.34 (Table 6). The bulk density ranged between 1.08 and 1.13. Analysis of variance (ANOVA) (Appendix 2a) revealed no significant differences ($P > 0.05$) in nutrient levels between the treatment plots before commencement of the experiment.

4.3 Soil moisture

At all stages when moisture levels were measured, there was no significant difference ($P > 0.05$) between the treatment means and also the mean moisture content at various distances from the hedge. Analysis of variance is shown in Appendices 2b and 2c. Except for treatment two and four, there was more moisture in the 0-30 cm depth as compared to the 30-60 cm depth 14 days after planting (Fig.1). At 50% tasselling there was more moisture in the 30-60 cm depth except in treatment four and eight (Fig.2). The difference between the two depths was

Table 6: Some selected physical and chemical properties of the soil at the experimental site at the beginning of the season in an alley cropping trial at Embu, Kenya

Treatment	pH	%TN	%OC	P	Ca ²⁺	Mg ²⁺	K ⁺	Al ³⁺	BD
1 Maize/calliandra intercrop + prunings	5.3	0.34	2.81	6.04	1.39	1.84	1.22	0.12	1.10
2 Maize/leucaena intercrop + prunings	5.1	0.32	2.75	6.45	1.46	1.92	1.08	0.09	1.10
3 Maize/calliandra intercrop + prunings + trenches	5.4	0.33	2.89	6.91	1.53	1.76	1.10	0.08	1.13
4 Maize/leucaena intercrop + prunings + trenches	5.3	0.34	2.82	5.59	1.55	1.98	1.19	0.04	1.08
5 Maize monocrop + calliandra prunings	5.0	0.31	2.71	10.09	1.63	1.69	4.02	0.21	1.08
6 Maize monocrop + leucaena prunings	5.4	0.33	2.73	6.30	1.41	1.82	1.27	0.08	1.13
7 Maize monocrop + 25 kg N/ha	5.5	0.34	2.72	7.12	1.49	2.00	1.09	0.10	1.08
8 Maize monocrop	5.3	0.32	2.69	7.06	1.53	1.96	1.18	0.09	1.08
CV %	5.5	10.1	7	37.1	32.2	17.8	151.4	116.9	7.56
Mean	5.3	0.33	2.76	6.94	1.50	1.90	1.52	0.10	1.09
P _{0.05}	NS	NS	NS	NS	NS	NS	NS	NS	NS

significant ($P < 0.05$). Except for treatment one and two, there was more moisture at the 0-30 cm depth as compared to the 30-60 cm depth at the milk stage (Fig.3). At harvesting, treatment four, six, seven and eight had more moisture in the 0-30 cm depth while treatment one, two, three and five had more moisture in the 30-60 cm depth (Fig.4).

4.4 Rainfall

Rainfall amounts during the study period were high compared to the previous season which was a normal season (Table 7). Most of the rain falls in November for a normal season, but during the experimental period rainfall was abnormally high for October and November and it remained high for the rest of the season. There was no likelihood of the crop plants suffering from water related stress.

4.5 Plant height, stem diameter and number of leaves

Analysis of variance for plant height and stem diameter revealed significant differences ($P < 0.05$) between treatment means (Table 8). Treatment three had the highest plant height while treatment four had the lowest. Both of these

Table 7: Rainfall data (mm) at the alley cropping trial at Embu, Kenya.

Month	1996/97	No. of rainy days	1997/98	No. of rainy days
September	1.9	3	1.8	2
October	13.2	5	386.9	22
November	242.2	22	355.3	25
December	0.5	1	139.4	18
January	0.9	2	166.3	19
February	0.0	0	164.7	7
March	91.9	6	163.2	9
Total	350.6	39	1377.6	92
Mean	50.1		196.8	

treatments had hedges and trenches. Treatment three had calliandra as the hedge tree while treatment four had leucaena as the hedge tree. Generally calliandra prunings had more effect on height than leucaena prunings. Treatment seven which had 25 kg N/ha and treatment six which had leucaena prunings had the same effect on plant height. The plant height ranged from 205.80 cm in treatment four to 241.90 cm in treatment three.

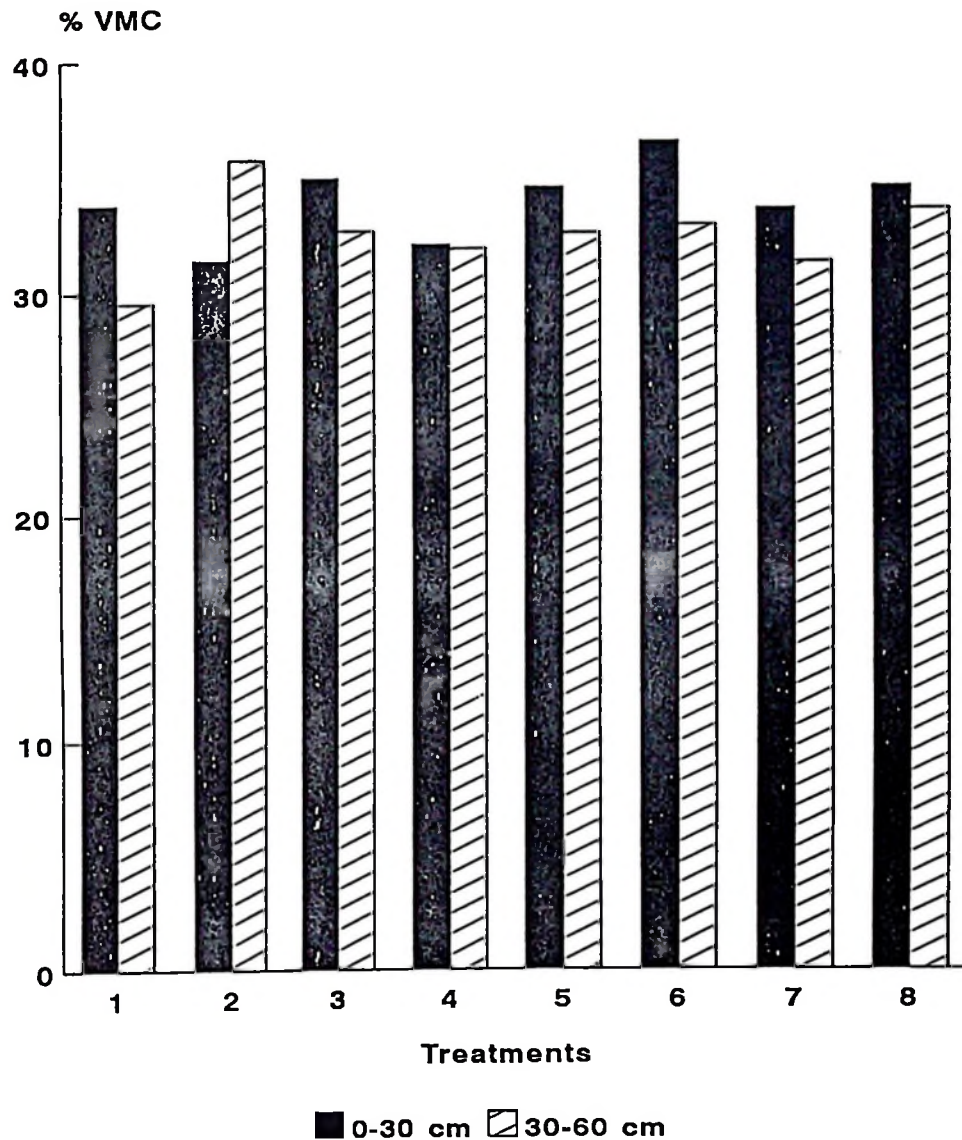


Fig. 1 Percent volumetric moisture content (VMC) 14 days after planting at various depths in an alley cropping trial at Embu, Kenya.

1. Maize/calliandra intercrop + prunings. 2. Maize/leucaena intercrop + prunings. 3. Maize/calliandra intercrop + prunings + trenches. 4. Maize/leucaena intercrop + prunings + trenches. 5. Maize monocrop + calliandra prunings. 6. Maize monocrop + leucaena prunings. 7. Maize monocrop + 25 kg N/ha. 8. Maize monocrop.

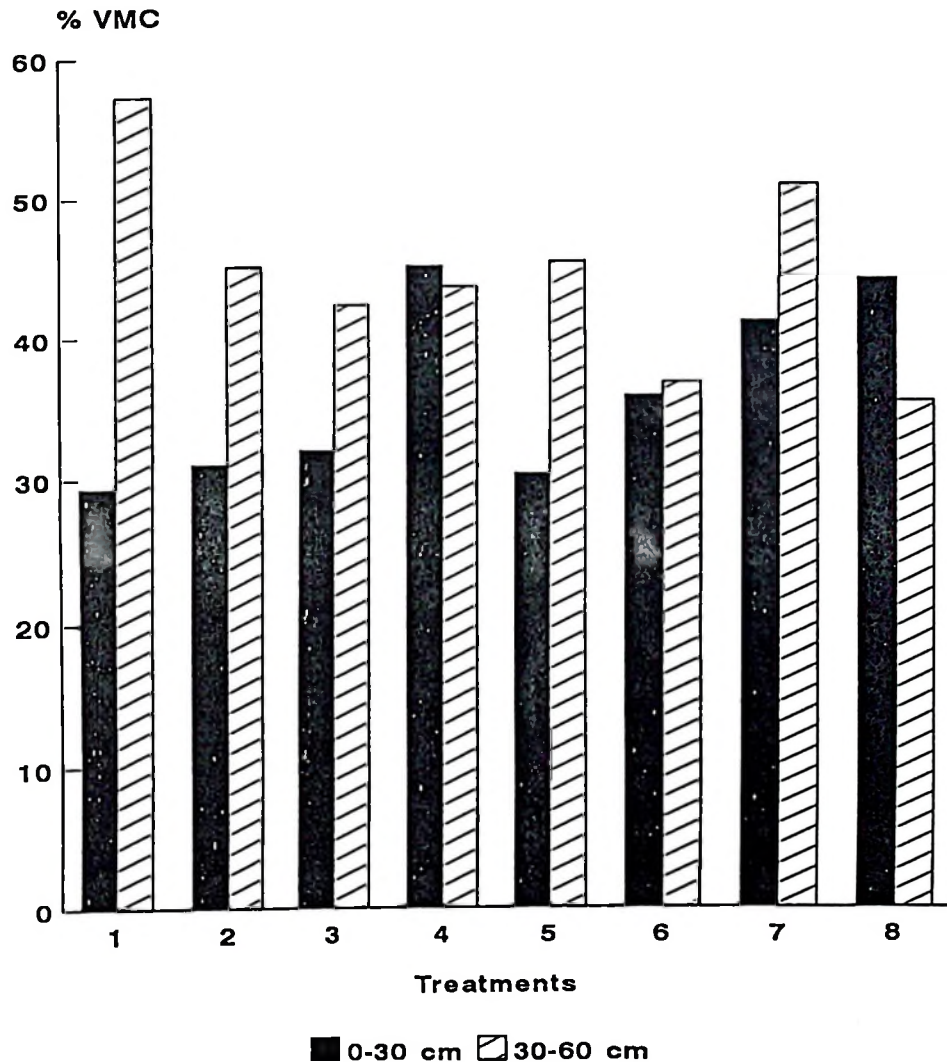


Fig.2 Percent volumetric moisture content (VMC) at 50% tasselling in an alley cropping trial at Embu, Kenya.

1. Maize/calliandra intercrop + prunings.
2. Maize/leucaena intercrop + prunings.
3. Maize/calliandra intercrop + prunings + trenches.
4. Maize/leucaena intercrop + prunings + trenches.
5. Maize monocrop + calliandra prunings.
6. Maize monocrop + leucaena prunings.
7. Maize monocrop + 25 kg N/ha.
8. Maize monocrop.

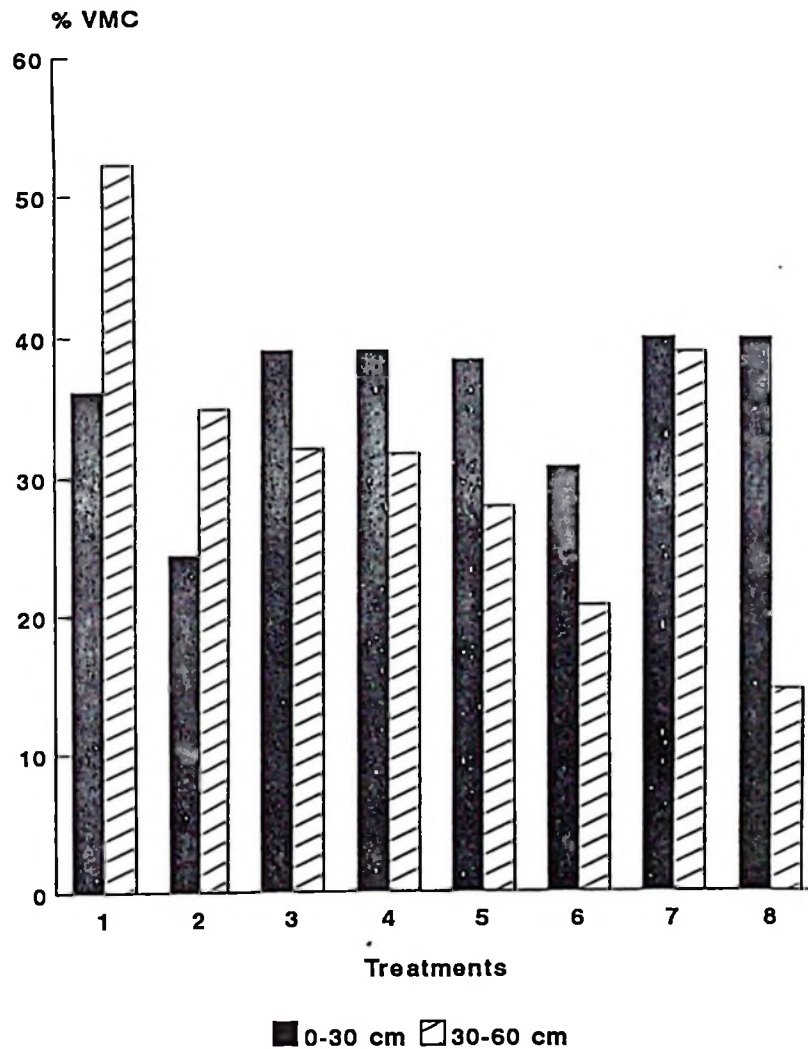


Fig.3 Percent volumetric moisture content (VMC) at milk stage in an alley cropping trial at Embu, Kenya.

1. Maize/calliandra intercrop + prunings. 2. Maize/leucaena intercrop + prunings. 3. Maize/calliandra intercrop + prunings + trenches. 4. Maize/leucaena intercrop + prunings + trenches. 5. Maize monocrop + calliandra prunings. 6. Maize monocrop + leucaena prunings. 7. Maize monocrop + 25 kg N/ha. 8. Maize monocrop.

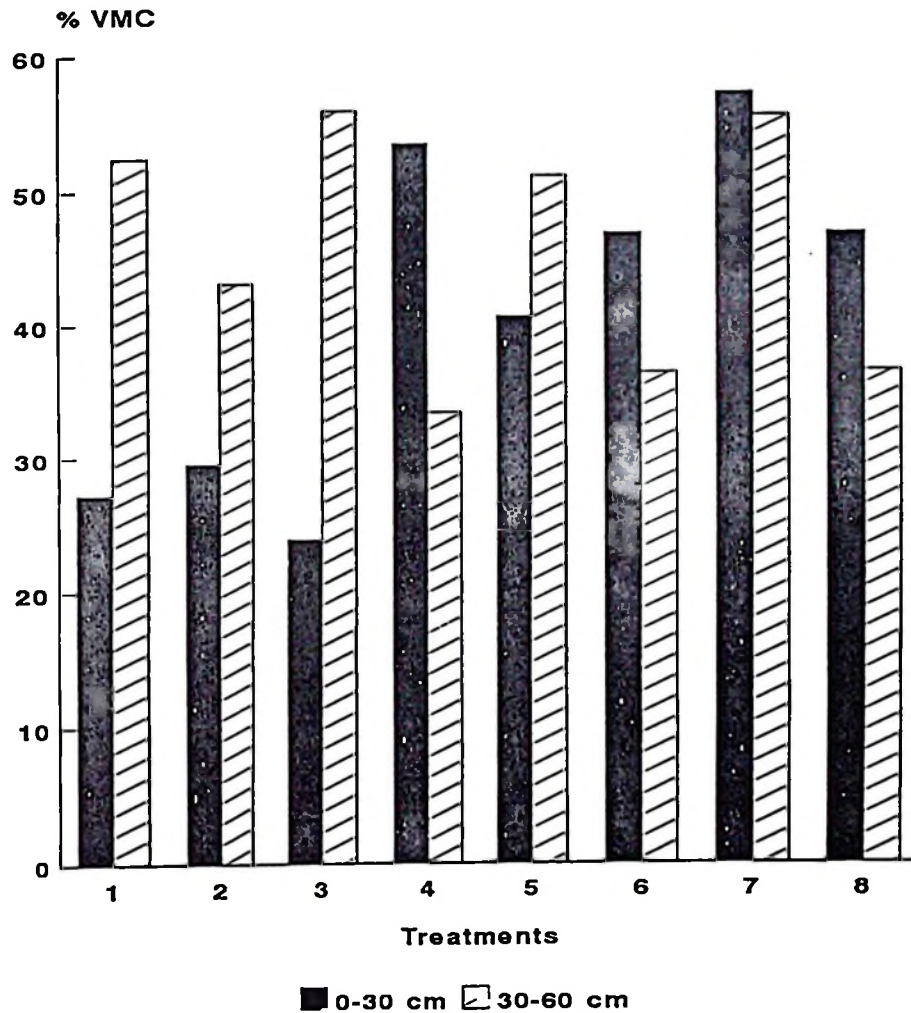


Fig.4 Percent volumetric moisture content (VMC) at harvesting in an alley cropping trial at Embu, Kenya.

1. Maize/calliandra intercrop + prunings.
2. Maize/leucaena intercrop + prunings.
3. Maize/calliandra intercrop + prunings + trenches.
4. Maize/leucaena intercrop + pruning + trenches.
5. Maize monocrop + calliandra prunings.
6. Maize monocrop + leucaena prunings.
7. Maize monocrop + 25 kg N/ha.
8. Maize monocrop.

Treatment seven had the highest diameter while treatment three had the lowest. Analysis of variance revealed significant differences ($P < 0.05$) between the mean stem diameters (Table 8). The monocropped treatments with prunings had the same effect on stem diameter (Table 8). For the hedge treatments, treatment three which had calliandra prunings and trenches had the lowest diameter while treatment two which had leucaena hedges and prunings had the highest stem diameter. The number of leaves averaged 10 in all treatments and did not differ significantly between treatments (Table 8) (Appendix 2f).

4.6 Maize leaf area index and above ground dry matter yield

There was no significant difference ($P > 0.05$) in leaf area index (LAI) among treatment means (Table 8). LAI was highest for treatment six and lowest for treatment seven. The hedge treatments had lower LAI than the monocropped treatments which had leaf prunings (treatments five and six) but was higher than for the monocropped treatments which had no prunings (treatment seven and eight). Trenching slightly improved leaf area index (Table 8). Analysis of variance for the leaf area index is shown in Appendix 2g.

Dry matter yield was highest in treatments which had leaf prunings (treatment one to six) and relatively low in the control (treatment eight) and treatment seven which

Table: 8 Maize leaf area index, plant height, stem diameter and number of leaves in an alley cropping trial at Embu, Kenya.

Treatment	LAI	Plant height (cm)	Number of leaves	Stem diameter (cm)
1 Maize/calliandra intercrop + prunings	1.77 a	237.08 abc	9.75 a	2.08 abc
2 Maize/leucaena intercrop + prunings	1.72 a	222.20 abc	9.93 a	2.28 ab
3 Maize/calliandra intercrop + prunings + trenches	1.83 a	241.90 a	10.10 a	1.93 c
4 Maize/leucaena intercrop + prunings + trenches	1.99 a	205.80 c	10.23 a	2.23 abc
5 Maize monocrop + calliandra prunings	2.03 a	225.77 abc	10.10 a	1.98 bc
6 Maize monocrop + leucaena prunings	2.13 a	230.27 ab	10.30 a	1.98 bc
7 Maize monocrop + 25 kg N/ha	1.52 a	231.35 ab	9.78 a	2.33 a
8 Maize monocrop	1.68 a	214.07 bc	9.75 a	2.23 abc

Means followed by the same letter are not significantly different according to Duncan's multiple range test (P > 0.05)

had no leaf prunings but fertilizer had been applied at a rate of 25 kg N/ha (Table 9). The mean values ranged between 106.55 and 136.45 g/plant. Analysis of variance revealed no significant differences ($P > 0.05$) between the treatment means (Appendix 2h). There was a positive correlation between dry matter yield and LAI, number of leaves, plant height and stem diameter. The correlation between dry matter yield and LAI was significant ($P < 0.05$) (Appendix 3).

4.7 Fine root biomass

4.7.1 Maize fine root biomass

The mean fine root biomass of treatment five which was monocropped and with calliandra prunings was significantly lower ($P < 0.05$) than that of treatment one which had calliandra hedge trees and prunings and eight which was the control treatment (Table 9). Monocropped treatments which had prunings incorporated (treatment five and six) had the lowest root biomass. Trenching reduced maize root biomass and treatments three and four were found to have lower root biomass compared to treatment one and two which had no trenches. For treatments three, five, six and seven, there was more root biomass in the 0-15 cm depth as compared to the 15-30 cm depth while treatment one, two, four and eight had more biomass

in the 15-30 cm depth (Fig.5). The root biomass was markedly higher in the 15-30 cm depth in treatment four as compared to the 0-15 cm depth (Fig.5). There was a general decrease in the root biomass with distance from the plant (Fig.6). At 10 cm from the plant, the root biomass of the maize plants was highest (Fig.6) and significantly different ($P < 0.05$) from the biomass at 20 and 30 cm from the plant. It would appear that root biomass does not decrease any further from 20 cm onwards.

4.7.2 Tree fine root biomass

Treatment two (which had leucaena as the hedge tree) had highest fine root biomass (Fig.7). Treatments With trenches to prevent root extension into the plot treatment three and four had equal amounts of fine root biomass but this was lower than for both treatment one and two (Fig.7). Data in Fig.7 also reveals that maize fine root biomass was higher than that of trees in all treatments except in treatment two. Generally there was low biomass in the top 15 cm compared to the 15-30 cm depth except for treatment two which had higher biomass in the top 15 cm (Table 10). In the 0-15 cm depth, treatment one, three, and four had equal amounts of biomass while in the 15-30 cm depth, treatment one and four had higher and equal amounts of fine root biomass compared to treatments two and three (Table 10). Mean root biomass decreased with distance from the hedge for both hedge species (Fig.8).

Analysis of variance revealed no significant differences ($P > 0.05$) in the mean fine root biomass between the various treatments, distances and depths. The ANOVA is shown in Appendix 2j.

4.8 Maize crop grain yield

Generally treatments with leaf prunings incorporated into the soil had higher maize grain yields compared to treatments without leaf prunings (Table 9). The highest yield was obtained from treatment five which had maize monocrop and calliandra leaf prunings incorporated and had 69.9 % more maize compared to the control. The mean yield of this treatment was significantly higher ($P < 0.05$) than that of treatment one, two, seven, and eight (Table 9).

This was followed by treatment six which had maize monocrop and leucaena prunings incorporated. The lowest yields were obtained from the control (treatment eight) followed by treatment seven which had no prunings but nitrogen fertilizer had been applied at a rate of 25 Kg N/ha (Table 9).

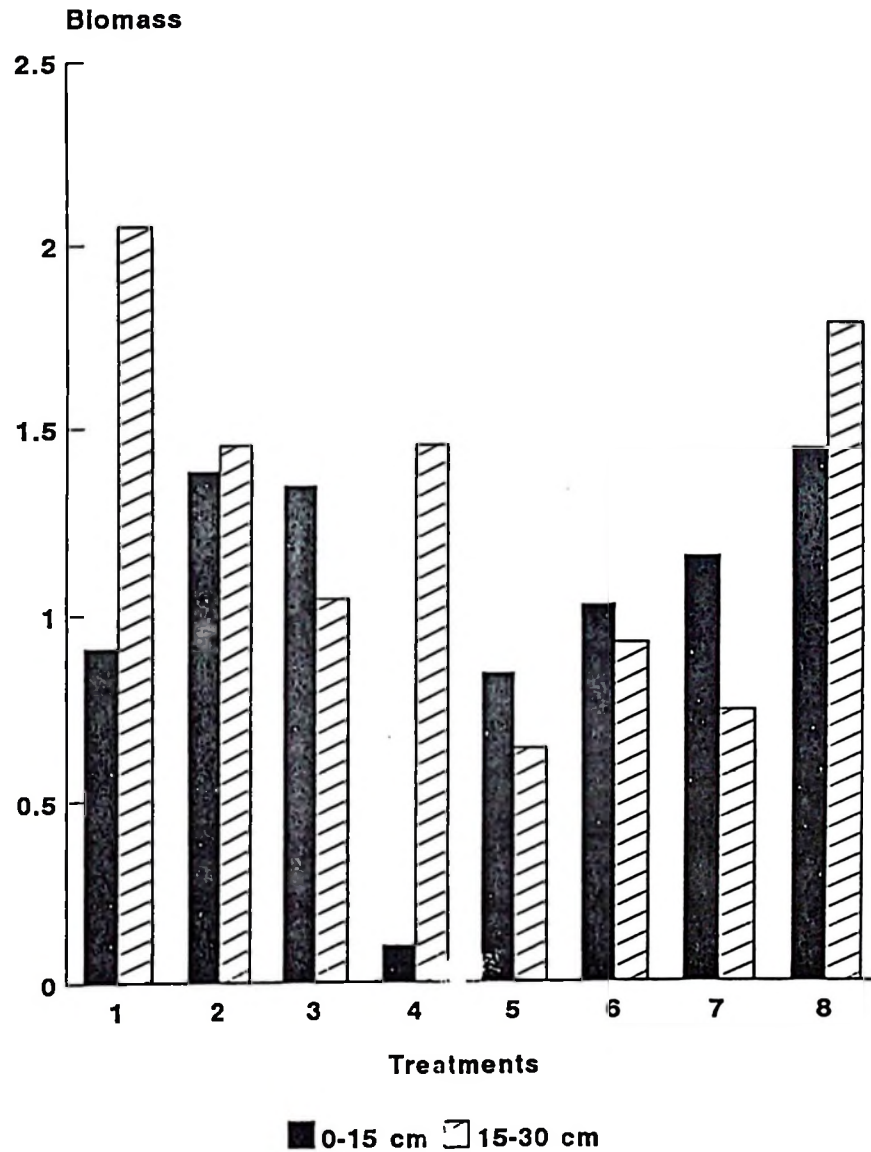


Fig.5 Maize root biomass (tons/ha) at various depths in an alley cropping trial in Embu, Kenya.

1. Maize/callindra intercrop + prunings. 2. Maize/leucaena intercrop + prunings. 3. Maize/callindra intercrop + prunings + trenches. 4. Maize/leucaena intercrop + prunings + trenches. 5. Maize monocrop + callindra prunings. 6. Maize monocrop + leucaena prunings. 7. Maize monocrop + 25 kg N/ha. 8. Maize monocrop.

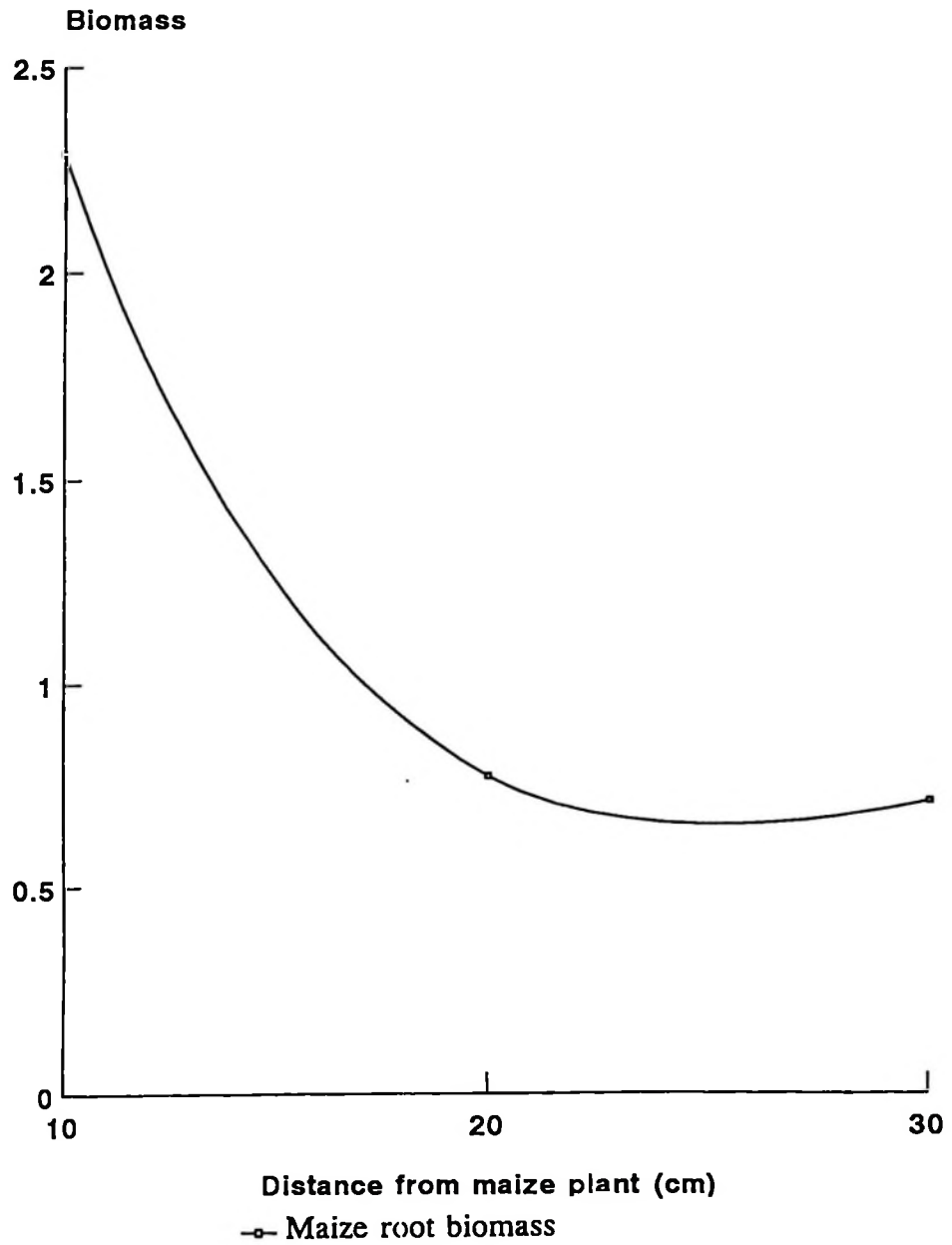


Fig.6 Maize root biomass (tons/ha) variation with distance from the plant (cm) in an alley cropping trial at Embu, Kenya.

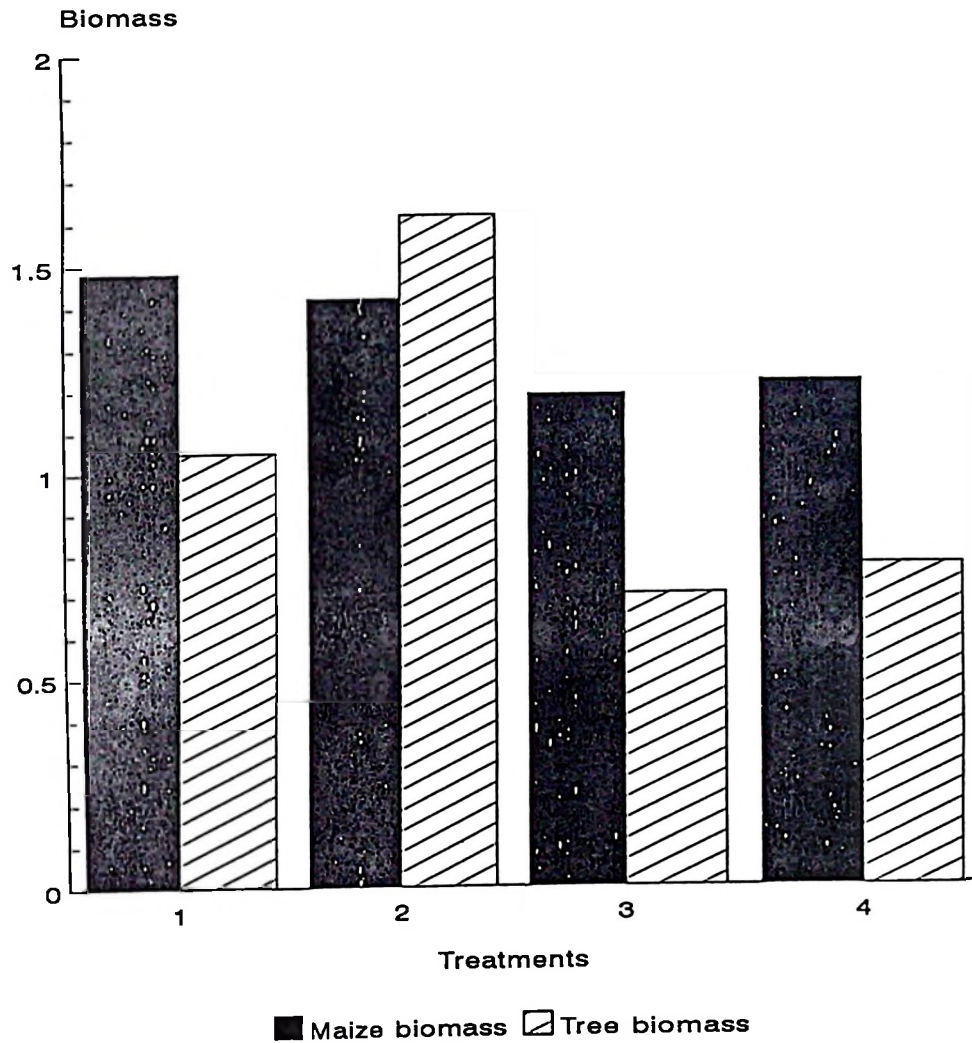


Fig.7 Maize root biomass (tons/ha) and tree root biomass (tons/ha) in an alley cropping trial at Embu, Kenya.

1. Maize/calliandra intercrop + prunings.
2. Maize/leucaena intercrop + prunings.
3. Maize/calliandra intercrop + prunings + trenches.
4. Maize/leucaena intercrop + prunings + trenches.

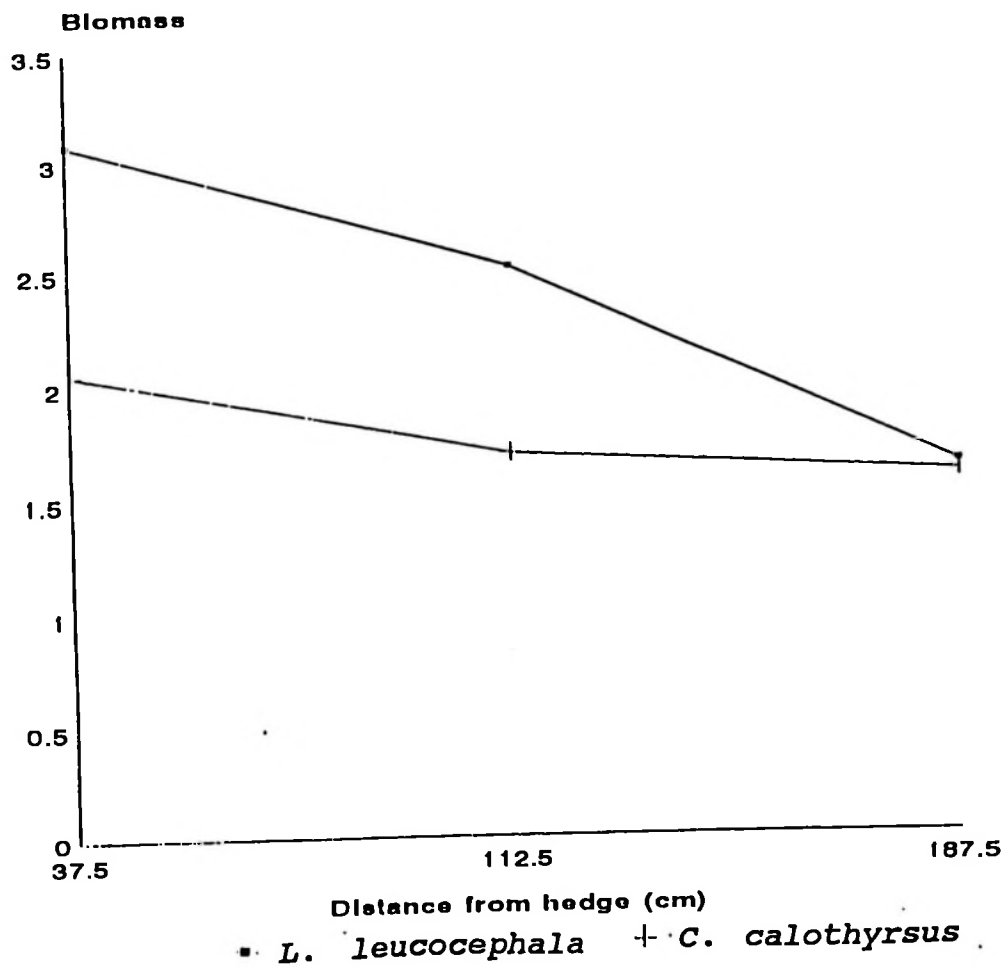


Fig. 8 *L. leucocephala* and *C. calothyrsus* tree root biomass (tons/ha) variation with distance from the hedge (cm) in an alley cropping Trial at Embu, Kenya.

Table: 9 Maize root biomass, above ground dry matter yield and maize grain yield in an alley cropping trial at Embu, Kenya

Treatment	Maize root biomass t ha ⁻¹	Above ground dry matter yield t ha ⁻¹	Grain yield t ha ⁻¹
1 Maize/calliandra intercrop + prunings	1.48 a	126.17 a	3.40 bcd
2 Maize/leucaena intercrop + prunings	1.41 ab	136.45 a	3.32 cd
3 Maize/calliandra intercrop + prunings + trenches	1.19 ab	106.55 a	3.89 abc
4 Maize/leucaena intercrop + prunings + trenches	1.22 ab	133.82 a	4.19 abc
5 Maize monocrop + calliandra prunings	0.74 b	133.25 a	5.55 a
6 Maize monocrop + leucaena prunings	0.97 ab	125.80 a	5.38 ab
7 Maize monocrop + 25 kg N/ha	1.45 ab	121.00 a	3.08 cd
8 Maize monocrop	1.61 a	122.17 a	1.67 d

Means followed by the same letter are not significantly different according to Duncan's multiple range test ($P > 0.05$)

The treatments with trenches to prevent root extension into the plot (treatments three and four) had higher maize yield than the treatments with hedge trees but without trenches (treatments one and two) (Table 9). For the treatments with hedge trees, leucaena hedge treatment (treatment two) yielded less compared to the calliandra hedge treatment (treatment one) (Table 9). There was a positive correlation between maize grain yield and the number of leaves, plant height and stem diameter and a negative correlation with LAI and dry matter yield. The correlation was significant ($P < 0.05$) for the number of leaves only (Appendix 3).

4.9 Distribution and interaction of maize and tree roots at different depths

In treatment one and two where trenching was not done, the maize root biomass was the same while the tree root biomass was higher for treatment two as compared to treatment one (Fig.7). In treatments three and four, maize had a markedly higher root biomass than the trees. Both calliandra (Treatment 3) and leucaena (Treatment 4) produced the same amount of root biomass and the two tree species did not differ in their effect on the maize root biomass (Fig.7). There was more maize and tree root biomass in the 15-30 cm depth as compared to the 0-15 cm depth in treatment one (Fig.9). In treatment two, the maize root biomass was equal at both depths while the tree root biomass was markedly higher in the 0-15 cm depth (Fig.9). For treatment four, the maize root biomass was markedly higher in the 15-30 cm depth. Treatments three and four had similar tree root biomass at the 15-30 cm depth.

Table: 10 Tree fine root biomass at various depths in an alley cropping trial at Embu, Kenya

Treatment	Tree root biomass tons/ha	
	0-15 cm	15-30 cm
1 Maize/calliandra intercrop + prunings	0.58	1.51
2 Maize/leucaena intercrop + prunings	2.45	0.77
3 Maize/calliandra intercrop + prunings + trenches	0.5	0.88
4 Maize/leucaena intercrop + prunings + trenches	0.55	1.05

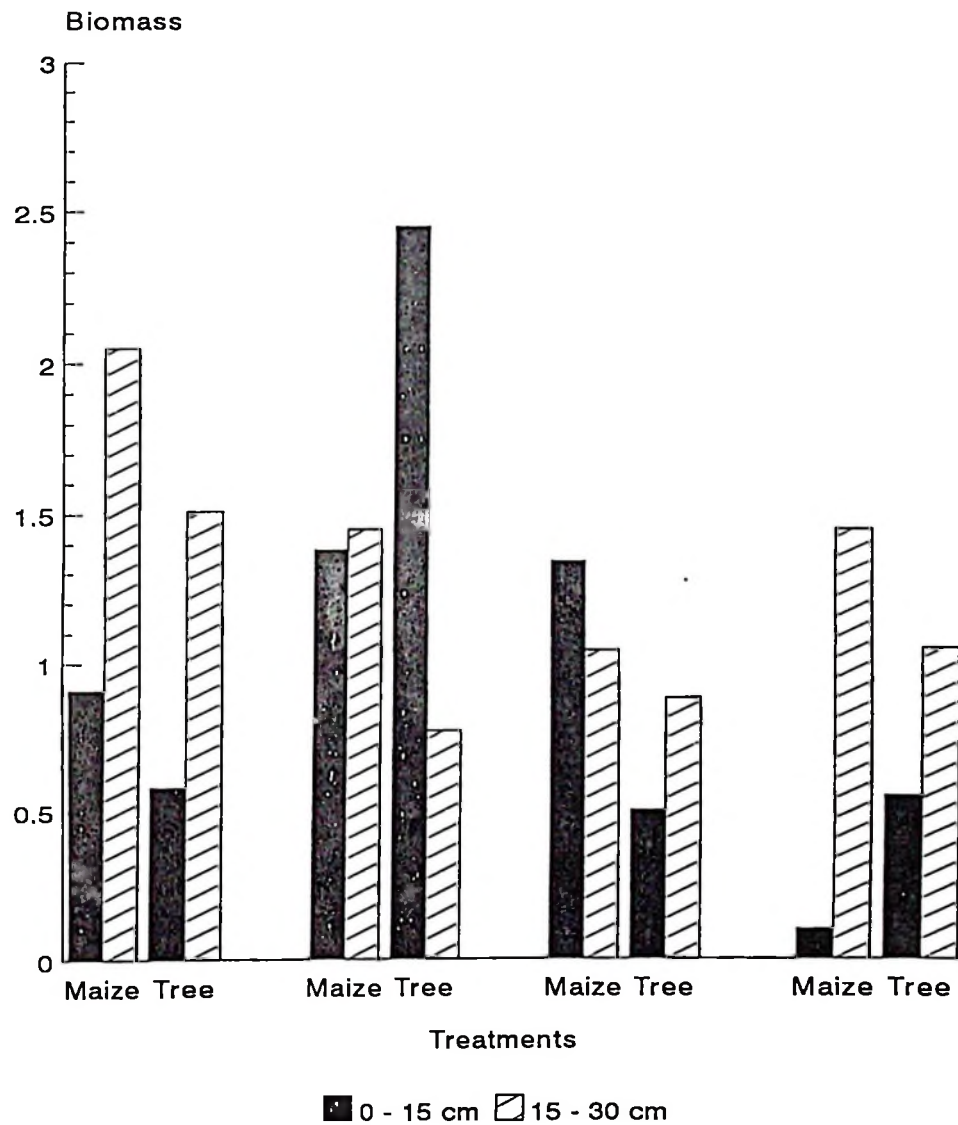


Fig.9 Maize root biomass (tons/ha) and tree root biomass (tons/ha) at various depths in an alley cropping trial at Embu, Kenya.

1. Maize/calliandra intercrop + prunings.
2. Maize/leucaena intercrop + prunings.
3. Maize/calliandra intercrop + Prunings + trenches.
4. Maize/leucaena intercrop + prunings + trenches.

CHAPTER FIVE

5. DISCUSSION

5.1 Soil and prunings nutrient status

The quality of the prunings incorporated in alley cropping determines the amount of nutrients which will be contributed to the soil. The quality of prunings applied in this experiment was low with leucaena prunings having 1.67% N, 0.24% P, 1.33% K, 0.33% Ca and 0.19% Mg (Table. 4) as compared to an experiment by Anthofer *et al.* (1998) in the Ethiopian highlands where nutrient concentrations as high as 5.09% N, 0.39% P, 2.64% K, 2.05% Ca, and 0.41% Mg were reported. Young (1997) reported nutrient concentrations in the range of 2.51-4.33% N, 0.15-0.3% P, 1.0-2.5% K and 1.02-3.0% Ca for leucaena prunings.

The nutrient content of the prunings depend on many factors including the tree species, nutrient concentration of the incorporated material (Bulderman, 1988) and the pruning frequency (Duguma *et al.*, 1988). In the present study, calliandra mulches contributed more nutrients to the soil than the leucaena mulches. The low nutrients in this experiment can be attributed to previous frequent prunings carried out to avoid shading of the crop.

From the soil analysis the soil nutrient levels were adequate apart from phosphorus, aluminium, calcium and organic carbon which were low and nitrogen levels which were medium. The soil was acidic with a mean pH value of 5.3 and a low bulk density of 1.09 (Table 6). Although phosphorus was low, no deficiency was observed during the season since there was an application of phosphorus at a rate of 50 kg P_2O_5 /ha in form of triple super phosphate. Nitrogen deficiency was observed in all the plots in the early stages of the crops growth and the leaves had a yellow/light green coloration. This improved progressively except in treatment eight where the deficiency symptoms persisted in some plants. The low aluminium levels were desirable since where the sub-soil is acidic, presence of aluminium restricts the roots to the top soil promoting root competition (Ong *et al.*, 1991). In soils with a high bulk density, the root soil contact is greater but root elongation growth is impaired (Marscher, 1995). Usually, plants grow poorly in soils of high bulk density. In this experiment the bulk density was low (Table 6).

5.2 Soil moisture

There was plenty of soil moisture as indicated by Figs 1-4. This was as a result of the El-nino rains which occurred during the growing season leading to high rainfall (Table 7). High rainfall hence high amounts of soil moisture causes roots to be concentrated in the top soil while low soil water content in the top soil impairs root elongation and thus decreases nutrient uptake (Marschner, 1995). Competition for moisture may not have therefore been an important factor during the growing season.

There is a possibility of the high rainfall amounts leading to loss of some of the nutrients released by the prunings and fertilizer through leaching and surface run-off.

5.3 Plant height, stem diameter and number of leaves

Calliandra prunings seemed to have more effect on plant height than leucaena prunings. Generally, Calliandra prunings contained more nutrients than the leucaena prunings (Table 4). From Table 8, it is not possible to conclude whether the plant height, stem diameter and number of leaves were affected by the hedge trees and trenching and stem diameter and number of leaves by the presence of the prunings.

5.4 Maize leaf area index and above ground dry matter yield

Leaf area index and above ground dry matter yield were improved by the application of prunings (Table 8 and 9). Trenches increased dry matter yield. This is in contrast to a report by Ssekabembe and Henderlong (1991) where trenches were found to depress dry matter yield. The increased dry matter yield due to trenching in this experiment can be attributed to reduced nutrient competition between the maize plants and the hedge trees. Hedgerows slightly depressed leaf area index.

5.5 Fine root biomass

5.5.1 Maize fine root biomass

The increased root biomass of maize in intercropped maize as compared to the monocropped maize (Table 9) is in agreement with other previous studies (Yamoah *et al.*, 1986 b; Govindarajan, 1996). In an experiment with black locust (*Robinia pseudoacacia*) as the hedge tree, Ssekabembe and Henderlong (1991) found results which were contrary to the above but these results were not reflected in the maize yield. According to Young (1997) combining trees and crops increases rooting densities and reduces inter-root distances which increases the likelihood of interplant competition.

Treatments with no prunings, hence low nutrient levels had more root biomass than those with prunings (Table 9). Those with hedges also had more root biomass than those without. There is a possibility of nutrient competition with the hedge trees which could have led to low nutrient levels hence the high root biomass. The rate of fine root development is related to the nutrient status of the soil. The poorer the nutrient reserves the faster the rate of fine root development (Berish, 1982; Young, 1997). This is also supported by Alexander and Fairley (1983) who found a general decrease in root biomass when nitrogen availability was increased by addition of fertilizers in cold temperate forests.

Soil water also has an influence on root development with more roots being produced when soil water availability is low (Govindarajan, 1996). In this experiment water was not limiting (Table 7). The fertilizer treatment also had more root biomass. There is a possibility of the applied fertilizer being leached beyond the crops rooting zone due to the high amounts of rainfall received during the season leading to low nutrient levels.

5.5.2 Tree fine root biomass

Tree fine roots generally comprise a small proportion of the total root biomass but play a key role in nutrient and water uptake. Where trenching was not done, leucaena hedges had more fine root biomass compared to calliandra (Fig.7). In this treatment most of the biomass was concentrated in the top 15 cm while for the calliandra treatment, most of it was concentrated in the 15-30 cm depth (Fig.9). Generally, fast growing trees have a dominantly superficial root system while trees with a deep tap root system and few horizontal branch roots have a low growth rate (Hairiah *et al.*, 1992). In an experiment conducted in Buberuka highland and central plateau region of Rwanda, leucaena was ranked as a fast growing tree when compared with calliandra (Yamoah *et al.*, 1989). Rooting depth is an important characteristic in determining the suitability of a tree for hedgerow intercropping. Calliandra can, therefore, be considered a better hedgerow tree based on the above characteristic. Similar results were reported by Hairiah *et al.* (1992).

Because of the abundance of its fine roots in upper soil horizons, leucaena would highly compete for nutrients and water with the food crops which generally have superficial root systems. In a similar experiment, Govindarajan (1996) found leucaena to be more competitive than calliandra when grown with maize. In this experiment, leucaena had half of calliandra's root density although its effect on maize performance was similar to that of calliandra. The desirable situation in intercropping would be the stratification of roots of different species so that they can feed in different soil horizons. In situations where nutrients and moisture are not limiting, superficial root systems may be beneficial by reducing loss of nutrients through leaching and soil erosion (Ssekabembe and Henderlong, 1991).

Digging trenches in some treatments did not prevent roots being found as high as 15 cm deep although the trenches were 50 cm deep. Presence of roots in the top soil layers even after trenching can be explained by the roots moving upwards to produce more fine roots in the upper soil layers. A similar behaviour was observed by Govindarajan (1996) and Singh *et al.* (1989) when working with leucaena. Presence of oxygen and nutrients in the top soil layers at the beginning of the season enables roots to grow into these soil layers. The top soil layers also have favourable biological and physical conditions as compared to the sub-soil (Marschner, 1995).

Pruning of trees which is a characteristic of hedgerow intercropping may also have an effect on the root distribution. With a low pruning height as was the case with the hedges in this study, more fine roots are formed, hence more competition (Hairiah

et al., 1992; Van noordwijk *et al.*, 1996).

5.6 Maize crop grain yields

Higher maize grain yields were observed in the treatments with leaf prunings as compared to those which had no leaf prunings (Table 9). Similar results were observed by Roescrane *et al.* (1992). In this experiment, for every kilogram of nitrogen applied in form of *Sesbania sesban*, *Gliricidia sepium*, *Calliandra calothyrsus*, *Cajanus cajan*, *Senna siamea* and *Leucaena leucocephala* mulch, approximately 12 kg of maize grains were produced. Gichuru and Kang (1989) also reported maize yield increase when calliandra mulches were used on maize at a rate of 6 tons/ha. The leaf prunings provide nutrients and especially nitrogen to the growing crop plants. In the present study, *Leucaena* and *Calliandra* prunings were expected to supply 105.19 and 145.39 kg N/ha respectively. Application of prunings has also been reported to lead to higher amounts of organic matter, potassium, calcium and magnesium in the soil (Young, 1997). Apart from this, the prunings also improve the physical characteristics of the soil which may be beneficial to crops growth (Ong *et al.*, 1991).

The highest yield was obtained when calliandra prunings were incorporated on the maize monocrop (Table 9). *Calliandra* prunings had more nitrogen, potassium, calcium and magnesium compared to the *leucaena* prunings (Table 4).

Higher nitrogen content in calliandra prunings was also reported by Hairiah *et al.*

(1992). For nutrients to be available from the prunings they have to undergo decomposition. The rate at which the decomposition takes place is important to make nutrients available to the crops at the time they are most needed (Yamoah *et al.*, 1986a). For leucaena and calliandra prunings, decomposition is relatively fast releasing nutrients into the soil within a short period (Young, 1997).

The fertilizer treatment yielded less compared to the treatments with leaf prunings (Table 9). The fertilizer was applied at half the recommended rate as calcium ammonium nitrate (CAN). The low yield can be attributed to leaching of nitrogen beyond the crops rooting zone and losses through surface run-off as the rainfall was very high at the time of application (Table 7). Low yields in the control can be attributed to low nutrient levels, particularly nitrogen.

Alley cropped treatments performed poorly as compared to treatments which were monocropped but had prunings (Table 9). These treatments were however better than treatments with half rate fertilizer and the control. Low yields in the hedge treatments was probably caused by a combination of low nutrient levels and insufficient solar radiation due to shading since the hedge was only pruned at the beginning of the season. The rows close to the hedgerows seemed to be affected more and were observed to be stunted during the growing period as compared to the middle rows. The grain yield of these rows was low and this could have contributed to the low yields in the alley plots. Low maize yields in maize rows close to the hedge have been reported by Yamoah *et al.* (1986b), Lal (1989) and Rosecrane *et*

al. (1992). The highest tree fine root biomass was found close to the hedge as compared to the other points at which the biomass was measured (Fig. 4). This could partly explain the reduced yields for rows close to the hedge.

In the humid tropics, competition for nutrients is an important factor since hedge trees and crops have a tendency to concentrate their roots in the surface soil which contains more mineral nutrients (Kramer and Boyer, 1995). Compared to calliandra, leucaena roots tend to be more superficially concentrated (Fig. 9) Similar results have also been reported by Hairiah *et al.* (1992). More competition with the food crops would therefore be expected from leucaena hedges. Reduced yields due to competition with hedge trees have also been reported by Singh *et al.* (1989); Mureithi *et al.* (1994); and Jama *et al.* (1995). The trenches increased maize grain yield (Table 9). Increased yields can be attributed to reduced nutrient competition between the maize plants and the hedge trees. Yield increases when barriers to root extension into the alley are installed have been reported by Singh *et al.* (1989) and Korwar and Radder (1994).

For leucaena and calliandra, unacceptable shading of the companion maize crop can be expected if the hedge is only pruned when the maize is being planted (Hairiah *et al.*, 1992). Maize being a non-shade tolerant crop, shading leads to poor growth especially for the row adjacent to the hedgerow. Shading may be more important with calliandra than leucaena since it produces a broad shrub-like dense canopy with many secondary branches while leucaena has a more open and higher canopy. Yield

reductions of the crop plant due to shading by the intercropped tree species have been reported (Duguma *et al.*, 1988; Lal, 1989; Hagger and Beer, 1993). Regular pruning may reduce the shading effect, hence lead to increased crop yields (Rosecrane *et al.*, 1992) but this also leads to low biomass production (Lulandala *et al.*, 1995) and nitrogen yield from the hedgerow prunings (Duguma *et al.*, 1988). The low biomass and nitrogen yield are due to partial shading of the hedgerow regrowth by the alley crop and disruptions in dry matter and nutrient accumulation which negatively affect subsequent regrowth. Frequent pruning may also affect the survival of the tree plants. Duguma *et al.* (1988) reported 25% mortality of *Gliricidia sepium* and 100% mortality of *Sesbania sesban* plants within six months as a result of monthly prunings. Pruning has also been reported to decrease nitrogen fixation by the plants (Kadiata *et al.*, 1997). This implies that pruned hedge trees would compete for nitrogen with intercropped food crops.

5.7 Distribution and interaction of maize and tree roots at different depths.

Generally, maize had more root biomass at the various depths compared to the trees (Fig.9). This is in contrast to what was reported by Jonsson *et al.* (1988) where the trees had twice the root biomass of the maize plants. In this experiment, the maize and trees were planted separately as compared to the experiment at Embu where the trees and maize were intercropped.

There is a general tendency of species to maintain a characteristic relationship between root and shoot dry weight (Marschner, 1995). When parts of the shoots are removed, plants tend to compensate this by lower root growth hence returning to a ratio characteristic for the species. This can partly explain why the trees had a lower root biomass as compared to the maize since the hedge trees were pruned at the beginning of the season.

For both the trees and the maize, the fine root biomass decreased with distance from the plant. A desirable root system should have fewer fine roots in the surface soil and roots that are concentrated close to the tree trunk and decrease markedly away from the tree base (Ruhigwa *et al.*, 1992). In an experiment with *Acioa barteria*, *Alchornea cardifolia*, *Senna siamea*, and *Gmelina arborea*, Ruhigwa *et al.* (1992) found the root dry weight to generally decrease with depth and away from the tree base except for *Gmelina arborea*. The number of fine roots also decreased with increasing depth for all species. In this experiment, the fine root biomass of leucaena was higher in the top soil layer (0-15 cm) while for calliandra it was higher in the lower soil layer (15-30 cm). For maize, the distribution with depth varied with some treatments having more fine root biomass in the top soil layer while others had more fine root biomass in the lower soil layer.

CHAPTER SIX**6. CONCLUSION AND RECOMMENDATIONS****6.1 Conclusion**

Incorporation of prunings into the soil and trenching reduced the maize fine root biomass. For the hedge trees, leucaena had more fine root biomass than calliandra with most of it concentrated in the top 15 cm. Both hedge trees had fine root biomass up to the middle of the alley which was 4.5 m wide although the biomass decreased progressively with distance from the hedge. Some degree of competition would therefore be expected between the maize plants and the hedge trees throughout the alley. Based on the fine root distribution, calliandra emerged a better alley cropping tree than leucaena.

Prunings increased maize grain and dry matter yield while trenching led to a slight increase in maize grain yield and an improvement in leaf area index. Prunings provide nutrients which are used by the plants while trenching reduces the tree root biomass hence reducing competition for moisture and nutrients between the trees and the crop plants. Reduction of hedge tree roots can be achieved locally by use of an ox-drawn plough during land preparation.

From above, below ground interactions are important in alley cropping. Understanding of the root distribution of trees/shrubs is therefore very important when selecting a species for use in agroforestry systems such as alley cropping. This will ensure that the selected species has minimal below ground competition with the crop plant.

There was a substantial decrease in crop yields due to the presence of the woody perennial. The reductions are largely due to competition for nutrients and some shading effect. In places where moisture is not limiting, the problem of nutrient competition can be reduced by use of increased amounts of prunings and fertilizer amendments for nutrients like phosphorus which is not sufficiently supplied by prunings.

6.2 Recommendations

From the study, below ground interactions are important but their negative effects can be reduced through root pruning. With the current high costs of fertilizers, prunings would go a long way in improving the crop yields. However, some further investigations need to be done to make this more feasible. For example to:

- (i) Monitor the nutrient realising patterns of leucaena and calliandra so as to synchronise nutrient release with crop plant growth demands to avoid losses through leaching.

- (ii) Carry out soil analysis during different stages of the plants growth to detect changes in the soil nutrient levels as a result of the prunings added and also determine whether the pruned roots have any effect on the nutrient status of the soil.

- (iii) Monitor the effect of root pruning on the hedge trees.

- (iv) Monitor the root biomass of trees when a trench deeper than 50 cm is used.

REFERENCES

- Akonde, T.P., Leihner, D.E. and Steinmuller, N. (1996) Alley cropping on an ultisol in sub-humid Benin. Long term effects on maize, cassava and tree productivity. *Agroforestry Systems* 34: 1- 12.
- Alexander, I.J. and Fairley, R.I. (1983) Effect of nitrogen fertilization on populations of fine roots and mycorrhizas in spruce humus. *Plant and Soil* 71; 49-53.
- Anthofer, J., Hanson, J. and Jutzi, S.C. (1998) Wheat growth as influenced by application of agroforestry -tree prunings in Ethiopian highlands. *Agroforestry Systems* 40: 1-18.
- Atta-Krah, A.N. (1990) Alley cropping with leucaena: Effect of short grazed fallows on soil fertility and crop yields. *Experimental Agriculture* 26: 1-10.
- Berish, C.W. (1982) Root biomass and surface area in three successional tropical forests. *Canadian Journal of Forest Research* 12: 699-704.
- Bulderman, A. (1988) The decomposition of the leaf mulches of *Leucaena leucocephala*, *Gliricidia sepium*, and *Flemingia macrophylla* under humid tropical conditions. *Agroforestry Systems* 7: 33-45.

Chamshama,S.A.O., Mugasha,A.G. and Maliondo,S.M.S. (1995) Performance of *Leucaena leucocephala* and *Prosopis chilensis* intercropped with maize in Gairo, Tanzania. In *Indigenous Nitrogen fixing trees with Potential for village afforestation (Tanzania)* - Final Report on the Tanzania component. pp. 5 - 14.

Chamshama,S.A.O., Mugasha,A.G., Klovstad,A., Haveraaen,O. and Maliondo,S.M.S. (1998) Growth and yield of maize alley cropped with *Leucaena leucocephala* and *Faidherbia albida* in Morogoro, Tanzania. *Agroforestry Systems* 40: 215-225.

Daughtry,C.S.T. and Hollinger,S.E. (1984) Costs of measuring leaf area index of corn. *Agronomy Journal* 76: 836-841.

Dhyani,S.K., Narain,P. and Singh,R.K. (1990) Studies on root distribution of five multipurpose trees in Doon Valley India. *Agroforestry Systems* 12: 149-161.

Duguma,B., Kang,B.T. and Okali,D.U.U. (1988) Effect of pruning intensities of three woody leguminous species grown in alley cropping with maize and cow pea on an alfisol. *Agroforestry Systems* 6: 19-35.

- Fownes, J.H. and Anderson, D.G. (1991) Change in nodule and root biomass of *Sesbania sesban* and *Leucaena leucocephala* following coppicing. *Plant and Soil* 138: 9-16.
- Garrity, D.P., Mercado, A. and Solera, C. (1992) Species interference and soil changes in contour hedgerows planted on inclines in acidic soils in Southeast Asia: In Kang, B.T., Osiname, A.O. and Larbi, A. (eds) *Alley farming Research and development*. Proceedings of the international conference on alley farming, Ibadan, Nigeria. pp. 351-365.
- Gichuru, M.P. and Kang, B.T. (1989) *Calliandra calothyrsus* in alley cropping system with sequentially cropped maize and cow pea in southwestern Nigeria. *Agroforestry Systems* 9: 191-203.
- Govindarajan, M. (1996) Below ground interactions at the tree-crop interface in the highlands of Kenya. PhD dissertation, University of Florida. pp. 128
- Groot, J.J.R. and Soumare, A. (1995) Root distribution of *Acacia seyal* and *Sclerocarya birrea* in Sahelian rangelands. *Agroforestry Today* 7 (1): 9-11.
- Hagger, J.P. and Beer, J.W. (1993) Effect on maize growth of the interaction between increased nitrogen availability and competition with trees in alley cropping. *Agroforestry Systems* 21: 239 - 249.

- Hairiah,K., Van Noordwijk,M., Santoso,B. and Syekhfani,M.S. (1992) Biomass production and root distribution of eight trees and their potential for hedgerow intercropping on an ultisol in Lampung. *Agrivita* 15: 54-68.
- Hauser,S. and Kang,B.T. (1993) Nutrient dynamics, maize yield and soil organic matter in alley cropping with *Leucaena leucocephala*. In Mulongoy,K. and Merckx,R. (eds). *Soil organic matter dynamics and sustainability of tropical agriculture*. John Wiley and Sons, Chichester, UK. pp. 215-222.
- Huxley,P.A., Pinney,A., Akunda,E. and Muraya,P. (1994) A tree/crop interface experiment with *Grevillea robusta* hedgerows and maize. *Agroforestry Systems* 26: 23 - 45.
- ICRAF (1997) *ICRAF Medium-Term plan 1998-2000*. ICRAF Nairobi, Kenya. pp. 77.
- Jama,B.A., Getahun,A., Ngugi,D. and Macklin,B. (1986) *Leucaena* alley cropping for the Kenyan coast. In Prinsley, R.T. and Swift, M.J. (eds). *Ameriolation of soil by trees: a review of current concepts and practices*. London Commonwealth Science Council. pp. 156-165.

- Jama, B.A., Getahun, A. and Ngugi, D.N. (1991) Shading effect of alley cropped *Leucaena leucocephala* on weed biomass and maize yield at Mtwapa, Coast province Kenya. *Agroforestry Systems* 13: 1-11.
- Jama, B.A., Nair, P.K.R. and Rao, M.R. (1995) Productivity of hedgerow shrubs and maize under alley cropping and block planting systems in semi-arid Kenya. *Agroforestry Systems* 31: 257 - 274.
- Jonsson, K., Fidjeland, L., Maghembe, J.A. and Hogberg, P. (1988) The vertical distribution of fine roots of five tree species and maize in Morogoro, Tanzania. *Agroforestry Systems* 6: 63 - 69.
- Kang, B.T. and Wilson, G.F. (1987) Alley cropping as a promising agroforestry technology. In Stepler, H.A. and Nair, P.K.R. (eds) *Agroforestry: a decade of development*. ICRAF, Nairobi, Kenya. pp. 227 - 243.
- Kadiata, B.D., Mulongoy, K. and Isirimah, N.O. (1997) Effect of tree pruning and pruning application to trees on nitrogen fixation by *Leucaena* and *Gliricidia*. *Agroforestry Systems* 39: 117-128.
- Kang, B.T., Van der Kruijs, A.C.B.M., and Cooper, D.C. (1989) *Alley cropping for food crop production in the humid and sub-humid tropics*. International Development Research Centre, Ottawa, Canada. pp. 16-26.

- Korwar, G.R. and Radder, G.D. (1994) Influence of root pruning and cutting interval of leucaena hedgerows on performance of alley cropped rabi sorghum. *Agroforestry systems* 25: 95-109.
- Kramer, P.J. and Boyer, J.S. (1995) *Water relations of plants and soils*. Academic press, New York. pp. 495.
- Lal, R. (1989) Agroforestry systems and soil surface management of a tropical alfisol. *Agroforestry Systems* 8: 7-29.
- Landon, J.R. (1991) *Booker tropical soil manual*. A handbook for soil survey and agricultural land evaluation in the tropics and subtropics. Longman, New York. pp. 738.
- Leihner, D.E., Ernst-Schaeber, R., Akonde, T.P. and Steinmuller, N. (1996) Alley cropping on an ultisol in sub-humid Benin: Changes in crop physiology and tree crop competition. *Agroforestry Systems* 34: 13 - 25.
- Lulandala, L.L.L., Munishi, P.K.T. and Maliondo, S.M. (1995) Effect of spacing and management regime on leucaena fodder yield and nutrient removal in alley cropping systems in Tanzania. *International Tree Crops Journal* 8: 129-137.

- Marschner,H. (1995) *Mineral nutrition for higher plants*. Academic Press, New York. pp. 889.
- Minae,S. and Nyamae,E. (1988) Agroforestry Research Project Proposal for the Coffee based system in the bimodal highlands, central and eastern provinces, Kenya. *AFRENA Report No. 16* ICRAF, Nairobi, Kenya. pp. 58.
- Mureithi,J.G., Taylor,R.S. and Thorpe,W. (1994) The effects of alley cropping with *Leucaena leucocephala* and of different management practices on the productivity of maize and soil chemical properties in lowland coastal Kenya. *Agroforestry Systems*. 27: 31 - 51.
- Mwangi,J.N., O'Neill, M.K., Mugendi, D.N., Kanga, L.M. and Karanja, J.N. (1997) Hedgerow intercropping for soil fertility improvement using *Calliandra calothyrsus* and *Leucaena leucocephala* with maize in Embu, Kenya. In O'Neill, M.K. (ed) *National Agroforestry Research project - KARI - Regional Research Centre - Embu. Annual Report March 1996 - March 1997*. pp. 109.
- Nair,P.K.R. (1993) *An introduction to Agroforestry*. Kluwer Academic Publishers. The Netherlands. pp. 499.

- Ong, C.K., Corlett, J.E., Singh, R.P. and Black, C.R. (1991) Above and below ground interaction in Agroforestry systems. *Forest Ecology and Management*. 45: 45-57.
- Rao, M.R., Ong, C.K., Pathak, P. and Sharma, M.M. (1991) Productivity of annual cropping and agroforestry systems on a shallow alfisol in Semi-arid India. *Agroforestry Systems* 15: 51 - 63.
- Rocheleau, D., Weber, F. and Field-Juma, A. (1988) *Agroforestry in Dryland Africa*. ICRAF, Nairobi, Kenya. pp. 311.
- Rosecrane, R.C., Brewbaker, J.L. and Fownes, J.H. (1992) Alley cropping of maize with nine leguminous trees. *Agroforestry Systems*. 17: 159 - 168.
- Ruhigwa, B.A., Gichuru, M.P., Mambani, B. and Tariah, N.M. (1992) Root distribution of *Acioa barteri*, *Alchornea cordifolia*, *Cassia siamea* and *Gmelina arborea* in an acid ultisol. *Agroforestry systems*. 19: 67-78.
- Salazar, A., Szott, L. T. and Palm, C.A. (1993) Crop-tree interactions in alley cropping systems on alluvial soils of the upper amazon basin. *Agroforestry Systems* 22: 67 - 82.

- Shannon,D.A., Vogel,W.O. and Kabaluapa,K.N. (1994) The effects of alley cropping and fertilizer application on continuously cropped maize. *Tropical Agriculture* 71: 163-169.
- Singh,R.P., Ong,C.K. and Saharan,N. (1989) Above and below ground interactions in alley cropping in semi-arid India. *Agroforestry Systems* 9: 259-274.
- Ssekabembe,C.K. and Henderlong,P.R. (1991) Below ground interactions in alley cropping; Appraisal of first year observations on maize grown in black locust (*Robinia pseudoacacia* L.) alleys. In "Gene" Garrett,H.E. (ed) Proceedings of the 2nd conference on Agroforestry in North America. Springfield, Missouri. pp. 58-73.
- Torres,F. (1983) Potential contribution of *Leucaena* hedgerows intercropped with maize to the production of organic nitrogen and fuel wood in the lowland tropics. *Agroforestry Systems* 1: 323-333.
- Van Noordwijk,M., Hairiah,K., Syekhfani,M.S. and Flach,E.N. (1991) *Peltophorum pterocarpa*, A tree with a root distribution suitable for alley cropping on acid soils in the humid tropics. In Persson,H. and McMichael,B.L. (eds). *Plant roots and their environment*. Elsevier, The Netherlands. pp. 526-532.

- van Noordwijk, M., Lawson, G., Soumare, A., Groot, J.J.R. and Hairiah, K. (1996) Root distribution of trees and crops: Competition and/or complementarity. In Ong, C.K. and Huxley, P. (eds) *Tree crop interactions A physiological approach*. CAB international, Wallingford, UK. pp. 319-364.
- Walsh, L.M. (1971) *Instrumental methods for analysis of soils and plant tissue*. Soil Science Society of America. Madison, Wisconsin, USA. pp. 222.
- Wilde, S.A., Corey, R.B. and Iyer, J.G. (1979) *Soil and plant analysis for tree culture*. Oxford and IBH Publishing Company, New Delhi. pp. 224.
- Yamoah, C.F., Agboola, A.A. and Mulongoy, K. (1986a) Decomposition, nitrogen release and weed control of prunings of selected alley cropping shrubs. *Agroforestry Systems* 4: 239-246.
- Yamoah, C.F., Agboola, A.A. and Wilson, G.F. (1986b) Nutrient contribution and maize performance in alley cropping systems. *Agroforestry Systems* 4: 247-254.
- Yamoah, C., Grosz, R. and Nizeyimana, E. (1989) Early growth of alley shrubs in the highland region of Rwanda. *Agroforestry Systems* 9: 171-184.

Young, A. (1997) *Agroforestry for soil management*. CAB International, Wallingford, UK. pp. 320.

APPENDICES

Appendix 1 : pH levels and nutrient ratings in an alley cropping trial at Embu, Kenya

Appendix 1a: pH ratings in an alley cropping trial at Embu, Kenya

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

Source (Landon, 1991)

Appendix 1b: Ratings for exchangeable K, Mg, and Ca in an alley cropping trial at Embu, Kenya

Nutrient	Measured value	Rating
K (m.e/100 g)	0.4-0.8	high
	0.2-0.4	medium
	0.03-0.2	low
Mg (m.e/100 g)	> 0.5	high
	0.2-0.5	medium
	< 0.2	low
Ca (m.e/100 g)	> 10	high
	< 4	low

Source (Landon, 1991)

Appendix 1c: Ratings for C, N, P and Al in an alley cropping trial at Embu, Kenya

Nutrient	Measured value	Rating
Organic C %	> 10	high
	4-10	medium
	< 4	low
Total N %	> 0.5	high
	0.2-0.5	medium
	< 0.2	low
P (ppm)	> 50	high
	15-50	medium
	< 15	low
Al %	> 85	high
	30-85	medium
	< 30	low

Source (Landon, 1991)

Appendix 2: ANOVA tables**Appendix 2a: ANOVA for some selected physical and chemical properties of soil
in an alley cropping trial at Embu, Kenya****(i) Dependent variable pH**

Source	DF	SS	MS	F	Pr > F
Rep	3	0.146	0.049	0.58	0.635
Trt	7	0.594	0.085	1.01	0.454
Error	21	1.769	0.084		

(ii) Dependent variable: Percent organic carbon

Source	DF	SS	MS	F	Pr > F
Rep	3	0.097	0.032	0.87	0.473
Trt	7	0.131	0.018	0.50	0.824
Error	21	0.784	0.037		

(iii) Dependent variable: Percent total nitrogen

Source	DF	SS	MS	F	Pr > F
Rep	3	0.002	0.0007	0.68	0.575
Trt	7	0.003	0.0004	0.44	0.865
Error	21	0.023	0.001		

(iv) Dependent variable: Phosphorus

Source	DF	SS	MS	F	Pr > F
Rep	3	19.201	6.400	0.96	0.429
TRt	7	53.119	7.588	1.14	0.376
Error	21	139.549	6.645		

(v) Dependent variable: Calcium

Source	DF	SS	MS	F	Pr > F
Rep	3	0.423	0.141	0.61	0.619
Trt	7	0.177	0.025	0.11	0.997
Error	21	4.893	0.233		

(vi) Dependent variable: Magnesium

Source	DF	SS	MS	F	Pr > F
Rep	3	0.208	0.069	0.61	0.617
Trt	7	0.340	0.049	0.43	0.875
Error	21	2.392	0.114		

(vii) Dependent variable: Potassium

Source	DF	SS	MS	F	Pr > F
Rep	3	23.657	7.886	1.49	0.245
Trt	7	28.766	4.109	0.78	0.612
Error	21	110.839	5.278		

(viii) Dependent variable: Aluminium

Source	DF	SS	MS	F	Pr > F
Rep	3	0.031	0.010	0.79	0.511
Trt	7	0.063	0.009	0.68	0.687
Error	21	0.278	0.013		

(ix) Dependent variable: Bulk density

Source	DF	SS	MS	F	Pr > F
Rep	3	0.101	0.034	4.93	0.010
Trt	7	0.014	0.002	0.29	0.952
Error	21	0.144	0.007		

Appendix 2b: ANOVA for percent volumetric moisture (VMC) content in an alley cropping trial at Embu, Kenya.

(i) Dependent variable: Percent VMC 14 days after planting

Source	DF	SS	MS	F	Pr > F
Rep	3	173.878	57.959	2.22	0.097
Trt	7	66.591	9.513	0.36	0.917
Depth	1	31.500	31.500	1.21	0.277
Error	52	1356.603	26.088		

(ii) Dependent variable: Percent VMC at 50% tasselling

Source	DF	SS	MS	F	Pr > F
Rep	3	2466.206	822.069	2.80	0.049
Trt	7	766.890	109.556	0.37	0.914
Depth	1	1157.701	1157.701	3.95	0.052
Error	52	15258.433	293.431		

(iii) Dependent variable: Percent VMC at Milk Stage

Source	DF	SS	MS	F	Pr > F
Rep	3	2653.235	884.412	2.99	0.039
Trt	7	2178.041	311.149	1.05	0.408
Depth	1	297.994	297.994	1.01	0.320
Error	52	15386.897	295.902		

(iv) Dependent variable: Percent VMC at Harvesting

Source	DF	SS	MS	F	Pr > F
Rep	3	5388.746	1796.249	5.37	0.003
Trt	7	1448.054	206.865	0.62	0.738
Depth	1	205.206	205.206	0.62	0.437
Error	52	17395.479	334.528		

Appendix 2c: ANOVA for percent volumetric Moisture Content (VMC) for the Treatments with Hedges

(i) Dependent variable: Percent VMC 14 days after Planting

Source	DF	SS	MS	F	Pr > F
Rep	3	173.814	57.938	1.67	0.185
Trt	3	96.679	32.226	0.93	0.434
Depth	1	8.051	8.051	0.23	0.632
Dist	1	17.119	17.119	0.49	0.486
Error	55	1912.635	34.775		

(ii) Dependent variable: Percent VMC at 50% tasselling

Source	DF	SS	MS	F	Pr > F
Rep	3	1014945.779	338315.260	1.04	0.382
Trt	3	945420.746	315140.249	0.97	0.414
Depth	1	362795.406	362795.406	1.12	0.295
Dist	1	349783.531	3497833.531	1.08	0.304
Error	55	17872091.496	324947.118		

(iii) Dependent variable: Percent VMC at Milk Stage

Source	DF	SS	MS	F	Pr > F
Rep	3	5186.762	1728.921	4.96	0.004
Trt	3	1668.020	556.007	1.59	0.201
Depth	1	79.433	79.433	0.23	0.635
Dist	1	257.201	257.201	0.74	0.394
Error	55	19172.940	348.599		

(iv) Dependent variable: Percent VMC at Harvesting

Source	DF	SS	MS	F	Pr > F
Rep	3	4864.438	1621.478	4.16	0.010
Trt	3	135.921	45.307	0.12	0.950
Depth	1	56.626	56.626	0.15	0.704
Dist	1	413.106	413.106	1.06	0.308
Error	55	21420.984	389.472		

Appendix 2d: ANOVA for plant height in an alley cropping trial at Embu, Kenya

Dependent variable: Height

Source	DF	SS	MS	F	Pr > F
Rep	3	3836.846	1278.949	5.73	0.005
Trt	7	3948.299	564.043	2.53	0.047
Error	21	4691.034	223.382		

Appendix 2e: ANOVA for stem diameter in an alley cropping trial at Embu, Kenya

Dependent variable: Diameter

Source	DF	SS	MS	F	Pr > F
Rep	3	0.178	0.059	1.41	0.268
Trt	7	0.680	0.097	2.31	0.065
Error	21	0.883	0.042		

Appendix 2f: ANOVA for the number of leaves in an alley cropping trial at Embu, Kenya.

Dependent variable: Number of Leaves

Source	DF	SS	MS	F	Pr > F
Rep	3	4.346	1.449	2.57	0.082
Trt	7	1.365	0.195	0.35	0.923
Error	21	11.837	0.564		

Appendix 2g: ANOVA for leaf area index (LAI) in an alley cropping trial at Embu, Kenya

Dependent variable: LAI

Source	DF	SS	MS	F	Pr > F
Rep	3	0.997	0.332	3.25	0.042
Trt	7	1.160	0.166	1.62	0.184
Error	21	2.147	0.102		

Appendix 2h: ANOVA for above ground dry matter yield in an alley cropping trial at Embu, Kenya

Dependent variable: Dry Matter

Source	DF	SS	MS	F	Pr > F
Rep	3	7660.476	2553.492	4.06	0.020
Trt	7	2560.147	365.735	0.58	0.763
Error	21	13194.257	628.298		

Appendix 2i: ANOVA for maize fine root biomass in an alley cropping trial at Embu, Kenya

Dependent variable: Biomass

Source	DF	SS	MS	F	Pr > F
Rep	3	10.975	3.658	2.89	0.037
Trt	7	14.178	2.025	1.60	0.138
Depth	1	5.191	5.191	4.10	0.044
Dist	2	102.812	51.406	40.63	0.0001
Error	178	225.197	1.265		

Appendix 2j: ANOVA for tree fine root biomass in an alley cropping trial at Embu, Kenya

Dependent variable: Biomass

Source	DF	SS	MS	F	Pr > F
Rep	3	5.615	1.872	0.81	0.489
Trt	3	16.874	5.625	2.44	0.067
Depth	1	0.008	0.008	0.00	0.953
Dist	3	4.282	1.427	0.62	0.603
Error	117	269.166	2.301		

Appendix 2k: ANOVA for maize grain yield in an alley cropping trial at Embu, Kenya

Dependent variable: Yield

Source	DF	SS	MS	F	Pr > F
Rep	3	12.127	4.042	2.54	0.084
Trt	7	44.623	6.375	4.00	0.006
Error	21	33.428	1.592		

Where: Rep- Replication Trt- Treatment

Dist- Distance VMC- Volumetric Moisture Content

Appendix 3: Partial correlation coefficients of variables in an alley cropping trial at Embu, Kenya.

	LAI	Number of leaves	Height	Diameter	Dry matter	Yield
LAI		0.234	0.421	0.023	0.438*	-0.109
Number of Leaves			0.217	-0.158	0.193	0.447*
Height				0.131	0.259	0.092
Diameter					0.187	0.066
Dry matter						-0.025
Yield						

Appendix 4: Diagrammatic plan of the experiment.

Rep 1

Trt 5	Trt 7	Trt 4	Trt 6	Trt 3	Trt 1	Trt 2	Trt 8
-------	-------	-------	-------	-------	-------	-------	-------

Rep 2

Trt 1	Trt 4	Trt 6	Trt 3	Trt 8	Trt 2	Trt 5	Trt 7
-------	-------	-------	-------	-------	-------	-------	-------

Rep 3

Trt 6	Trt 3	Trt 2	Trt 1	Trt 8	Trt 4	Trt 7	Trt 5
-------	-------	-------	-------	-------	-------	-------	-------

Meterological station

Rep 4	Trt 3	Trt 8	Trt 4	Trt 7	Trt 6	Trt 2	Trt 1	Trt 5
-------	-------	-------	-------	-------	-------	-------	-------	-------

0.05