"THE SPATIAL AND TEMPORAL DISTRIBUTION OF THE ACTIVE ROOTS OF *Cassia siamea* Lam. AND *Zea mays* L. (cv. Katumani Composite B), IN ALLEY CROPPING UNDER SEMI-ARID CONDITIONS IN MACHAKOS DISTRICT, KENYA".

A thesis submitted in partial fulfilment of the requirements for the degree of Master of Science in Plant physiology and Biochemistry (Botany) in the University of Nairobi.

BY

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To

My parents

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DECLARATION

I, Gregory Ouma Umaya, hereby declare that this thesis is my original work and has not been presented for a degree in any other university.

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TABLE OF CONTENTS

	PAGE
Title	i
Dedication	ii
Declaration	iii
Table of contents	iv
List of tables	vi
List of figures	ix
List of plates	x
List of abbreviations	x
Acknowledgement	xi
Abstract	xiii
1 CHAPTER I	
INTRODUCTION AND REVIEW OF LITERATURE	1
1.1.1 An overview of the problem	1
1.1.2 Definition, Scope and development of Agroforestry	4
1.1.3 Relevance of the study	6
1.1.4 The objectives of the study	7
1.2 REVIEW OF LITERATURE	8
1.2.1 Plant factors affecting the distribution of roots	9
1.2.2 Environmental factors affecting the distribution of roots	10
1.2.3 Root competition in agroforestry, strategies of avoiding and overcoming it in mixed cultures	16
2 CHAPTER II	
MATERIALS AND METHODS	20
2.1 Experimental site characterisation	20
2.2 Layout of the experiment	21

2.3 Sampling, washing and separating the roots 26

2.4 Measuring of the parameters and the methods used for analysing the data 30

3 CHAPTER III

RESULTS 39

3.1 Classification and characterisation of the roots of cassia and maize 39

3.2 Methods of identifying the roots, estimating the root length and data analysis 39

3.3 Effects of distance and depth on the distribution of cassia root length 43

3.3.1 Effect of distance and depth on the distribution of maize root length 51

3.4 Maize yield 67

4 CHAPTER IV

DISCUSSION AND CONCLUSIONS 69

4.1 Methodology 69

4.2 Rainfall and evaporation during the crop seasons 72

4.3 Distribution of cassia and maize root length 73

4.4 Assessment of competition for water between the roots of cassia and maize 76

4.5 Assessment of competition for nutrients between the roots of cassia and maize, and maize yield 78

4.6 Limitations in the experiment 82

4.7 CONCLUSIONS 85

4.8 Suggestions 87

4.9 REFERENCES 88

Appendix 97

LIST OF TABLES

LIST OF TABLES	PAGE
Table 2.1. A summary of field operations during the two crop seasons.	25
Table 2.2. r-values of the correlation between the standard deviation and the mean of treatments for cassia and maize root length (before transformation) sampled at different dates during the 2 seasons.	25
Table 3.1a. The percentage contribution of each cassia diameter class to the total root length of cassia less than or equal to 1.5 mm.	40
Table 3.1b. The percentage distribution of cassia roots which have root diameter less than or equal to 0.5 mm.	40
Table 3.1c. Some characteristics of cassia and maize roots of diameter less than or equal to 0.5 mm.	40
Table 3.2a. Analysis of variance table of 'F' ratio for root length. For cassia in agroforestry in 1st season 1989/1990.	44
Table 3.2b. Analysis of variance table of 'F' ratio for root length. For cassia in agroforestry in 2nd season 1990.	44
Table 3.3a. Effect of different distances from the cassia hedgerow and different soil depth intervals from the soil surface on cassia root length distribution shown at 32 DAS in 1st season (Mean of 3 replications).	46
Table 3.3b. Effect of different distances from the cassia hedgerow and different soil depth intervals from the soil surface on cassia root length distribution shown at 46 DAS in 1st season (Mean of 3 replications).	46
Table 3.3c. Effect of different distances from the cassia hedgerow and different soil depth intervals from the soil surface on cassia root length distribution shown at 59 DAS in 1st season (Mean of 3 replications).	47

Table 3.3d. Effect of different distances from the cassia hedgerow and different soil depth intervals from the soil surface on cassia root length distribution shown at 89 DAS in 1st season (Mean of 3 replications). 47

Table 3.4a. Effect of different distances from the cassia hedgerow and different soil depth intervals from the soil surface on cassia root length distribution shown at 36 DAS in 2nd season (Mean of 3 replications). 48

Table 3.4b. Effect of different distances from the cassia hedgerow and different soil depth intervals from the soil surface on cassia root length distribution shown at 56 DAS in 2nd season (Mean of 3 replications). 48

Table 3.4c. Effect of different distances from the cassia hedgerow and different soil depth intervals from the soil surface on cassia root length distribution shown at 70 DAS in 2nd season (Mean of 3 replications). 49

Table 3.4d. Effect of different distances from the cassia hedgerow and different soil depth intervals from the soil surface on cassia root length distribution shown at 84 DAS in 2nd season (Mean of 3 replications). 49

Table 3.4e. Effect of different distances from the cassia hedgerow and different soil depth intervals from the soil surface on cassia root length distribution shown at 98 DAS in 2nd season (Mean of 3 replications). 50

Table 3.5a. Analysis of variance table of 'F' ratio for root length. For maize in agroforestry in 1st season 1989/1990. 60

Table 3.5b. Analysis of variance table of 'F' ratio for root length. For maize in agroforestry in 2nd season 1990. 60

Table 3.6a. Effect of different distances from the cassia hedgerow and different soil depth intervals from the soil surface on maize root length distribution shown at 59 DAS in 1st season (Mean of 3 replications). 62

Table 3.6b. Effect of different distances from the cassia hedgerow and different soil depth intervals from the soil surface on maize root length distribution shown at 89 DAS in 1st. Season (Mean of 3 replications). 62

Table 3.7a. Effect of different distances from the cassia hedgerow and different soil depth intervals from the soil surface on maize root length distribution shown at 36 DAS in 2nd season (Mean of 3 replications). 64

Table 3.7b. Effect of different distances from the cassia hedgerow and different soil depth intervals from the soil surface on maize root length distribution shown at 56 DAS in 2nd season (Mean of 3 replications). 64

Table 3.7c. Effect of different distances from the cassia hedgerow and different soil depth intervals from the soil surface on maize root length distribution shown at 70 DAS in 2nd season (Mean of 3 replications). 65

Table 3.7d. Effect of different distances from the cassia hedgerow and different soil depth intervals from the soil surface on maize root length distribution shown at 84 DAS in 2nd season (Mean of 3 replications). 65

Table 3.7e. Effect of different distances from the cassia hedgerow and different soil depth intervals from the soil surface on maize root length distribution shown at 98 DAS in 2nd. Season (Mean of 3 replications). 66

Table 3.8a. Maize yield per plant in a row (g). 68

Table 3.8b. Mean comparisons for maize yield. 68

LIST OF FIGURES

PAGE

Figure 2.1. Experimental layout at Katumani (DARP). 22

Figure 3.1. Regression of the Tennant's method upon of the Vernier microscope method. 42

Figure 3.2a. Distribution of maize and cassia root length at vegetative (32 DAS) stage. (1st crop season 1989/1990). 52

Figure 3.2b. Distribution of maize and cassia root length at tasselling (46 DAS) stage. (1st crop season 1989/1990). 53

Figure 3.2c. Distribution of maize and and cassia root length at silking and grain filling stage (59 DAS) stage. (1st crop season 1989/1990). 54

Figure 3.2d. Distribution of maize and and cassia root length at maturity (89 DAS) stage (1st crop season 1989/1990). 55

Figure 3.3a. Distribution of maize and cassia root length at silking (56 DAS) stage. (2nd crop season 1990). 56

Figure 3.3b. Distribution of maize and cassia root length at grain filling (70 DAS) stage. (2nd crop season 1990). 57

Figure 3.3c. Distribution of maize and and cassia root length at post grain filling (84 DAS) stage. (2nd crop season 1990). 58

Figure 3.3d. Distribution of maize and and cassia root length at maturity (98 DAS) stage. (2nd crop season 1990). 59

LIST OF PLATES

Plate 2.1. Shows root washing operation.	29
Plate 3.1 Shows the difference in colour between cassia and maize roots. The former are black while the latter are white.	41

LIST OF ABBREVIATIONS AND SYMBOLS

ANOVA	= Analysis of variance.
cv	= Coeffiecint of variation.
DIST. (D)	= Distance.
D_1	= Distance 45 cm from the cassia hedgerow
D_2	= " 90cm " " " "
D_3	= " 135cm " " " "
D_4	= " 180cm " " " "
D * L	= Distance and Depth interaction.
L_1	= Soil depth interval 0 - 10cm.
L_2	= " " " 20 - 30cm.
L_3	= " " " 40 - 50cm.
L.S.D.	= Least Significant Test
ns	= Non significant.
S.E.	= Standard Error
R^2	= Residual square.
TREAT.	= Treatment.
*	= Significant at 0.05 probability level.
**	= Highly significant at 0.01 " "
***	= " " " 0.001 " "

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ABSTRACT

A study on root competition in alley cropping was carried out in Machakos district, Kenya (Latitude 1^{o} 33′ South and Longitude 37^{o} 14′ East). The study was carried out in an alley cropping agroforestry system, involving *Cassia siamea* Lam. and maize (*Zea mays* L. cv. Katumani composite B). The aim of this study was to assess the existence and seriousness of root competition in top soil space as manifested by the distribution of the active roots of cassia and maize, both in space and time.

Maize was planted in three rows in the alley boarded by two cassia hedgerows. Distribution of the active roots of cassia and maize in space was investigated at 4 different distances, at an interval of 45 cm from the cassia hedgerow, and in 3 soil depth positions. Roots were sampled by an auger from these positions at a sampling interval of 2 weeks, starting from about 32 days after sowing (DAS) maize, and continued upto about 98 DAS. The experiment was done during 2 successive crop seasons. The first crop season was during the short rains of 1989/1990, while the second crop season was during the long rains of 1990.

During both the short and long rains crop growing seasons, the distribution of cassia root length was consistently significantly different ($p < 0.001$)

between the depths. Depth L_1 (0 - 10)cm had significantly less roots ($p < 0.01$) than depth L_2 (20 - 30)cm and depth L_3 (40 - 50)cm. Depths L_2 and L_3 had same amount of root length. There was no significant difference in cassia root lengths among the four distances away from the hedge. Thus, the cassia roots are uniformly distributed across the alley, the distribution differing only between depths. There was no interaction between the distances and the depths. The root length of cassia at any depth level does not vary statistically significantly over different distances and vice versa. In the case of maize, the root distribution was affected by both the distances and depths. This could possibly be explained by the fact that the distribution of maize roots depends on the age of the plants and on spacings and is more responsive to moisture status.

The root length density of maize was by far greater than that of cassia in the top 0 - 10 cm space, implying that cassia is not competing with maize for water and/or nutrients at that depth. However, at critical growth stages there is a serious overlap of roots of the two plants in the remaining depths, differing with distance from the hedge, with cassia roots occupying more or near-equal soil volume compared to maize, thus a likeliness of competition. The distribution of overlapping roots appears to explain at least part of the surprising maize yield depressions in the middle rows compared to the rows adjacent to the cassia hedges. Due to the extensive overlap of the roots in soil layers below 10 cm, competition may be expected under limiting water and/or nutrient conditions. Thus, cassia may not be a suitable choice for alley cropping under semi-arid conditions, unless most of its active roots can be properly managed to absorb resources below the feeding rhizosphere of the active roots of maize. In order to achieve this, either or both suggestion(s) could be considered for trial: Lopping cassia hedges to heights greater than 50 cm above the soil surface. Alteranatively, when the hedges are being established, cassia tree seedlings could be planted in sunken holes about 30 cm deep in the soil.

CHAPTER I

1 INTRODUCTION AND REVIEW OF LITERATURE

1.1.1 An overview of the problem

Hunger still plagues many developing countries, but it is especially widespread in Africa (FAO, 1985). On the other hand, the developed countries produce more than enough food to feed their people (FAO, 1988). The African problems are many. These include, among others, the large human population, characterised by a high birth rate, and often inadequate, always unpredictable rainfall. Hence any agricultural practice is a big gamble with the weather. The challenge to Africa in general is to seek ways of how to increase her food production by practising farming methods which would lead to near zero soil degradation, and hence conservation of the environment. It is particularly so for Kenya, which has approximately 583,000 sq km of land of which 80% is either arid or semi-arid land (ASAL) of low agricultural potential. Nevertheless, it must feed her increasing population. About eighty five percent of the population lives in the rural areas, relying heavily on agriculture and agriculture related activities for income (Obudho, 1987).

Kenya produces enough maize for local consumption except when there is drought. For example, there was a shortage of maize during the 1984/85 drought (Cohen and Lewis, 1987). But now, owing to the population pressure, the little high potential land has been subdivided. These subdivisions have reduced farm hectarages per head. The majority of this increasing number of small scale farmers cannot afford to buy the required farm inputs. This results in relatively low yields in their farms.

It is therefore apparent that for increased food production more efforts must also be directed to the abundant arid and semi-arid lands. But the problem is that rainfall in these areas is inadequate and unreliable, and the soils are often difficult to conserve (FAO, 1987). Occasionally, the rainfall in the ASAL is both enough and evenly distributed in a season, but still the crop yield remain low. Under such circumstances, low inputs and unfavourable management practices identifiable with farmers in these areas are to blame and not the weather conditions. Pastoralism is the main activity in many parts of ASAL, but of late the size of the grazing lands have decreased. Loss of dryland grazing areas is attributed, at least in part, to the need for more agricultural land and reduction of nomadic life style, and to a lesser extent to expansion in tourism industry in the country. Large grazing areas have been turned into game parks (Lofchie, 1987). Environmental degradation and related hardship occur to a more or less equal extent in all agriculturally marginal areas. For instance Machakos district, where the present study was carried out, experiences persistent food and fuel wood shortages. The major foods such as maize, beans and pigeon peas are in short supply (Ministry of Planning and National Development (M.P.N.D.) 1989-1993). The present annual production of maize in the district is 182,000 metric tonnes, while the demand is 273,000 metric tonnes. Pigeon peas demand is estimated to be 68,000 metric tonnes in 1993 against an average production of 35,000 metric tonnes. The population density is as high as 350 persons per square kilometre in hilly erosion prone high potential areas, which form a mere 5.4% of the total area. About 55 percent of the land is not cultivable (M.P.N.D., 1989-1993).

It is important to stress that systems of land use that enhance sustainable agricultural production are needed. In addition, it has been noted that direct fuel wood production is more economical than rural electrification in terms of minimising costs, maintenance of enough food and minimisation of environmental degradation (Hosier and O'keefe, 1980). Agroforestry seems a likely potential alternative available, and also when the target areas are arid and semi-arid lands. Suitable agroforestry farming technology may make the inhabitants self sufficient and not reliant on foodstuff imported from other agriculturally suitable districts.

1.1.2 Definition, scope and development of Agroforestry

Agroforestry designates land use techniques which imply the combination of trees with crops or with domestic animals or both (Budowski, 1979). According to Burley (1983), agroforestry is a collective name for land use systems that incorporate trees and agricultural crops or animals to meet social objectives at the level of small holders or rural communities.

Agroforestry practices refer to an arrangement of components (trees, crops, pastures and livestock) in time and space. For instance, agrosilviculture is a system of growing trees and crops in association. On the other hand, sylvopastoral practices refer to mixing trees and livestock on pasture in space. Agroforestry systems refer to a specific local example of a practice, characterised by plant species, management, environment and socio-economic functioning (Young, 1987). The goal of an agroforestry system is to optimise yield per unit area of production, whilst at the same time respecting the principles of sustained yield. It aims at providing food, fodder, domestic timber, shade and means of soil conservation.

Alley cropping or hedgerow intercropping is yet another example of agroforestry practice. It is a low external input crop production method in which crops are grown in spaces between the rows of planted woody trees/shrubs (Getahun, 1980; Kang *et al*., 1981; IITA, 1982; Balasubramanian, 1983; Nair, 1983). The trees are pruned at intervals to prevent shading of the crop, and to provide mulch and fodder or mulch only.

Agroforestry concepts are not new in Kenya. What is modern is the current scientific research approach being followed in order to understand and improve the system. "Shamba" systems are among the earliest documented agroforestry practices in Kenya (Mburu, 1980). Its success depended on the availability of forests to clear and willing workers who needed land to cultivate. The forestry department would allocate forest land to farmers. The farmers would then clear, cultivate and plant trees together with crops on the allocated land. Such an arrangement permitted the farmers to harvest their crops for two to three years in reward of their labour. The forestry department, on the other hand, had the trees well managed at initial stages hence allowing the trees to establish properly.

The Ministry of agriculture, as a way of conserving soil and water, encourages the growing of fodder crops, fruit trees and other types of trees on the edge terraces, in association with regular agricultural crops like maize, potatoes and pastures. Of more recent development is the establishment of the Dryland Agroforestry Research Project (DARP) within the Department of Forestry. A number of non - governmental organisations (NGO's) are also involved in the promotion of agroforestry. In this field the International Council for Research in Agroforestry (ICRAF) is leading.

1.1.3 **Relevance of the study**

One of the drawbacks in alley cropping systems is competition for available water, light and nutrients. Competition for available nutrients and water would be expected if both the tree and the crop have overlapping active root distribution in space and time. However, the reverse situation is desirable in hedgerow intercropping.

A Dryland Agroforestry Research Project (D.A.R.P.) 1985/1986 report indicated that in seasons of poor rainfall, maize productivity in the alleys was less than in the controls without *Cassia siamea* Lam. It therefore appeared that cassia may compete with maize for water under limiting water conditions. However, in a good rainfall season the productivity was reversed in that maize in the alleys was more productive than maize in the control. This must be the result of increased moisture retention due to mulching. Mungai (in-prep.) study on the same field confirmed these trends and reasoning. However, maximum yield increases had only the same order of magnitude as the losses due to the area occupied by the trees.

1.1.4 The objectives of the study

The main aim of this study was to assess the existence and the seriousness of root competition in the top soil space, as manifested in the distribution of the active roots of *Cassia siamea* Lam. and *Zea mays* L. to be investigated, both in space and time. In order to achieve this, the following specific objectives were set:

a) To find methods of properly distinguishing between roots of maize and cassia and methods of sampling these roots appropriately.

b) To measure the active root lengths of both maize and cassia at different

   (i) distances from the cassia hedgerow
   (ii) depths
   (iii) stages of growth and consequently calculate root length density and to measure the diameters of their actively absorbing roots.

c) To correlate meteorological data such as rainfall and evaporation which could be relevant to competition studies.

d) To attempt to relate the root study with a study on transpiration/water stress simultaneously carried out in the same plots (Netondo, in-prep.).

1.2 REVIEW OF LITERATURE

A knowledge of the spatial distribution of roots is essential in order to assess the supply of water and nutrients available to the plant (Mengel and Barber, 1974a; Tardieu, 1988a; Pages *et al.*, 1989). Spatial root distribution is also an important factor determining the choice of suitable fertilizer and water management practices (Chaudhary and Prihar, 1974). If alley crops are to be suitably selected and managed optimally, the distribution of roots of the associated components in space and time must be understood (Huck, 1983). The root length per volume of soil is the relevant parameter with respect to water and nutrient uptake (Bohm, 1979; Anderson and Ingram, 1989; Van Noordwijk, 1989).

Relatively more research has been carried out on the above ground parts of plants than on the below ground components. This is because studies of plant root systems are expensive, labour intensive and time consuming (Bohm, 1979; Haynes, 1980). Separation of the living roots from the soil material and debris, and measuring root parameters is extremely involving (Collins *et al.*, 1987; Habib, 1988). Tree root systems present extra problems because of their size and number, and the great depths they penetrate. Thus, more emphasis has been put on crop shoot systems, because they are easier to study. Comparatively very little is known about the distribution of roots in agroforestry systems, since the two disciplines, agriculture and forestry, were rarely interlinked (Young, 1987).

The growth and distribution of plant roots are genetically controlled but is largely modified by both environmental and plant factors (Russell, 1977; Kramer, 1983; Klepper, 1986; Sutton, 1987). Such factors include soil moisture, temperature, aeration, compactness, and cultural practices. These genetical and environmental factors usually interact, therefore it is difficult to isolate the effect of any single factor.

1.2.1 Plant factors affecting the distribution of roots

In most plant species, the growth and distribution of roots are genetically predetermined; the shoot and roots are proportionally related (Klepper, 1986). Deep rooted plants will always tend to develop deep roots, and shallow rooted plants will always tend to develop shallow ones, unless opposed by environmental factors (Kramer, 1983). Similarly, a plant with fibrous root systems will just grow the fibrous roots and not tap roots, because the type of root it grows is genetically predetermined. Cultivar differences of such kind may be significant in field experiments where root growth is not restricted as opposed to potted or green house experiments.

Age and stage of development of a plant affect the distribution of the roots. Maize root length density increases with an increase in time as the crop grows (Taylor and Klepper, 1973; Aina and Fapohunda, 1986). The increase is rapid in the vegetative stage, relatively constant during flowering and grain filling and finally decreases rapidly (Mengel and Barber, 1974a). These changes correspond to the vegetative, transition into reproductive and reproductive phases respectively. Mengel and Barber (1974a) measured the highest maize root length density to be 4.05 cm^{-2} in the 0 - 15 cm layer, 79 days after planting, while a maximum density in the zones below 0 - 15 cm occurred 1 - 2 weeks later. Maximum or minimum root density values vary with varieties.

1.2.2 Environmental factors affecting the distribution of roots

Environmental factors, mainly the soil environment, influence the distribution of roots in a number of ways. Clay soils often limit root growth and distribution due to deficient aeration and physical resistance to root penetration (Kramer, 1983). More space is occupied by water (non-capillary pore space) and less, air causing poor aeration. When clay dries up, it develops constricting forces which decrease corn (*Zea mays* L.) root weight (White, 1977). Both the gravel size and concentration have a significant effect on maize root length. The total root length of maize decreased by 50% for 25% and by 75% for 75% gravels. The average depth of root penetration was 20, 17, 18, 2 and 1 cm for gravel percent of 0, 10, 25, 50, and 75 respectively (Babalola and Lal, 1977). Generally, sand or gravel do not favour root penetration, unlike loamy soils (Klepper, 1986).

Evaporation of moisture from the soils reduces the volume occupied by pores. This can cause soil to mechanically resist or impede root extension, because roots seldomly penetrate pores smaller than their diameters (Russell, 1977; Miller, 1986). Soil bulk density and soil strength are the indices of soil resistance to root growth, and their threshold values vary with the soil types. Bulk densities of 1.55, 1.65, 1.80 and 1.85 appear to impede root growth in moist clay loamy, silt loam, sandy loams and loamy fine soils respectively (Miller, 1986).

The effect of compacted soil on the distribution of root length is well known. Logsdon *et al.* (1987) found that the root length of 6 day old maize seedlings decreased linearly as soil bulk density increased. A compacted clay-loam soil restricted lateral distribution of maize (FI hybrid of LGI) roots in the space between two maize rows (Tardieu, 1988a and 1988c). Shierlaw and Alston (1984) found that root length density was higher in soil above the compacted layers, whilst the quantity was reduced within the compacted layers. They noticed that the reduction was accompanied by an increase of diameters of roots. This variability of the distribution of maize roots in compacted soils is more pronounced in the upper 0 - 20 cm layer than in other depths (Beyrouty *et al.*, 1988) as long as there is no hardpan underneath (Robertson *et al.* 1980). Studies by Simmons and Pope (1987) on yellow poplar (*Liriodendron tulipifera* L.) and sweet gum (*Liquidambar styraciflua* L.) also showed that both root length and weight are significantly greater at lower than at higher bulk densities.

When the soil is compacted and also deficient in oxygen, the distribution and growth of roots are more severely retarded than from the effect of each factor singly (Kramer, 1983). Poor aeration limits the distribution of maize and tree roots (Follet *et al.*, 1974; Simmons and Pope, 1987). In general, Oxygen Diffusion Rates (O.D.R) of 0.2 μg cm^{-2} min^{-1} or less limit most roots but the values depend on the species and temperature.

Anderson (1987) found that the distribution of corn roots is significantly affected by the lateral position from the row, and by depth from the surface. More roots were within the row and in the inter-row space 19 cm away from the row. Over 70% of the total maize root length density or root weight may be located in the upper 22.5 cm soil space (Aina and

Fapohunda, 1986; Junying *et al.*, 1988). However, both may decrease by as much as 90% in the upper (0 - 14 cm) depth, and by 50% just below this (14 - 17 cm, depth Anderson, 1987). Similarly, about 75% of the total root length of barley (cv. Beecher) was in the top 15 cm space, and significantly decreased almost exponentially with depth (Gregory *et al.*, 1984; Brown *et al.*, 1989). Not more than 20% of the total measured corn root length was found below 75 cm in a sandy soil with a declining water table (Follet *et al.*, 1974), but maize roots are capable of colonising, though poorly, soil layers below 200 cm (Kramer, 1983). In contrast, trees in general tend to grow deeper roots than cereal crops. For instance, *Cassia spectablis* sends its roots to 120 cm depth (Balasubramanian and Sekayange, 1986).

Other root characteristics such as average root radius and root mass per length are also affected by depth and position. The smallest corn root diameters are in 0 - 10 cm upper soil layer (Anderson, 1987), while fine roots of *Cassia spectablis* are concentrated at 15 - 30 cm depth (Balasubramanian and Sekayange, 1986). Those of *Eucalyptus camaldulensis* are located at 40 - 50 cm (Zohar, 1985). Similarly, about 60% of fine roots of douglas fir (*Pseudotsuga menziesii* (Mirb.) Franco.), cedar (*Thuja plicata* Donn.) and hemlock (*Tsuga heterophylla* (Raf.) Sarg.) trees, all of approximate equal ages and growing in a common environment, were found to occupy the upper 20 cm, immediately below the humus layer (Eis, 1987). However, high percentages, ranging 79 - 85 in the upper 60 cm soil space, have been reported for hard forests roots (Kochenderfer, 1973).

Either excess or deficient soil water limit the distribution of roots in the soil. Less than 10% of the total root length of maize were found below 75 cm in a declining water table (Follet *et al.*, 1974). Robertson *et al.* (1980) observed that maize plants receiving light infrequent irrigation developed longer root lengths, and penetrated to deeper soil layers, than the ones subjected to frequent or medium infrequent irrigation. They concluded that the less irrigated maize grew longer and deeper roots in order to tap more moisture. Allmaras *et al.* (1975) also made the same conclusion when they observed that maize grew roots to soil depth equal or greater than the maximum depth of water uptake. Lack of water is known to drastically reduce maize root length density, especially if the shortage coincides with tasselling period (Aina and Fapohunda, 1986). This may explain the susceptibility of reproductive stages to water deficit.

Low soil temperature retard root growth and hence the distribution. Higher temperature on the other hand have the reverse effect, but only to a certain limit. Root length and weight densities of Pearl millet

(*Pennisetum typhoides* S. & H., cv. BK 560) were reported to increase exponentially with thermal time (Gregory, 1986b). Water tables shallower than the height of capillary rise may form a heat sink and retard maize root growth at early stages (Follet *et al.*, 1974).

Mulching significantly decreases soil temperatures and improves the soil moisture status (Lal, 1974; Onderdonk and Ketcheson, 1973) and in warmer areas consequently results in higher root lengths and root length densities. The opposite, reduction of tea root growth under mulched tea, was reported in the cooler area of Kericho, Kenya (Othieno *et al.*, 1985). Soil moisture content is generally higher for layers 0 - 10 and 10 - 20 cm in mulched than in unmulched plots (Lal, 1974). Chaudhary and Prihar (1974) maize results showed that: i) wheat (*Triticum aestivum* L.) mulch significantly increased maize root length density in the upper 20 cm space; ii) root density was higher in cultivated plots and iii) maize root lateral spread was significantly greater in the upper mulched layer. Maize stover mulch facilitated the uptake of Nitrogen and Phosphorus fertilizers in the top soil space and resulted in more roots (Onderdonk and Ketcheson, 1973). The findings of Gregory *et al.* (1984), Brown *et al.* (1987) and Anderson (1987) also independently show that the interactive effects of N and P fertilizers and minimum tillage significantly increase the root length of cereals in the upper 0 - 20 cm soil space.

1.2.3 Root competition in agroforestry, strategies of avoiding and overcoming it in mixed cultures

Root competition in agroforestry systems usually occur whenever the tree/shrub and the associated crop have overlappings of the active roots in the top soil space. The roots of *Prosopis juliflora* highly compete for water and nutrients and permit no normal growth of plants in their rhizosphere (Shah *et al.*, 1957). Prajapati *et al.* (1971) also noted that the yield of *Sorghum vulgare* L. declined with increasing proximity to a *P. juliflora* hedgerow. Sorghum plants 1 m from the tree hedge bore no grains, while those at 2 m and 6 m from the hedge yielded 42 and 61.2 kg/ha respectively. Even only 25 Prosopis trees on an acre of Santa Rita experimental range, Arizona (U.S.A.), reduced grass forage production by 25% (Clarke, 1968). The growth and yield of sorghum (*Sorghum bicolar* moench), castor (*Ricinus communis*), and cowpea (*Vigna unquilata*) decreased with increasing proximity to leucaena hedgerows (Singh *et al.*, 1989). The growth and yield of the three crops decreased from 150% to 20% of sole crop as the distance from hedgerows decreased from 150 cm to 30 cm. This drop was mainly attributed to competition for water between the crops and leucaena. The sole crops had no hedgerows but were planted on experimental plots of equal area as the intercrop plots. Similarly, cotton plants further away from a *Eucalyptus camadulensis* shelter-belt bore more balls than those closer to the hedge (Zohar, 1985). An investigation on root distribution revealed that the majority of the absorbing roots of both plants share, due to overlapping, resources located within 40 - 80 cm soil space, but eucalyptus roots were more efficient. Lal (1989) too observed a reduction in yield of cowpea sown in the alleys of either sepium or leucaena.

Two plants do not compete with each other as long as the water, nutrients, O_2, CO_2, light, and heat supplies are non - limiting (Haynes, 1980). The success of a plant or species in competition for water will depend on its rate of root extension, either laterally to reach the soil unexploited by other plants, or vertically to utilise deeper water supplies (Donald, 1963; Kramer, 1983). Differences within species in terms of the number of seminal roots and the diameter of xylem vessels may enable one to out-compete another at specific sites (Gregory, 1986a). A plant with the higher root density of the absorbing roots is likely to be the winner when in competition with an associate which has less denser roots (Gregory, 1986a).

The atlas variety of wheat (*Triticum aevistivum*

L.) out-competed the vauger variety because it produces denser and more ramifying roots (Donald, 1963). Similarly, *Pinus sylvestris* does better than spruce *(Picea abiens)*, because its mean daily root elongation (12.0 mm) is greater than spruce's (4.8 mm). Thus it is able to tap soil resources from deeper soil horizon before spruce (Bartsch, 1987). Rye grass (*Lolium perenne* L.) is a superior competitor than the associated Couch grass (*Elytrigia repens*(L.) Desv.) because the former develops more root mass in the top soil space (Baan and Ennik, 1982). It has been suggested that grasses may possess competitive advantages over clovers for nutrients (particularly P, K & S) and water supply, because they generally have longer and more finely branched roots (Haynes, 1980). Many successful competitors have more root biomass than the associated losers (Krammer, 1983; Russell, 1977).

Leucaena leucocephala rarely competes with crops grown in the alley (Kang *et al.*, 1981). This may be because leucaena develops deeper roots than the associated crop and therefore the tree - crop root distributions are separated in space (Kang *et al.*, 1981). For the same reason, *Cassia siamea* appeared suitable for alley cropping with maize (Balasubramanian and Sekayange, 1986). Whereas cassia had very few roots in the upper 0 - 15 cm space and more in the layer below, maize roots showed the opposite trend in their distribution. Insignificant reduction in yield observed in maize planted next to either well pruned leucaena, *Grilicidia sepium* or cassia hedgerows is mainly due to shading by the trees (Kang *et al.*, 1981; Yamoah *et al.*, 1986). However, when droughts are prolonged, these tree/shrubs reduce maize yield due to competition for soil moisture (Lal, 1989). Maghembe *et al.* (1988) hold a different view. They consider, from their experience, these trees inappropriate for alley cropping, because they found them to have similar root distribution to maize. This shows the site - specificness of many results on root competitions.

CHAPTER II

2 MATERIALS AND METHODS

2.1 Experimental site characterisation

The field site was at Machakos district, Katumani Dryland Research Station, Kenya. It is about 70 km South - East of Nairobi. It lies in the sub-humid to semi-arid zone at a latitude of 1^{o} 33′ South and a longitude of 37^{o} 14′ East, at an altitude of 1560 m above sea level (ICRAF, 1988). The average annual precipitation of 716 mm falls mainly in two seasons, "Long Rains", lasting from March to May, with an average of approximately 265 mm rain, and the "Short Rains", from October to December, with an average of 245 mm (ICRAF, 1988). But there is annual variation both in distribution and amounts received. The water loss through potential evapotranspiration is about 1800 mm per year. The mean annual temperature is 19.2^{o}C with the lowest monthly average in August (17.1^{o}C) and the highest in March (21.3^{o} C). The wind blows mainly from an easterly direction (80 - 100 degrees), with average monthly speeds ranging from 7.2 to 12.0 km/hr (ICRAF, 1988).

The predominant soil type is a well-drained, dark, brown, reddish-brown sandy clay (Nadar, 1984). They are moderately leached with (pH 6.0 - 6.5), and base saturation (50 - 80%). The soil belongs to the class

Luvisols according to FAO category (Ministry of Economic Planning and Development Programme, 1981), order Alfisols and suborder Ustalfs (US Soil Taxonomy), cited by ICRAF (1988).

2.2 Layout of the experiment

Six experimental blocks were randomly selected (Figure 2.1). Each block measured 10 m by 3.6 m. *Cassia siamea* hedgerow had been established in 3 out of the 6 blocks, while the 3 remaining blocks had no cassia hedgerows. The blocks with cassia hedgerows and the blocks without cassia hedgerows, are referred to as Agroforestry system (AF), and Non Agroforestry system (NAF) blocks respectively. Thus, experimental plots in the AF and NAF blocks are referred to as AF and NAF plots respectively.

Within each AF block there were 2 established cassia hedges at between row spacing of 3.6 m. The in-row spacing of cassia was 0.25 m. In between the 2 cassia hedges, 3 maize rows were sown parallel to the hedges at a spacing of 0.9 m (between rows) and 0.3 m (in-row). The 3 maize rows in the AF blocks were designated as follows;

R_{1AF} = maize row planted next to the cassia hedgerow on the eastern side of the experimental layout.

R_{2AF} = maize row planted in the middle of the

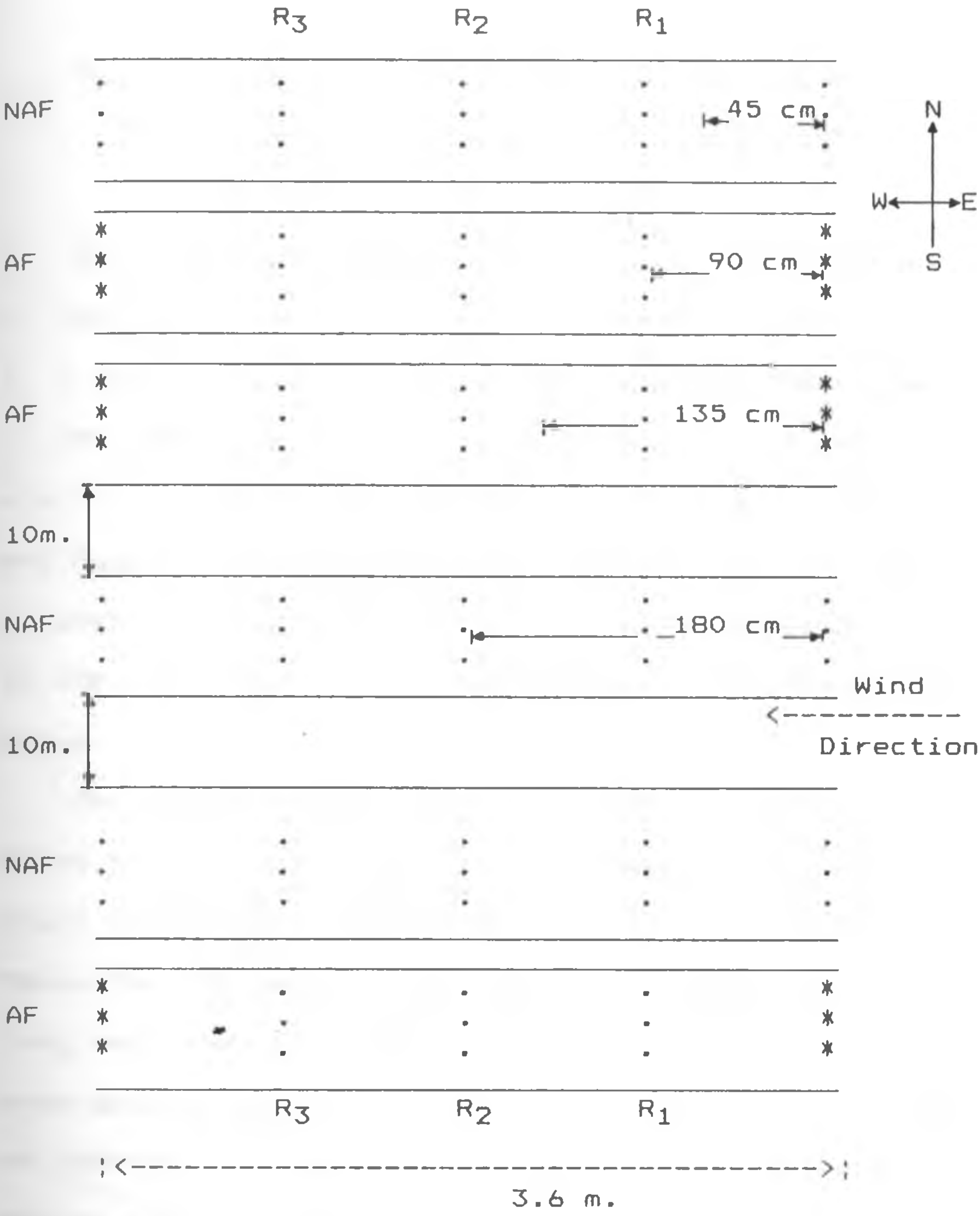

Figure 2.1. Experimental layout at Katumani (DARP).

LEGENDS

**** ______ Cassia hedgerows
.... ______ Maize rows
AF ______ Agroforestry block
NAF ______ Non Agroforestry "
R_1 to R_3 ______ Maize row_1 to row_3

Spacing between cassia hedgerows = 3.6 m
Spacing between cassia within a row = 0.25 m
Spacing between maize rows = 0.9 m
Spacing between maize within a row = 0.3 m

alley.

R_{3AF} = maize row planted next to the other cassia hedgerow on the western side of the experimental layout.

Rows R_{1AF} and R_{3AF} bordered the cassia hedgerow. In the NAF blocks, each tree row (hedge) was replaced by a row of maize, giving a total of five maize rows in the NAF blocks. Only 3 rows in the NAF blocks, which corresponded to the other 3 rows, R_{1AF}, R_{2AF} and R_{3AF} in the AF blocks, were considered for the purpose of this experiment. The 3 corresponding rows in the NAF blocks were designated as R_{1NAF}, R_{2NAF} and R_{3NAF}.

Maize was planted for two successive seasons. Maize for the first experiment was planted during the short rains season of October 1989 - January 1990. Maize for the second experiment was planted during the long rains season of March - June 1990. Thus first crop season refers to planting during the short rains of 1989/90, and second crop season refers to planting during the long rains of 1990. The alleys were hand hoed. Cassia hedges were lopped to 50 cm height and the cuttings referred to as fresh mulch were incorporated in the top soil space prior to sowing maize. No mulch was incorporated in the top soil space in NAF plots. Table 2.1 below shows a summary of field operations.

A two factor factorial experiment was used on the agroforestry system. The treatments were replicated 3 times in the three selected experimental blocks. One of the factors investigated was the effect of distance from the cassia hedgerow on the distribution of active roots of cassia and maize in the alley. The distance factor was assessed at four levels, where each level was a specific distance from the cassia hedgerow towards the alley. The four levels of distance were:

Distance 1 (D_1) = 45 cm from the cassia hedgerow towards alley

Distance 2 (D_2) = 90 cm " " " " " "

Distance 3 (D_3) = 135 cm " " " " " "

Distance 4 (D_4) = 180 cm " " " " " "

Distances 2 and 4 lay within the maize rows, D_1 next to the hedge and is between cassia hedge and maize row, and D_3 between maize rows.

The other factor was depth of soil layer from the surface, it had 3 levels:

Depth 0 - 10 cm (L_1) from the surface.

Depth 20 - 30 cm (L_2) " " "

Depth 40 - 50 cm (L_3) " " "

All the three levels of depth were measured over all levels of distance. Therefore in total there were twelve factorial combinations (D_1L_1 to D_4L_3), resulting from the 4 by 3 factorial experimental arrangement;

Operation	1st season 1989-90. Date	2nd season 1990. Date
Establishing cassia hedges	Nov. 1983.	Nov. 1983.
Lopping of cassia hedges	13/10/1989.	15/03/1990.
Incorporating mulch	13/10/1989.	16/03/1990.
Sowing Katumani maize	31/10/1989.	17/03/1990.
Thinning maize	24 DAS.	24 DAS.
Weeding	Frequent.	Frequent.

Table 2.1. A summary of field operations during 1st and 2nd crop seasons.

Season	Sampling date	r-values Cassia	r-values Maize
1st crop season.	32 DAS	0.93 ***	0.92 ***
	46 DAS	0.67 *	0.77 ***
	59 DAS	0.86 ***	0.57 *
	89 DAS	0.68 *	0.96 ***
2nd crop season.	56 DAS	0.60 *	0.57 *
	70 DAS	0.91 ***	0.62 *
	84 DAS	0.93 ***	0.85 ***
	98 DAS	0.61 *	0.74 ***

Table 2.2. Correlation (r) between the mean and standard deviations for cassia and maize root length data before transformation to logarithm base 10. d.f = (n-2)= 10.

D_1L_1	D_2L_1	D_3L_1	D_4L_1
D_1L_2	D_2L_2	D_3L_2	D_4L_2
D_1L_3	D_2L_3	D_3L_3	D_4L_3

2.3 Sampling, washing and separating the roots

An auger (corer) was used to remove 384.65 cm^3 of soil core containing both roots of cassia and maize from these positions. The auger was a hand driven type consisting of a 15 cm steel tube with a serrated cutting edge mounted on a 100 cm shaft with a plunger to remove the core (Bohm, 1979). It has an internal diameter of 7.0 cm, and the soil was extracted in 10 cm segments. Sampling was started 1 m away from the edge of the each plot column, then inwards at steps of about 1 m for successive sampling dates to avoid overlap. Cores were removed in-between two maize plants within a row. Sampling frequency was two weeks, commencing approximately four weeks after the emergence of maize seedlings and continuing upto when maize matured. At each particular sampling time, thirty six soil-root cores were removed and each placed in a labelled 10 litre plastic bucket. During the second growing season, the same sampling pattern was followed except that sampling was started 1.5 m away from plot edges - opposite to where it began the previous season - to ensure fresh sampling positions.

A modified version of the Gottingen method, described by Bohm (1979) was used for washing the roots. The 36 soil cores were singly soaked overnight in water in order to break the large soil particles into fine ones. Thereafter, the mixture containing roots was stirred by hand to disperse the soil particles from the roots. Stirring was continued until the mixture became a homogeneous suspension. Heavy soil particles settled at the bottom of the pail while roots remained floating in the suspension. The suspension, without the settled soil particles, was filtered through a cheese cloth serving as a sieve (Schuurman and Goedewagen, 1971). The sieve cloth was spread on a wire mesh resting on the rim of a perforated drum. The roots were trapped by the sieve and the fine suspended soil particles passed through. This operation was sped up by using water flowing at a constant low pressure through hose pipes connected to a nearby water tank (plate 2.1). Thus roots on the cheese cloth were freed from adhering soil suspension. The pail with the remaining soil was again filled with tap water and the process of suspension and decantation repeated. This process of soaking, stirring, decantation and filtration was repeated until all the roots were obtained from the soil suspension. Heavy soil particles which remained in the pail were disposed, and the pail cleaned awaiting washed roots to be transferred. Finally, the water was directed to push the roots to centre of the cheese cloth. The sieve cloth was then carefully turned inside out over the already cleaned bucket containing some water. The roots were then washed in the bucket by gently passing water on the cloth from the side without roots. Any remaining root on the cheese cloth was picked up by a sepal (fine brush). At this stage, roots were ready to be separated from debris. The process was repeated upto the 36th pail.

Roots were water floated in dissecting basins. Then using forceps (Schuurman and Goedewagen, 1971; Bohm, 1979) and fine sepals, they were separated from the organic matter and put in clear plastic petri-dishes. Cassia roots were separated from maize by colour. *Cassia siamea* Lam. roots are black (Ball, 1985) while maize (*Zea mays* L. cv. Katumani composite B) roots are white. A preliminary investigation was done by tracing the roots of these plants upto their tips by carefully removing the soil before sampling the roots by an auger began.

Colour and texture of the roots of the two plants were then compared. Colour, turgidity and flexibility were used as criteria of separating the live roots from the dead (Berish and Ewell, 1988; Anderson and Ingram, 1989). Distinction made between live and dead roots by the criterion of root colour conformed with a procedure used by Berish and Ewell (1988) and a recommendation by Anderson and Ingram (1989). Live

Plate 2.1. Shows root washing operation.

maize roots were white and rigid, while dead ones were brown and flaccid. Dead cassia roots were rotten and hollow. The plots were kept weed free by frequent weeding.

2.4 Measuring of the parameters and the methods used for analysing the data

To establish diameter class of the active roots or fine roots, the diameter of roots from 72 samples were measured and categorised as having root tips or no root tips, having root hairs or no root hairs by using a linear vernier microscope (Griffin & George Ltd. U.K.). There were as many as 100 rootlets in some samples. From this classification, roots which had diameters less than or equal to 0.5 mm, and those roots with diameters greater than 0.5 mm but less than or equal to 1.5 mm were taken to represent very fine and fine roots respectively.

The choice of root diameter class less than or equal to 1.5 mm, to represent the diameter of active or fine roots, was commensurate with other published diameter ranges. For instance, Bohm (1979) classified roots with diameters less than or equal to 0.5 mm as very fine roots, and roots with diameters greater than 0.5 mm but less than or equal to 2.0 mm as fine. Anderson and Ingram (1989) recommend that roots with diameters less than or equal to 0.5 mm be classified as very fine while roots with diameter greater than

0.5 mm but less than or equal to 2.0 mm be classified as fine. Eis (1987) classified fine roots of hemlock, cedar and douglas-fir trees as roots less than or equal to 2.0 mm root diameter.

Roots were divided by eye into two different diameter classes namely: roots less than or equal to 0.5 mm and roots greater than 0.5 mm but less than 1.5 mm. Dividing roots by eye into different diameter classes is a method widely used in routine root studies. Habib and Chadoeuf (1989) divided the maize roots by eye into three diameter classes: low root diameter (LRD) as roots with diameter class less than or equal to 0.5 mm, medium root diameter (MRD) as roots greater than 0.5 mm but less than or equal to 1.5 mm, and high root diameter (HRD) as roots from the diameter class greater than 1.5 mm.

Root length is a relevant parameter with respect to water and nutrient uptake (Anderson and Ingram, 1989; Van Noordwijk, 1989). The method suggested by Tennant (1975) was used to measure the root lengths. First a square grid, measuring 0.5 cm by 0.5 cm, was drawn on a tracing paper, then photocopied on transparencies. An estimation of the root length of active roots was done using all roots measuring less than or equal to 1.5 mm in diameter. Transparent petri dishes containing roots $\leq$ 1.5 mm were laid on transparencies. The number of intersections (N) between the roots and the vertical and horizontal grid lines was counted. The relationship becomes;

$$L = \frac{3.14ND}{4}, \text{ units in cm.}$$

Where; L = Length of roots

N = No of intersections between roots and grid lines.

D = Grid size, in this case 0.5 cm.

N was counted by a hand counter tally. The grid size 0.5 cm was chosen because it was more accurate than size 1.0 cm. Each and every root sample was counted thrice, every time randomly arranging the roots in the dish by shaking and changing position on the grid before counting. L was calculated from the average. Root lengths were measured separately for cassia and maize. Therefore, for any single sampling time, there were 72 root samples, 36 for cassia and 36 for maize, and a minimum of 216 sample countings.

The accuracy of Tennant's method was checked by comparing with values obtained when measuring root lengths using the linear vernier microscope. Forty three samples were used in this case, but each sample had numerous roots.

Root Length Density (RLD), is the amount of root length in a known volume of soil. It is sometimes abbreviated as L_{rv}, where;

L = Length.

r = Root

v = Volume of soil.

$$\text{RLD } (L_{rv}) = \frac{\text{Root length}}{384.65} \text{ (units in cm. cm}^{-3}\text{, or simply cm}^{-2}\text{).}$$

The figure 384.65 is the volume of soil carried by the auger i.e. 3.14 times $(3.5)^2$ times 10.

Maize in all the treatment plots was harvested per plant on a row basis. The mean grain and cob weights were determined for each plant in a row.

Meteorological data were obtained from ICRAF weather station, situated about 100 m away from the experimental site. Monthly averages for rainfall and evaporation, class A pan, during the period of study were of special interest for competition studies.

Root length values obtained by Tennants method were linearly regressed upon the values obtained by the actual measurement using a vernier microscope. This was to find out how close the relationship between the two methods was, and to estimate the % error by which Tennant's method estimated the root length. Root length data for the analyses of variances were even more accurately estimated, since the mean of three independent grid counts for each root sample was used to calculate the root length (Section 2.4.). Improved versions of Tennant's method designed to estimate the root length more quickly and accurately are currently used. Collins *et al.* (1987) used a photocopier, a light box and a bar code reader. Computer simulated models are increasingly being used to estimated the root length (Pages *et al.*, 1989).

The distribution of cassia and maize roots in the agroforestry was of great interest. Therefore, the distribution was compared with the distribution in the sole maize crop system (non-agroforestry) as reported in other related work to correlate the maize distribution in the two systems. In addition, the distribution of maize roots was also studied by mapping the distribution of maize roots along the profile wall on the non-agroforestry (Mungai in-prep).

Maize root length in auger volume of soil generally increased with time at each depth until a maximum was reached then decreased. The maize root length density and root length in the NAF plots have been summarised and presented in appendix I. The rather sparse rooting density at the start of the season corresponds to initial maize growth periods after germination, but increases with the age of the plant. This observation was similar to those reported by Taylor and Klepper, (1973); Barber and Mengel, (1974a).

During the second crop season, maize root length in cores sampled between two maize plants within a row (D_4) in depth positions 20 - 30 and 40 - 50 cm was throughout the season higher than maize root length in soil cores taken from the maize interrow space (D_3), but at the same depth positions. A similar maize root distribution pattern was also observed at depths 40 -

50 cm during the first crop season. These results were consistent with the findings of Anderson (1987).

Analyses of variance were done on the root length data from AF to find whether the distribution of the roots was affected by either distance or depth or both. The variances of the raw root length data were heterogeneous. As a rule, the variances should be homogeneous (Little and Hills, 1978; Steel and Torrie, 1981; Gomez and Gomez, 1984). It was found that this was due to a functional relationship between the means and standard deviations of the treatments (Table 2.2). As a remedy, the raw data for cassia and maize root length were transformed to logarithm base 10 preceding the analysis as required by rules of analyses of variances (Little and Hills, 1978; Steel and Torrie, 1981; Gomez and Gomez, 1984). Raw data can also be transformed to logarithm base 10 when the treatment main effects are additive because analyses of variance also assume non-additivity of main treatment effects (Little and Hills, 1978; Steel and Torrie 1981; Gomez and Gomez, 1984).

A number of cases concerning transformation of raw root data, in order to achieve variance homogeneity, have been published. Berish and Ewell (1988) transformed raw data to logarithm base 10 when they found that the variances of raw root mass were not homogeneous, but were generally proportional to the square of the means. Anderson and Ingram (1989) recommend that as a general procedure, raw root length data be transformed to logarithm base 10 preceding a statistical test. Sylvia and Neal (1990) logarithm transformed root-length data of onions, *Allium cepa* L., prior to running ANOVA procedures. Tardieu (1988b) attributed the functional relationship between the standard deviation and the mean of corn root length to the bimodal distribution of corn roots in each depth.

The analyses of variances were done separately for cassia and maize root length data. The sources of variability are blocks, treatments, distance, depth interactions and error. The blocks (replications) of AF were randomly selected from the experimental layout. The corresponding degree of freedom (d.f) calculated from the formula (n - 1) = 2., i.e 3 - 1 = 2. The 12, distance and depth combinations (D_1L_1 to D_4L_3, section 2.2) are represented by treatments, and d.f = 12 - 1 = 11. Analyses of variance to find whether the levels at each factor vary significantly is shown in the tables as well. Distance and depth factors have d.f = 3 and 2 because they have factor levels 4 and 3 respectively. Degree of freedom is 1 less than factor levels. D*L in the tables of F-ratios (see chapter 3) represents interaction between distance and depth factors. Whenever a significant 'F' ratio was obtained, means of root length (means of transformed data to logarithm base 10) were separated using the Least Significant Difference Test (LSD). Mean comparison was done for all the levels in each factor. For instance, a significant 'F' ratio for distance factor meant 6 mean comparisons, because there are 4 levels of distance factor. The six comparisons arise as follows;

1 The mean difference between 45 cm(L_1) and 90 cm(L_2)
2 " " " " 45 cm(L_1) and 135 cm(L_3)
3 " " " " 45 cm(L_1) and 180 cm(L_4)
4 " " " " 90 cm(L_2) and 135 cm(L_3)
5 " " " " 90 cm(L_2) and 180 cm(L_4)
6 " " " 135 cm(L_3) and 180 cm(L_4)

Similarly, a significant 'F' ratio for depth meant 3 mean comparisons, because there are 3 levels of depth factor. Mean root length at depth interval 0 - 10 cm (L_1) is compared with the means at depth intervals 20 - 30 cm (L_2) and 40 - 50 cm (L_3). Lastly, means at depth intervals 20 - 30 cm (L_2) and 40 - 50 cm (L_3) are compared. Least significance test values were calculated separately for distance and depth factors. Other analyses of variance were also done to find whether the yield of maize per plant was the same in all the 3 rows in the alley of the agroforestry system. Again, whenever there was a significant difference in maize yield per plant between the 3 rows, mean comparison was by LSD. The results of mean yield separation were essential for identifying the maize rows which yielded highest and lowest grains and cobs, and consequently for assessing whether maize yield was affected by proximity to the hedgerows.

Whereas the data in LSD tables 3.3a-3.4e and 3.6a-3.7e are logarithm base 10 transformed, the accompanying figures 3.2a-3.3d illustrate the distribution of the active roots of cassia and maize at certain DAS using non transformed data (Sections 3.3 and 3.3.1). It is recommended whenever logical, that pictorial presentation of data is done using non transformed values (Gomez and Gomez, 1984). However, data in the tables can be reported in either transformed or non transformed values.

CHAPTER III

3 RESULTS

3.1 Classification and characterisation of cassia and maize roots

These are the results obtained when cassia and maize roots, sampled 32 DAS of maize in the first crop season, were classified and characterised. Only the roots with a diameter range less than or equal to 1.5 mm were considered. Results are given in Tables 3.1a, 3.1b and 3.1c. It follows from these results that maize and cassia roots of root diameters less than or equal to 0.5 mm had more or less the same proportion of root tips and root hairs (Table 3.1c).

3.2 Methods of identifying the roots, estimating the root lengths and data analysis

Cassia roots are black while the roots of maize are white in colour (plate 3.1). Tennant's method accurately estimated the root length as was seen in the close relationship between the two methods (Figure 3.1). An error of 1.33%, found to be associated with the method is lower than the 9% reported by Karthy *et al.* (1978) obtained while using the same method to estimate the root length of wheat. Obviously, therefore, the regression of Tennant's method upon the vernier microscope, which served as a reference or

Root diameter class (mm)	%Mean	S.E.
0 - 0.5	71.6	± 7.8
0.5 - 1.5 with root hair.	22.6	± 6.5
0.5 - 1.5 without root hair.	5.8	± 3.8

Table 3.1a. The percentage contribution of each cassia root diameter class to the total root length of cassia less than or equal to 1.5 mm.

Depth	%Mean	S.E.
0 - 10cm	83.2	± 16.0
20 - 30cm	68.2	± 11.1
40 - 50cm	74.8	± 10.0

Table 3.1b. The percentage distribution of cassia roots which have root diameter class less than or equal to 0.5 mm.

Plant.	% roots with tips	% roots with hairs	% roots with tip&hairs
cassia	94.1 ± 4.1	49.2 ± 7.7	48.7 ± 6.7
maize	98.0 ± 0.6	47.3 ± 11.0	47.5 ± 9.0

Table 3.1c. Some characteristics of cassia and maize roots which have root diameters less than or equal to 0.5 mm.

Plate 3.1. Shows the difference in colour between cassia and maize roots. The former are black while the latter are white.

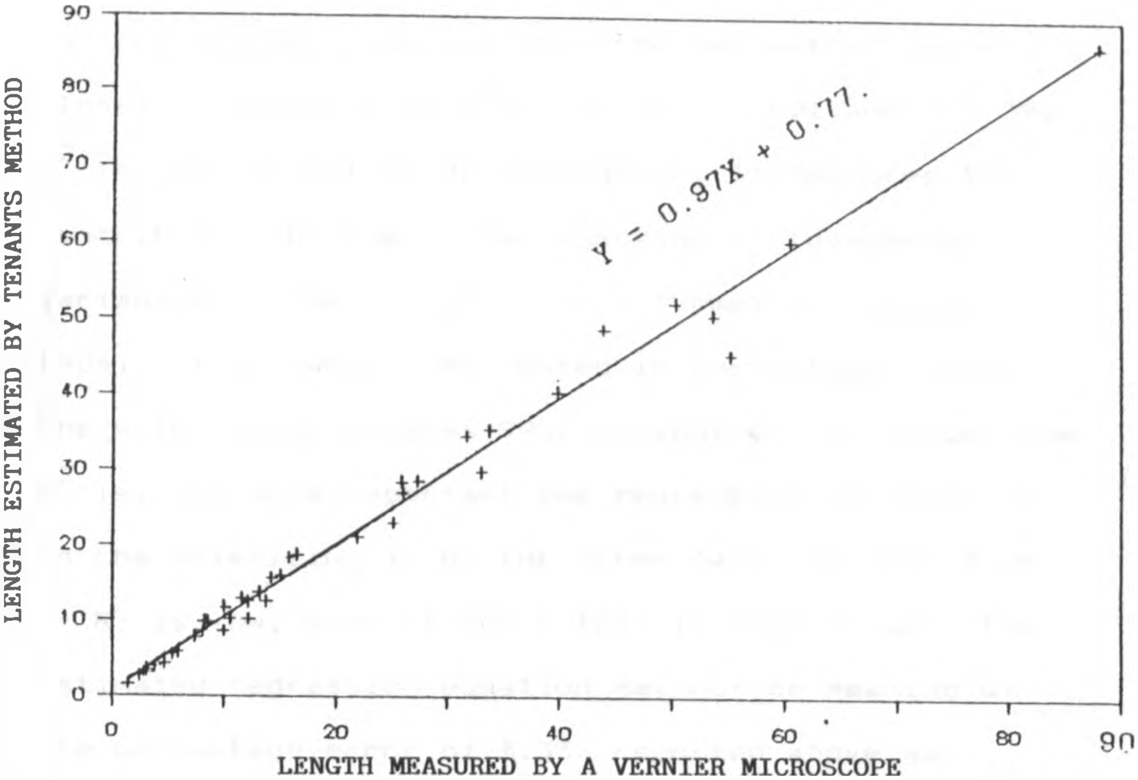

Figure 3.1 . Regression of Tennant s method upon the Vernier microscope method.

Regression Output:	
Constant	0.771798
Std Err of Y Est	2.215747
R Squared	0.986769
No. of Observations	41
Degrees of Freedom	39

X Coefficient(s)	0.970689
Std Err of Coef.	0.017988

control method, revealed that the two methods were closely related, with $R^2 = 0.99$, $p \leq 0.001$ and $n = 39$. R^2 is coefficient of determination. It measures the contribution of the linear function of independent variables to the variation in Y (Gomez and Gomez, 1984). It is usually expressed in percentage. Thus, the value above becomes 99%. Obviously, the larger the R^2 is, the more important the regression equation is in characterizing Y. On the other hand, if the value of R^2 is low, even if the F test is significant, the estimated regression equation may not be meaningful. The percentage error of 1.33% reported above was calculated as; $(1- R^2)$ times 100%, which is equal to (1- 0.9867) times 100% = 1.33%. The root length raw data had indeed to be transformed because an assumption of analysis of variance, of independence between the means and the variance, was violated (see section 2.4; Table 2.2).

3.3 Effect of distance and depth on the distribution of cassia root length

Distance from the cassia hedgerow had statistically no significant effect on the distribution of the length of cassia. It was depth which significantly ($p \leq 0.001$) influenced the distribution of cassia root length during the two crop seasons (Tables 3.2a and 3.2b).

Since the D*L interaction is not significant

Source of Var.	d.f	Date of root sampling (DAS)			
		32	46	59	89
Blocks	2	0.13 ns	4.16 *	1.80 ns	0.62 ns
Treat.	11	2.24 ns	7.56 ***	5.00 ***	2.26 ns
Dist.	3	1.26 ns	3.05 ns	2.40 ns	0.93 ns
Depth	2	7.95 ***	35.90 ***	21.97 ***	8.37 ***
D * L	6	0.82 ns	0.37 ns	0.66 ns	0.88 ns
Error	22				
Total	35				
cv		45.40%	22.97%	34.69%	32.67%

Table 3.2a. Analysis of Variance table of 'F' ratio for root length. For cassia in agroforestry in 1st season 1989/90.

Source of Var.	d.f	Date of root sampling (DAS)				
		36	56	70	84	98
Blocks	2	0.86 ns	0.06 ns	0.64 ns	2.68 ns	0.22 ns
Treat.	11	4.24 ***	4.98 ***	5.30 ***	5.78 ***	2.68 ns
Dist.	3	1.86 ns	2.50 ns	2.21 ns	1.42 ns	2.42 ns
Depth	2	15.23***	22.36***	23.20***	28.74 ***	9.84***
D*L	6	1.77ns	0.43ns	0.87ns	0.30ns	0.34ns
Error	22					
Total	35					
cv		19.24%	28.11%	31.25%	26.65%	39.64%

Table 3.2b. Analysis of Variance table of 'F' ratio for root length. For cassia in agroforestry in 2nd season 1990.

(Tables 3.2a and 3.2b) and the **D** by L tables of means is presented, **D** means averaged over all levels of factor L and the L means averaged over all levels of factor **D** are compared (Gomez and Gomez, 1984). In other words, distance (factor **D**) means averaged over all levels of depth (factor L) namely, 0 - 10 cm, 20 - 30 cm and 40 - 50 cm intervals are compared. Similarly, depth (factor L) means averaged over all levels of distance (factor **D**) namely, 45 cm, 90 cm, 135 cm and 180cm from the cassia hedgerow are compared. For example, in Table 3.3a, distance means 1.34, 0.99, 1.49 and 1.20 averaged over all the three levels of depth intervals are compared. Likewise, depth interval means 0.74, 1.63 and 1.40 averaged over all the four level of distance are compared. The 4 distance means presented in the bottom row, denoted by $Av.^c$, while the 3 depth interval means are in the far right column of the table, denoted by Av^r. The LSD test values for $Av.^c$ and $Av.^r$ means are given at the bottom of each table.

Cassia root length in soil depths 20 - 30 and 40 - 50 cm were statistically the same at any particular sampling time during the two seasons. However, the length of cassia roots in the soil depth 0 - 10 cm was significantly ($p \leq 0.01$) less than the length at either depths 20 - 30 cm or 40 - 50 cm throughout the seasons (Table 3.3a to table 3.4e). Cassia root length density was comparatively more sparsely distributed in

		Mean Root Length in cm.				
Date	Depth interval (cm)	Distance from the cassia hedgerow (cm) 45	90	135	180	$Av.^r$
32 DAS	0 - 10	0.63	0.43	1.10	0.78	0.74
	20 - 30	1.92	0.98	1.93	1.67	1.63
	40 - 50	1.48	1.56	1.43	1.14	1.40
	$Av.^c$	1.34	0.99	1.49	1.20	

$LSD_{.01}$ for Depth (row) averages, i.e. $Av.^r$ = 0.66

$Av.^c$ (Distance) = non-significant.

Table 3.3a. Effects of Different Distances from the Hedgerow and Different Soil Depth intervals from the Soil Surface on Root Length of Cassia shown at 32 DAS in 1st season (mean of 3 replications)

		Mean Root Length in cm.				
Date	Depth interval (cm)	Distance from the cassia hedgerow (cm) 45	90	135	180	$Av.^r$
46 DAS	0 - 10	0.71	0.79	1.07	0.60	0.79
	20 - 30	1.61	1.64	2.01	1.37	1.66
	40 - 50	2.04	1.87	1.95	1.65	1.88
	$Av.^c$	1.45	1.43	1.68	1.21	

$LSD_{.01}$ for Depth (row) averages, i.e. $Av.^r$ = 0.38

$Av.^c$ (Distance) = non-significant.

Table 3.3b. Effects of Different Distances from the Hedgerow and Different Soil Depth intervals from the Soil Surface on Root Length of Cassia shown at 46 DAS in 1st season (mean of 3 replications).

The corresponding LSD values for depth Av^r. and distance Av^c. are given at the bottom of the table.

Date	Depth interval (cm)	Mean Root Length in cm. Distance from the cassia hedgerow (cm) 45	90	135	180	Av.^{r}
59 DAS	0 - 10	0.44	0.23	0.88	0.48	0.51
	20 - 30	1.68	1.21	1.75	1.16	1.45
	40 - 50	1.41	1.20	1.35	1.39	1.34
	Av.^{c}	1.18	0.88	1.33	1.01	

$LSD_{.01}$ for Depth (row) averages, i.e. Av.^{r} = 0.44

Av.^{c} (Distance) = non-significant.

Table 3.3c. Effects of Different Distances from the Hedgerow and Different Soil Depth intervals from the Soil Surface on Root Length of Cassia shown at 59 DAS in 1st season (mean of 3 replications).

Date	Depth interval (cm)	Mean Root Length in cm Distance from the cassia hedgerow (cm) 45	90	135	180	Av.^{r}
89 DAS	0 - 10	0.74	1.10	1.14	0.91	0.97
	20 - 30	2.04	1.73	1.35	1.43	1.66
	40 - 50	1.80	1.86	1.33	1.58	1.88
	Av.^{c}	1.53	1.56	1.27	1.31	

$LSD_{.01}$ for Depth (row) averages, i.e. Av.^{r} = 0.53

Av.^{c} (Distance) = non-significant.

Table 3.3d. Effects of Different Distances from the Hedgerow and Different Soil Depth intervals from the Soil Surface on Root Length of Cassia shown at 89 DAS in 1st season (mean of 3 replications).

Date	Depth interval (cm)	Mean Root Length in cm. Distance from the cassia hedgerow (cm) 45	90	135	180	Av.^{r}
36 DAS	0 - 10	0.99	1.29	1.37	1.22	1.22
	20 - 30	2.20	1.75	1.99	1.58	1.88
	40 - 50	1.80	1.57	1.39	1.24	1.50
	Av.^{c}	1.66	1.54	1.58	1.53	

$LSD_{.01}$ for Depth (row) averages, i.e. Av.^{r} = 0.34

Av.^{c}(Distance) = non-significant.

Table 3.4a. Effects of Different Distances from the Hedgerow and Different Soil Depth intervals from the Soil Surface on Root Length of Cassia shown at 36 DAS in 2nd season (mean of 3 replications).

Date	Depth interval (cm)	Mean Root Length in cm. Distance from the cassia hedgerow (cm) 45	90	135	180	Av.^{r}
56 DAS	0 - 10	0.98	0.82	0.92	0.60	0.83
	20 - 30	1.96	1.48	1.91	1.37	1.68
	40 - 50	2.29	1.85	1.72	1.73	1.90
	Av.^{c}	1.74	1.38	1.68	1.23	

$LSD_{.01}$ for Depth (row) averages,i.e. Av.^{r} = 0.48

Av.^{c}(Distance) = non-significant.

Table 3.4b. Effects of Different Distances from the Hedgerow and Different Soil Depth intervals from the Soil Surface on Root Length of Cassia shown at 56 DAS in 2nd season (mean of 3 replications).

		Mean Root Length in cm.				
Date	Depth interval (cm)	Distance from the cassia hedgerow (cm) 45	90	135	180	Av.[r]
70 DAS	0 - 10	1.00	0.32	0.55	0.82	0.68
	20 - 30	2.17	1.78	1.58	1.57	1.78
	40 - 50	1.61	1.26	1.74	1.41	1.50
	Av.[c]	1.59	1.12	1.29	1.27	

$LSD_{.01}$ for Depth (row) averages, i.e. Av.[r] = 0.47

Av.[c] (Distance) = non-significant.

Table 3.4c. Effects of Different Distances from the Hedgerow and Different Soil Depth intervals from the Soil Surface on Root Length of Cassia shown at 70 DAS in 2nd season (mean of 3 replications).

		Mean Root Length in cm.				
Date	Depth interval (cm)	Distance from the cassia hedgerow (cm) 45	90	135	180	Av.[r]
84 DAS	0 - 10	1.00	0.69	0.55	0.81	0.76
	20 - 30	2.08	1.90	1.90	1.68	1.89
	40 - 50	1.73	1.56	1.50	1.31	1.53
	Av.[c]	1.60	1.38	1.32	1.27	

$LSD_{.01}$ for Depth (row) averages, i.e. Av.[r] = 0.43

Av.[c] (Distance) = non-significant.

Table 3.4d. Effects of Different Distances from the Hedgerow and Different Soil Depth intervals from the Soil Surface on Root Length of Cassia shown at 84 DAS in 2nd season (mean of 3 replications).

		Mean Root Length in cm.				
Date	Depth interval (cm)	Distance from the cassia hedgerow (cm) 45	90	135	180	Av.^{r}
98 DAS	0 - 10	1.01	0.60	0.98	0.47	0.77
	20 - 30	1.79	1.64	1.51	1.38	1.58
	40 - 50	2.08	1.17	1.82	1.28	1.59
	Av.^{c}	1.63	1.14	1.44	1.04	

$LSD_{.01}$ for Depth (row) averages, Av.^{r} = 0.60

Av.^{c}(Distance) = non-significant.

Table 3.4e. Effects of Different Distances from the Hedgerow and Different Soil Depth intervals from the Soil Surface on Root Length of Cassia shown at 98 DAS in 2nd season (mean of 3 replications).

the 0 - 10 cm top soil space than within 20 - 30 and 40 - 50 cm soil depths. Cassia root length density was higher in soil depths 20 - 30 and 40 - 50 cm, with approximately equal relative distribution trends within the two soil layers, especially in the second season (Figs. 3.2a-3.3d, see last part of sec. 2.4).

3.3.1 Effect of distance and depth on the distribution of maize root length

Distance and depth concurrently affected the distribution of the length of maize roots at 59 DAS during the first season (Table 3.5a). Distance alone influenced the maize root distribution at 89 DAS during same crop season. Table 3.5a shows the analysis of variance table of `F' ratio for maize root length during the 1st crop season, 1989/1990.

During the second season, distance and depth together affected the distribution of maize root length in the agroforestry at 36 DAS (Table 3.5b). So this effect of the two factors on the distribution of maize root length independently was observed only once as it was in the previous season. Distance factor alone affected the root distribution at 56, 84 and 98 DAS. In both the seasons there was no statistically significant interaction between the factors (D*L). The results in Tables 3.5a and 3.5b. Same pattern (section 3.3) of presenting tables of comparisons of distance means averaged over all levels of depth, and

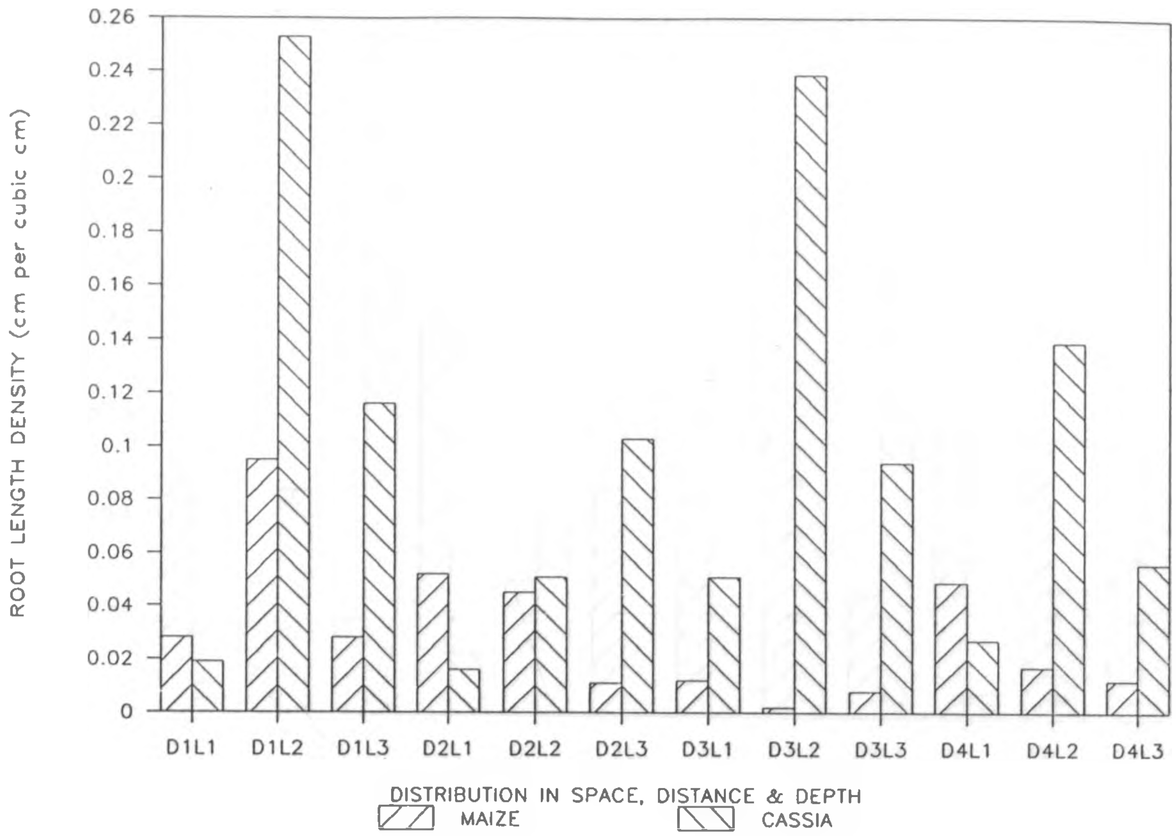

Figure 3.2a. Distribution of maize and Cassia root length at vegetative (32 DAS) stage. (1st crop season 1989/1990).

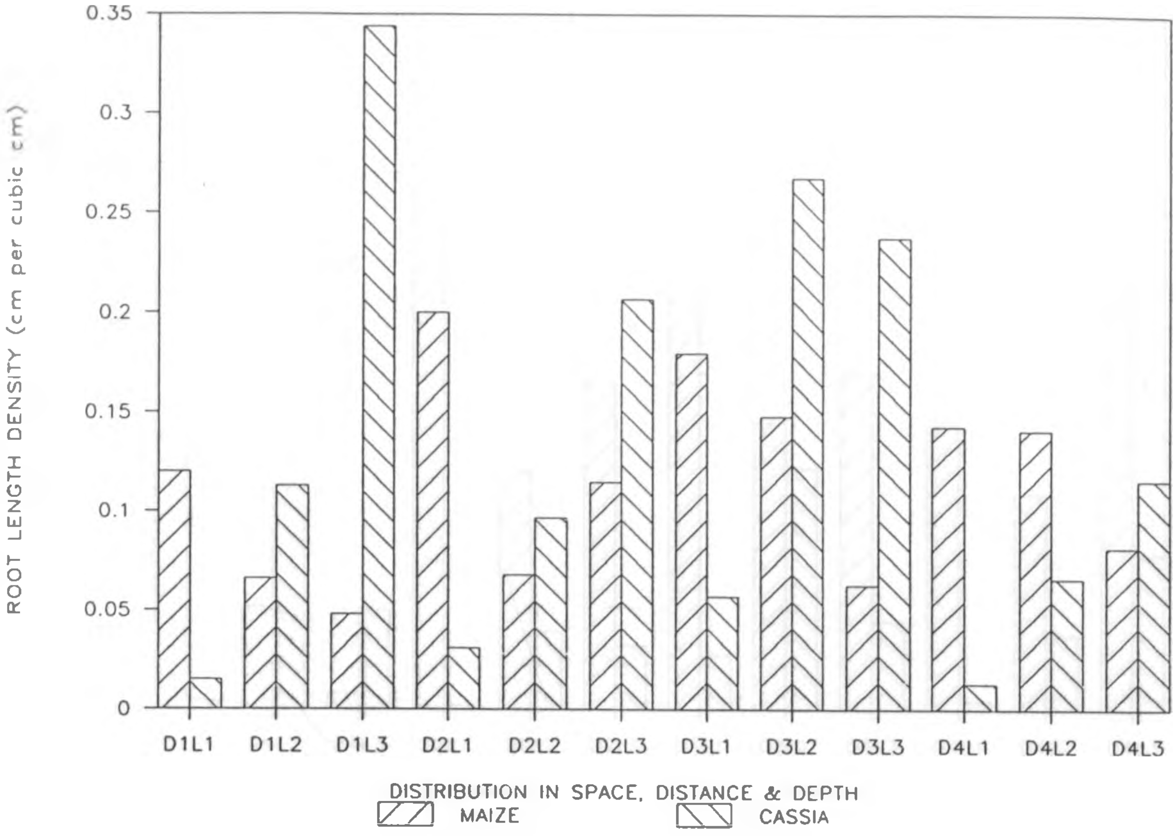

Figure 3.2b. Distribution of maize and Cassia root length at tasselling (46 DAS) stage. (1st crop season 1989/1990)

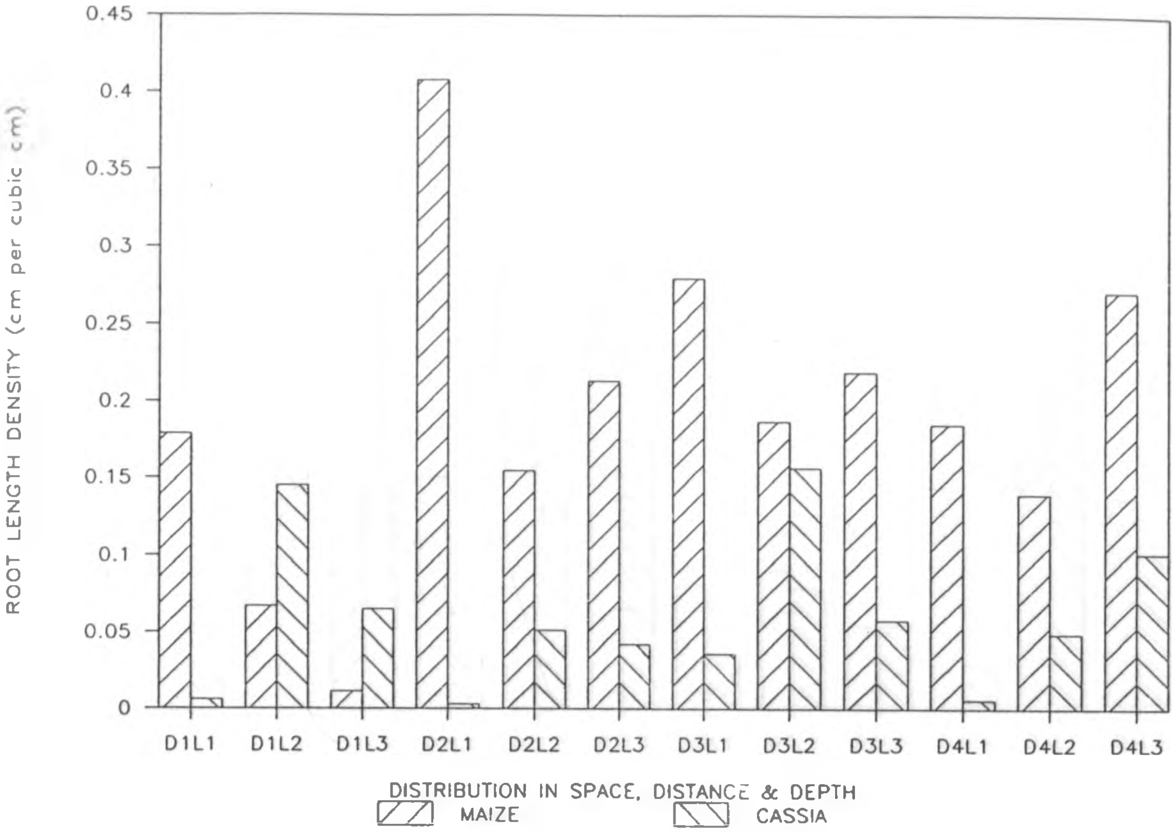

Figure 3.2c. Distribution of maize and Cassia root length at silking and grain filling stage (59 DAS) stage. (1st crop season 1989/1990).

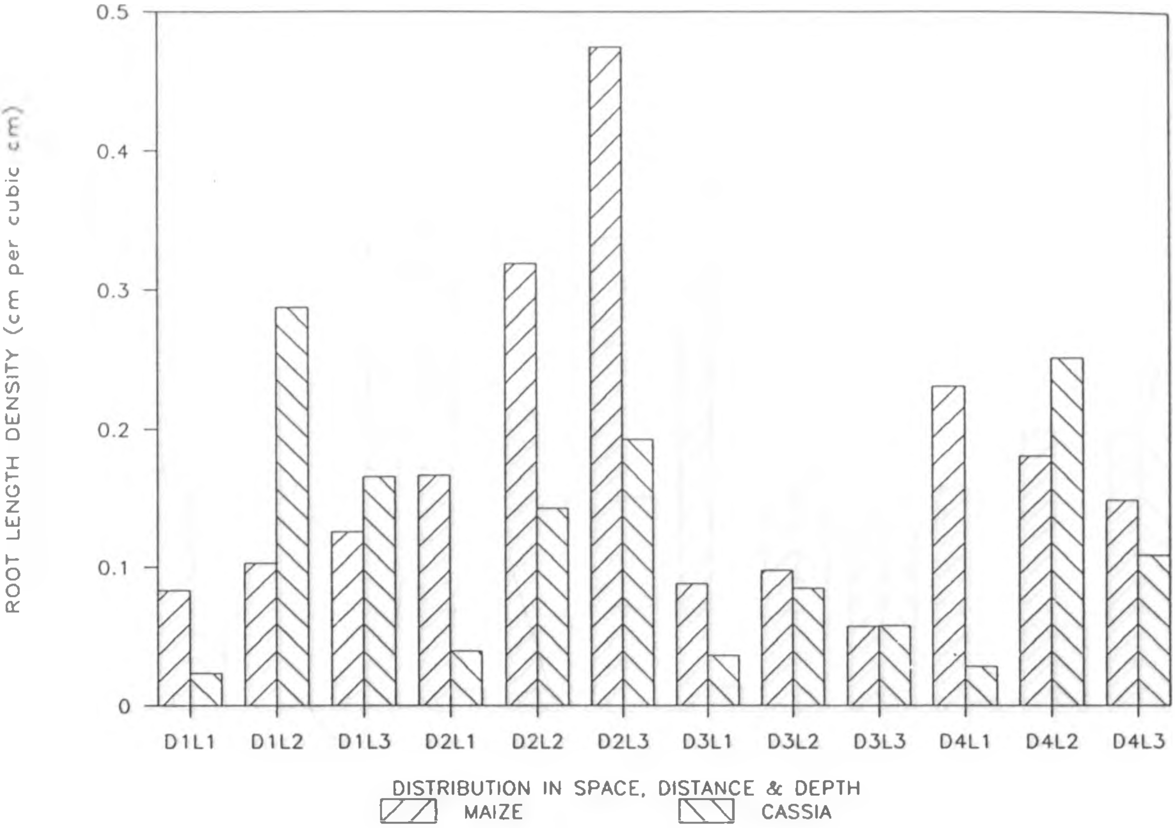

Figure 3.2d. Distribution of maize and Cassia root length at maturity (89 DAS) stage. (1st crop season 1989/1990).

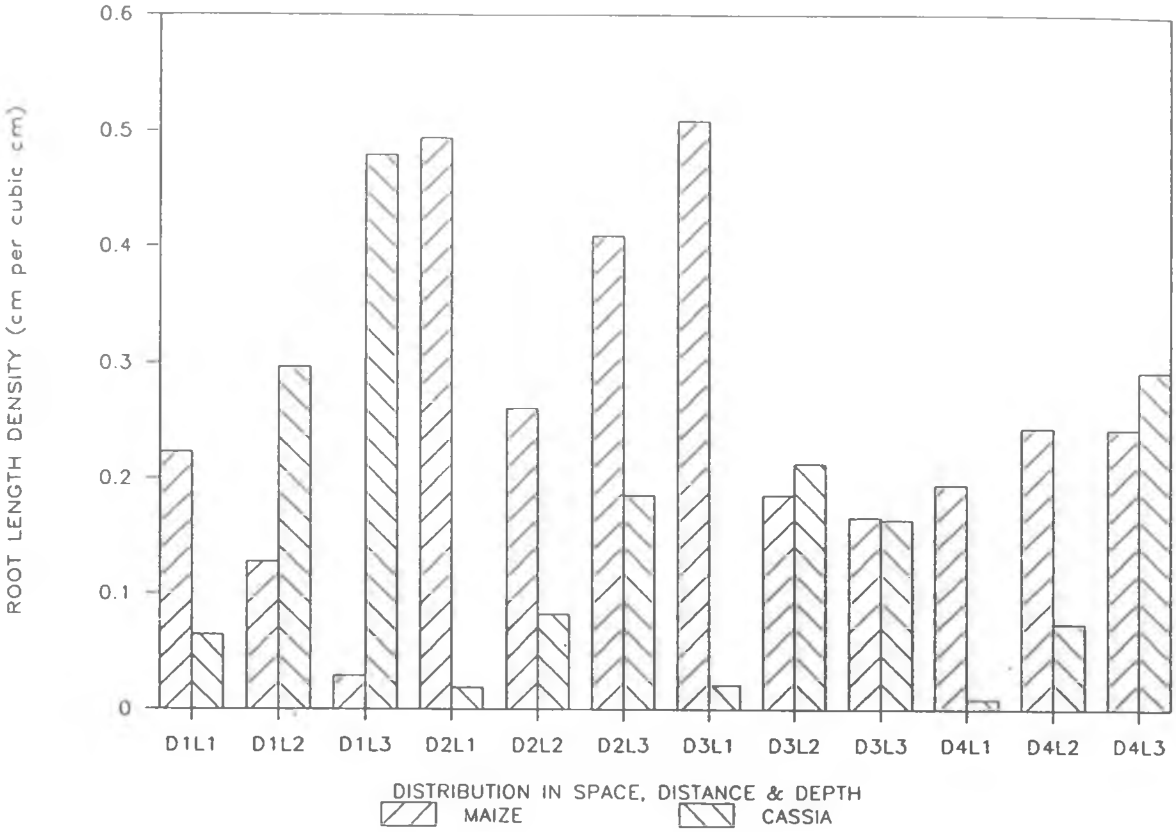

Figure 3.3a. Distribution of maize and cassia root length at silking (56 DAS) stage. (2nd crop season 1990).

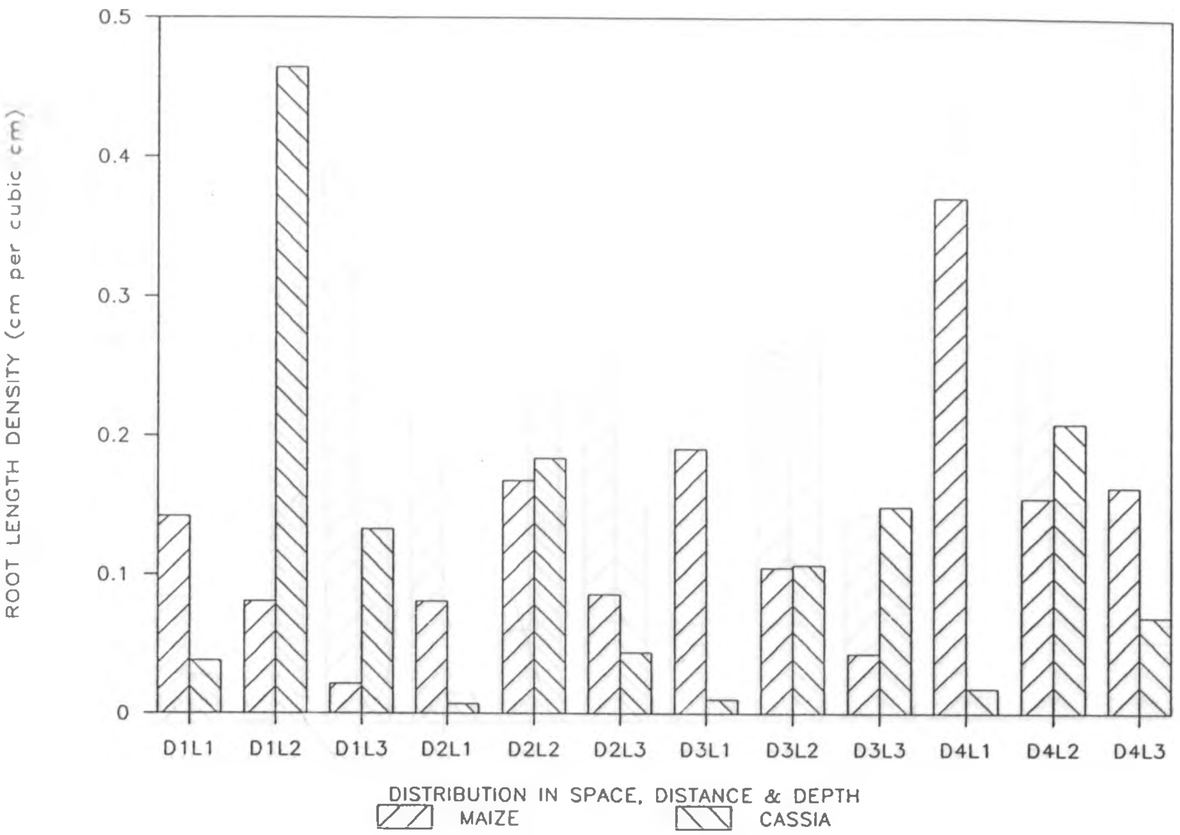

Figure 3.3b. Distribution of maize and cassia root length at grain filling (70 DAS) stage. (2nd crop season 1990).

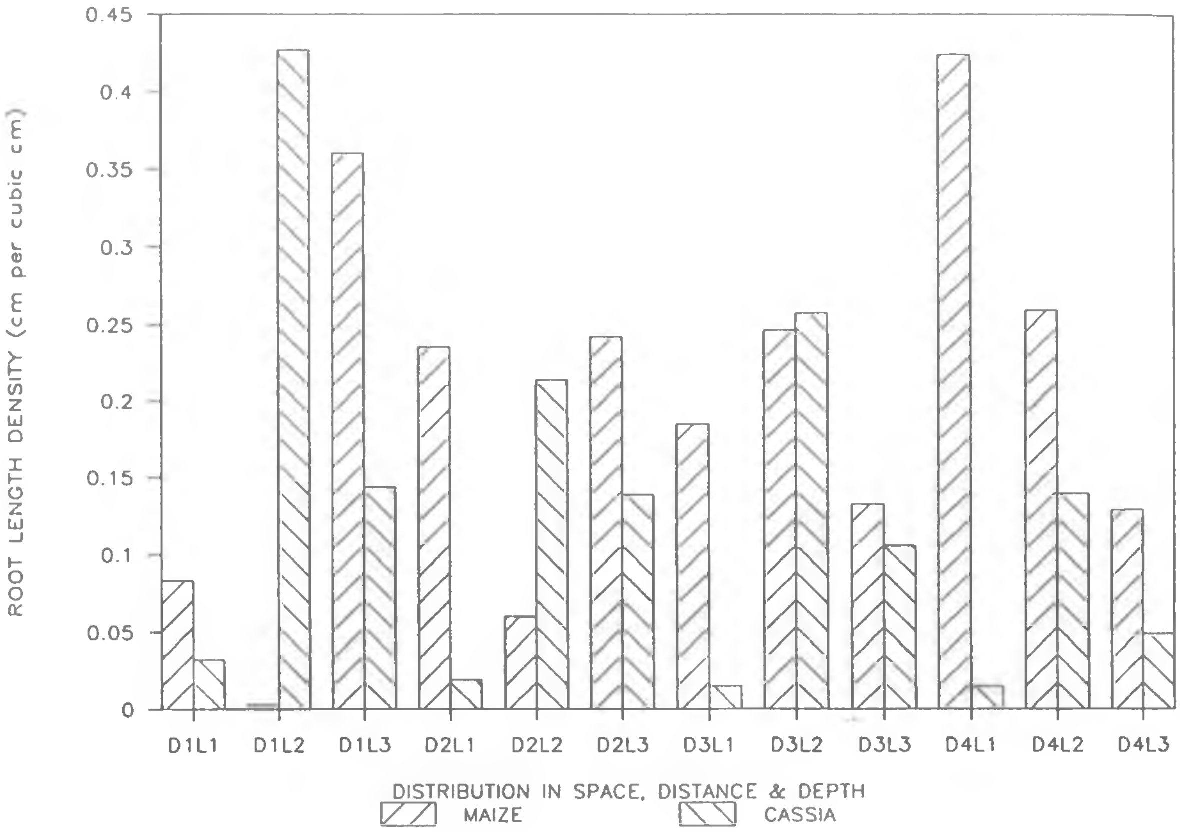

Figure 3.3c. Distribution of maize and cassia root length at post grain filling (84 DAS) stage. (2nd crop season 1990).

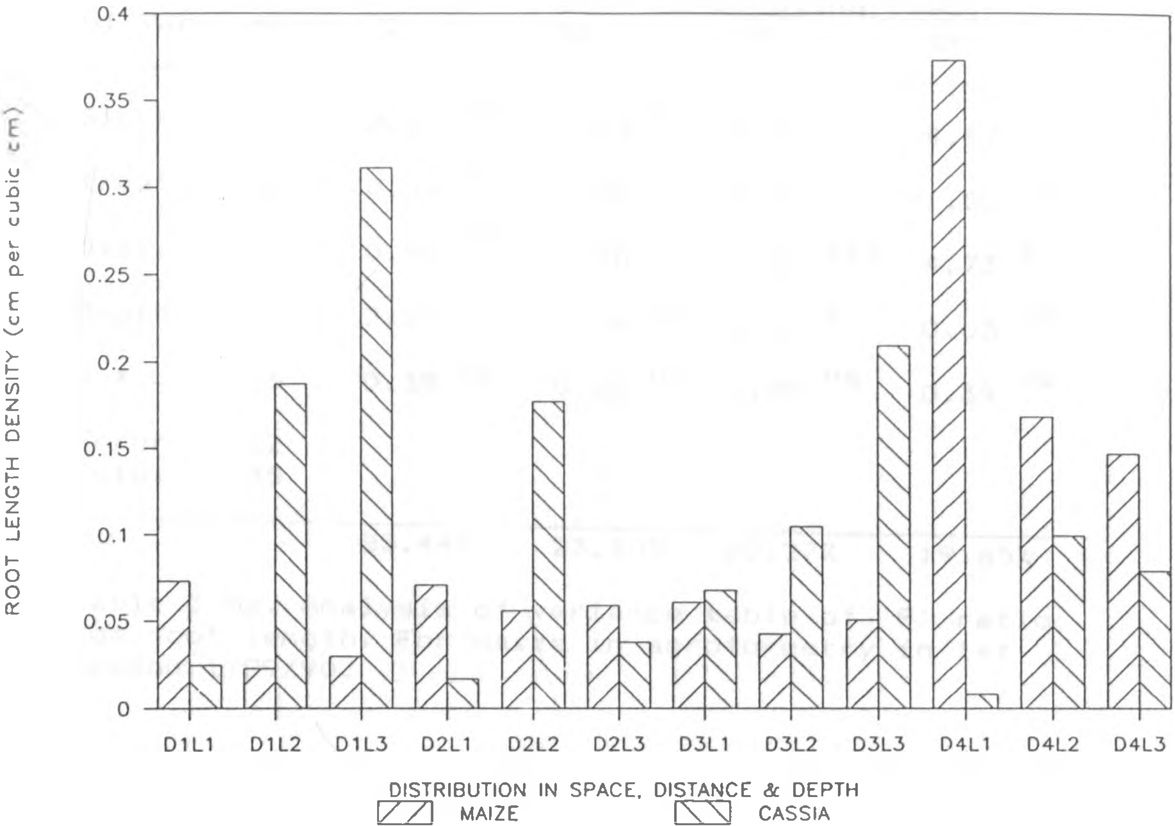

Figure 3.3d. Distribution of maize and cassia root length at maturity (98 DAS) stage. 2nd crop season 1990.

Source of Var.	d.f	32	Date of sampling (DAS) 46	59	89
Blocks	2	2.21 ns	3.63 *	4.67 *	4.17 *
Treat.	11	0.86 ns	0.88 ns	4.44 ***	1.52 ns
Dist.	3	0.96 ns	0.58 ns	7.60 ***	4.73 *
Depth	2	2.12 ns	2.04 ns	5.52 *	0.05 ns
D * L	6	0.39 ns	0.65 ns	2.50 ns	0.39 ns
Error	22				
Total	35				
cv		85.44%	23.10%	22.27%	19.65%

Table 3.5a. Analysis of variance table of 'F' ratio for root length. For maize in agroforestry in 1st season 1989/90.

Source of Var.	d.f	36	Date of root sampling (DAS) 56	70	84	98
Blocks	2	5.11 *	2.50 ns	0.80 ns	2.46 ns	1.33 ns
Treat.	11	3.55 **	2.26 *	2.23 *	3.38 *	2.18 ns
Dist.	3	5.87 ***	5.91 ***	2.50 ns	8.28 ***	6.83 **
Depth	2	6.33 **	1.74 ns	4.72 *	3.12 ns	0.69 ns
D * L	6	1.47 ns	0.62 ns	1.26 ns	1.02 ns	0.34 ns
Error	22					
Total	35					
cv		52.15%	28.19%	27.03%	21.10%	37.20%

Table 3.5b. Analysis of Variance table of 'F' ratio for root length. For maize in agroforestry in 2nd season 1990.

vice versa are used for similar tables in this section. A comparison of means in the first season (59 DAS) showed the root length of maize within depth 0 - 10 cm to be significantly ($p \leq 0.01$) different from the length in depths 20 - 30 and 40 - 50 cm (Table 3.6a). Roots length in depths 20 - 30 cm and 40 - 50 cm were equally distributed. Maize root length sampled at 45 cm from the hedge was statistically significantly less than those at remaining distances. The latter distances had statistically equal root lengths. At 89 DAS, mean root length comparison revealed that distance 90 cm and distance 180 cm had a root distribution that differed statistically non significantly but, distance 90 cm and distance 135 cm from the hedgerow were statistically different in maize root length distribution. The effect of distance and depth of the distribution of maize root length during this first season is illustrated in Tables 3.6a and 3.6b. At 32 and 46 DAS, there was no statistically significant distribution of maize root length in neither distance nor depth positions (Table 3.5a). Therefore, further analysis of the tables showing the effect of distance and depth at such sampling dates were not necessary.

In the second crop season, distance 45 cm was again noted to exhibit a different distribution of maize roots from the rest of the other distances. The mean root length at 90 cm was significantly different from

	Mean Root Length in cm.					
Date	Depth interval (cm)	Distance from the cassia hedgerow (cm) 45	90	135	180	$Av.^{r}$
59 DAS	0 - 10	1.83	2.14	2.04	1.86	1.97
	20 - 30	1.20	1.69	1.86	1.35	1.53
	40 - 50	0.51	1.91	1.78	1.94	1.54
	$Av.^{c}$	1.18	1.91	1.90	1.72	

$LSD_{.01}$ for Depth (row) averages, i.e. $Av.^{r}$ = 0.43.

$LSD_{.05}$ for Distance(column) averages, i.e. $Av.^{c}$= 0.50

Table 3.6a. Effects of Different Distances from the Hedgerow and Different Soil Depth intervals from the Soil Surface on Root Length of Maize shown at 59 DAS in 1st season (mean of 3 replications).

	Mean Root Length in cm.					
Date	Depth interval (cm)	Distance from the cassia hedgerow (cm) 45	90	135	180	$Av.^{r}$
89 DAS	0 - 10	1.50	1.80	1.45	1.90	1.66
	20 - 30	1.60	1.92	1.33	1.69	1.64
	40 - 50	1.69	2.04	1.31	1.68	1.68
	$Av.^{c}$	1.60	1.92	1.36	1.76	

$LSD_{.05}$ for Distance (column) averages, i.e. $Av.^{c}$ = 0.32

$Av.^{r}$(Depth) = non-significant.

Table 3.6b. Effects of Different Distances from the Hedgerow and Different Soil Depth intervals from the Soil Surface on Root Length of Maize shown at 89 DAS in 1st season (mean of 3 replications).

maize root length at distance 180 cm on 84 and 98 DAS of maize. For root length at 135 cm the difference with 180cm was statistically significant at 98 DAS. Whenever depth affected the distribution of maize root lengths, it was depth 0 - 10 cm and 40 - 50 cm which were consistently significantly different. Depths 0 - 10cm and 20 - 30 cm showed different root distribution that were statistically not significant although the latter was always lower. Effect of distance and depth on the distribution of maize root length during the second crop season is shown in tables 3.7a to 3.7e. In all cases more of maize roots were found in the top soil space 0 - 10 cm than in either 20 - 30 cm or 40 - 50 cm soil depths at any distance.

Distributions of maize and cassia root lengths at vegetative, reproductive and maturity stages of growth during the two seasons are shown in figures 3.2a to 3.2d and 3.3a to 3.3d respectively. A general trend showed that there was little overlap between the roots of cassia and maize at depth 0 - 10 cm (L_1). However, relatively more overlap of the root systems of the two plants was observed between 20 - 30 (L_2) and 40 - 50 cm (L_3) soil layers. The apparent greater root overlap at depths 20 - 30 and 40 -50 cm was consistent throughout the two crop seasons, with little exception, largely due to the little amounts of cassia roots in the top layer.

		Mean Root Length in cm.				
Date	Depth interval (cm)	Distance from the cassia hedgerow (cm) 45	90	135	180	Av.^{r}
36 DAS	0 - 10	0.31	1.26	1.42	1.57	1.14
	20 - 30	0.20	1.26	1.00	0.89	0.84
	40 - 50	0.42	0.37	0.63	0.63	0.51
	Av.^{c}	0.31	0.96	1.02	1.03	

$LSD_{.01}$ for Depth (row) averages, i.e. Av.^{r} = 0.50

$LSD_{.05}$ for Distance(column) averages, i.e. Av.^{c} = 0.42

Table 3.7a. Effects of Different Distances from the Hedgerow and Different Soil Depth intervals from the Soil Surface on Root Length of Maize shown at 36 DAS in 2nd season (mean of 3 replications).

		Mean Root Length in cm.				
Date	Depth interval (cm)	Distance from the cassia hedgerow (cm) 45	90	135	180	Av.^{r}
56 DAS	0 - 10	1.52	2.25	2.28	1.82	1.97
	20 - 30	1.27	1.94	1.74	1.93	1.72
	40 - 50	0.74	2.07	1.68	1.90	1.90
	Av.^{c}	1.18	2.09	1.90	1.88	

$LSD_{.05}$ for Distance (column) averages, i.e. Av.^{c} = 0.47

Av.^{r}(Depth) = non-significant.

Table 3.7b. Effects of Different Distances from the Hedgerow and Different Soil Depth intervals from the Soil Surface on Root Length of Maize shown at 56 DAS in 2nd season (mean of 3 replications).

		Mean Root Length in cm.				
Date	Depth interval (cm)	Distance from the cassia hedgerow (cm) 45	90	135	180	Av.^{r}
70 DAS	0 - 10	1.73	1.35	1.85	2.17	1.76
	20 - 30	1.35	1.66	1.60	1.58	1.55
	40 - 50	0.74	1.43	1.21	1.65	1.25
	Av.^{c}	1.27	1.48	1.55	1.80	

$LSD_{.05}$ for Depth (row) averages,i.e. Av.^{r} = 0.35

Av.^{c}(Distance) = non-significant.

Table 3.7c. Effects of Different Distances from the Hedgerow and Different Soil Depth intervals from the Soil Surface on Root Length of Maize shown at 70 DAS in 2nd season (mean of 3 replications).

		Mean Root Length in cm.				
Date	Depth interval (cm)	Distance from the cassia hedgerow (cm) 45	90	135	180	Av.^{r}
84 DAS	0 - 10	1.44	1.90	1.80	2.04	1.80
	20 - 30	0.90	1.32	1.97	1.96	1.54
	40 - 50	1.16	1.42	1.62	1.68	1.47
	Av.^{c}	1.17	1.55	1.80	1.89	

$LSD_{.05}$ for Distance(column) averages, i.e.^{c} = 0.33

Av.^{r}(Depth) = non-significant.

Table 3.7d. Effects of Different Distances from the Hedgerow and Different Soil Depth intervals from the Soil Surface on Root Length of Maize shown at 84 DAS in 2nd season (mean of 3 replications).

		Mean Root Length in cm.				
Date	Depth interval (cm)	Distance from the cassia hedgerow (cm) 45	90	135	180	Av.^{r}
98 DAS	0 - 10	0.90	1.38	1.35	2.13	1.44
	20 - 30	0.74	1.31	1.45	1.75	1.32
	40 - 50	0.91	0.88	1.29	1.74	1.21
	Av.^{c}	0.85	1.19	1.36	1.87	

$LSD_{.05}$ for Distance(column) averages, i.e. Av.^{c}= 0.48

Av.^{r}(Depth) = non-significant.

Table 3.7e. Effects of Different Distances from the Hedgerow and Different Soil Depth intervals from the Soil Surface on Root Length of Maize shown at 98 DAS in 2nd season (mean of 3 replications).

3.4 Maize yield

Analysis of the first crop yield showed that some statistically significant differences existed between maize grain yields from the three rows R_{1AF}, R_{2AF} and R_{3AF} ($p \leq 0.05$). A comparison of the mean grain yields revealed that the mean grain weights from R_{1AF} and R_{2AF} were the only significantly different pairs in the agroforestry systems. R_{1AF} performed better than R_{3AF}, and R_{3AF} yielded more than R_{2AF}.

The grain yield of second harvest; from the three rows, was only significantly different between R_{1AF} and R_{3AF} ($p \leq 0.05$), R_{1AF} still yielded more grains and cobs than the other rows. Maize yield from the other three corresponding maize rows in the non agroforestry system plots (R_{1NAF}, R_{2NAF} and R_{3NAF}) were comparatively lower during the two crop seasons. Mean grain and cob weight per plant in the rows for the two seasons are summarised in table 3.8a. Results of mean comparisons are presented in Table 3.8b. Mean maize yield from the group rows in the agroforestry was consistently different ($p \leq 0.05$) from the corresponding group of rows in the non agroforestry system.

Row	1st crop season 1989/90. Mean grain wt.(g).	1st crop season 1989/90. Mean cob wt. (g).	2nd crop season 1990. Mean grain wt. (g).	2nd crop season 1990. Mean cob wt. (g).
R_{1AF}	94.37	107.64	84.95	92.51
R_{2AF}	79.79	91.48	73.45	89.01
R_{3AF}	86.29	103.96	67.81	78.51
R_{1NAF}	70.20	80.70	55.47	63.17
R_{2NAF}	60.07	74.24	52.68	60.40
R_{3NAF}	66.80	77.62	58.82	67.13

Table 3.8a. Maize yield per plant (grain and cob) in the rows (g) for the AF-system and NAF-system.

	Differences of grain yield of maize plant in a row (g) in the agroforestry system.			
Rows	1st crop season Diff. in grain wt.	1st crop season $LSD_{.05}$	2nd crop season Diff. grain wt.	2nd crop season $LSD_{.05}$
$R_{1AF}-R_{2AF}$	14.58	11.35	11.50	12.61
$R1_{AF}-R_{3AF}$	8.07	11.19	17.14	12.45
$R_{2AF}-R_{3AF}$	6.51	11.26	5.64	12.60

Table 3.8b. Comparisons for maize yields in different rows (grain).

CHAPTER IV

4 DISCUSSION AND CONCLUSION

4.1 Methodology

Design of the experiment presented a problem. It was not practically possible to completely randomise levels of depth and distance factors. The position of the cassia hedgerow remained fixed. The difficulty in randomising some factors of interest such as distance from the hedgerow in agroforestry research, and the accompanying problematic statistics, are well known (Burley, 1983; ICRAF, 1990). In fact, the suitability of applying common agricultural experimental Complete Block Designs (CBD) such as Randomised Complete Block Design (RCB) and Completely Randomised Design (CRD) for agroforestry experiments is questionable (Huxley and Mead, 1988). Neither can the designs be successfully applied in plant row spacing experiments (Pearce, 1985). A solution to the problem of design in inter-crop and agroforestry experiments seems to lie in the use of systematic spacing designs (Huxley and Maingu, 1978; Burley, 1983). Such designs would introduce randomisation at higher levels and make statistical tests more meaningful (Nelder, 1962). With systematic designs, randomisation is achieved by repeating the set of systematically arranged treatments at different locations within the experiment. Fortunately, this was also done for this study. At each sampling time, all the sets of treatments were repeatedly sampled at three different sites within the experimental units. Sampling was repeated at an interval of two weeks, five times in each crop season. Furthermore, the precision of the design was increased by imposing a factorial experiment (Burley, 1983).

However, one of the limitations of systematic designs, even though their use in designing agroforestry experiments is suggested, is that they do not cater for carrying out tests of significance. Hence it is not possible to draw precise conclusions from results of systematic experimental designs. In other words, it is not possible to express the findings in terms of probability level as is often done with the common agricultural designs. The other limitation with systematic designs is that at present they are less better understood than the other designs. More research is still required in the area of inter-crop experimental design with special reference to systematic spacing or ecological approach designs (Huxley and Mead, 1988). In the absence of a well established systematic spacing design, other designs may still be used. Very significant F-ratios with $p \leq 0.001$ (Tables 3.2a and 3.2b) nevertheless proved that the design used was not a serious limitation. Pictorial representation of the data also depicted clearly the effect of distance and depth on the distribution of cassia and maize root lengths.

Three characteristics distinguished in table 3.1c, namely the presence of root tips, root hairs and thinner root diameter, meant that roots classified as less than or equal to 0.5 mm in diameter were young and hence most functional in terms of water and nutrient absorption. Young unsuberised roots are known to absorb water and nutrients more rapidly than old suberised roots (Russell, 1977; Kramer, 1983). Rapid water and nutrient absorption occur in the unsuberised root region behind the root tips. All the roots with the diameter less than or equal to 0.5 mm observed possessed the unsuberised region behind the root tip, hence were most likely actively involved in absorption (Esau, 1965; Fahn, 1974). Presence of root hairs was important for the uptake of relatively immobile elements such as phosphate, by maintaining extensive contact between the roots and soil (Kramer, 1983). Cassia being a perennial plant, its roots greater than 0.5 but less than or equal to 1.5 mm in diameter could still effectively absorb water and nutrients (Kramer, 1983).

Tennant's (1975) grid method estimated the root length of cassia and maize accurately, as was determined with vernier microscope measurements (see section 3.2).

4.2 Rainfall and evaporation during the crop seasons

Total amounts of rainfall were 469.2 mm and 630.3 mm during the first and second crop seasons respectively. October and April had the highest rainfall amounts (Appendices IIIa and IIIb). Total evaporations of the class A pan were 677 mm and 574.6 mm during the first and second crop seasons respectively. Evaporation was highest in October and March during the two crop seasons. Monthly evaporation average exceeded monthly rainfall average throughout the first season but only in the last two months of the second season.

The rainfall was adequate for successful growth of Katumani composite B maize, which requires a minimum of 200 mm of fairly distributed rainfall for each crop season (Mwendwa, 1983). The rainfall distribution was favourable to the growth of the maize. This was because above rainfall requirements for this cultivar was distributed during the vegetative and reproductive stages (approximately the first 60 DAS) during each crop season as seen in appendix II. Decrease in the intensity of rainfall after these growth periods normally does not lead to yield reduction. Short rains came late October after a drought. A lot of water had evaporated during the first 27 days, while the rains started at the end of the month, coinciding with planting time (Table 2.1 and appendix II). Therefore, the drought which prevailed prior to planting had no bearing on maize yield.

4.3 Distribution of cassia and maize root length

Depth apparently had an overriding effect on the distribution of cassia root length in space and time. Proximity to the cassia hedgerow had no statistically significant influence on the distribution of cassia root length in space and time within the distance of 180cm from the cassia row. The non-significant effect of proximity to the hedgerow is evidenced by the fact that the F-ratios in tables of analysis of variances showed that distances gave no significance throughout the two crop seasons (Tables 3.2a and 3.2b). Depth of soil layer influenced the distribution of cassia root length in that the density in the top 0 - 10 cm soil layer was comparatively sparser than the distribution within other depths (Tables 3.3a - 3.4e) This pattern of distribution obtained by the auger method, correlated with the results of cassia root distribution studies of marking the root distribution on the profile wall (Mungai, in-prep.). Similar patterns of cassia root distribution have been reported (Balasubramanian and Sekayange, 1986). Kang *et al.* (1981) also noted that *Luecaena leucocephala* has few roots distributed in the top 0 - 20 cm soil space. Probably cassia grows a lot of roots in the deeper wetter soil horizons as an inherent strategy to avoid water stress.

Age and stage of development of maize, depth of soil layer and relative position to the maize row were found to influence the distribution of maize root length in space and time. In most cases, or taken on average, more maize root length was found in the upper 0 - 10 cm layer than in either soil depths 20 - 30 or 40 -50 cm (Tables 3.6a - 3.7e). It has been reported that maize root length is abundantly distributed in the top soil space (Follet *et al.*, 1974; Aina and Fapohunda, 1986; Anderson, 1987 Junying *et al.*, 1988).

At 89 and from 84 DAS onwards, in first and second crop season respectively, the distribution of maize root length was no longer affected by soil depth layer (Table 3.5a and 3.5b). Equal distribution of maize root length within the three soil layers at those later stages may be explained by senescence of roots at the top 0 - 10 cm soil layer being balanced by an increase of maize roots in the remaining two depths (Mengel and Barber, 1974a). Incidentally, soil layers 20 - 30 and 40 - 50 cm were wetter than 0 - 10 cm layer from 55 DAS maize during the two crop seasons, as shown by soil moisture content data (Netondo, in-prep.). Hence at these stages moist soil conditions stimulated growth of young roots. Growth of maize roots at the top may have been stunted not only because the roots were old, but also due to the drying up of the soil down the profile.

In addition to soil depth, age and stage of development of the maize plant, relative position to the maize row also had an influence on the distribution of maize root length. For instance, comparatively less maize root length was found at a distance 45 cm from the cassia hedgerow than at distance 90 cm and distance 180 cm respectively from the cassia hedgerow (Tables 3.6a to 3.7e). Distance 45 cm was boarded by cassia hedgerow on one side and only one maize row on the other side. However, distances 90 cm and 180 cm had more roots because they were located within the maize rows (Figure 2.1). Distance 135 cm from the cassia hedgerow, even though not located within maize rows, had more maize roots than distance 45 cm because of its positions between two maize rows. The general trend in the distribution of mean root length at the four positions is shown in tables 3.6a to 3.7e. As seen from the tables, distance 45 cm had the least mean maize root length throughout the two crop season except at 89 DAS of the first crop and a few single -layer exceptions. Unequal rates of senescence of the maize roots at different positions may have resulted in the observed departure from the trend. Anderson (1987) also observed that the distribution of maize root length was influenced by relative position to the maize row.

4.4 Assessment of competition for water between cassia and maize roots

Under the conditions of the two seasons during which the study was carried out, cassia and maize roots very likely did not compete for water since the rainfall was above the average required by Katumani maize (Section 4.2, Appendices IIIa -IIIb). The rainfall was well distributed with the above rainfall requirement received during the vegetative and reproductive stages (Appendix II). In addition to the absence of water stress at the most water sensitive growth stage, the Katumani maize also benefited from the increased soil moisture status due to application of mulch. Nadar (1984) reported that the soil moisture condition after the rains stop or decrease from the third month after planting is important for grain filling stage in Katumani maize, grown in Machakos district. Katumani Composite B can produce substantial yields with as less as 200 mm of fairly distributed rainfall in a season (Mwendwa, 1983). This conclusion of no competition for water is supported by results of transpiration rates, stomatal conductance and leaf-air temperature difference of cassia and maize in those seasons (Netondo, in-prep.). If cassia was to compete with maize for water and overlapping situations would not have been known, maize in the rows next to the cassia hedgerow would in the first instance have been expected to suffer from water stress more than maize plants in the rows at the middle of the alley. This kind of differences could have been shown by different transpiration rates, stomatal conductance, leaf - air temperature differences between maize plants next to the cassia hedgerow and maize plants in the rows in the middle of the alleys. However, analysis of variance showed these plants physiological parameters in maize plants next to the cassia plant were not significantly different from that of maize in the middle of the alleys (Netondo, in-prep.).

Soil layer 0 - 10 cm (L_1) was almost exclusively occupied by maize roots. However, there was overlapping of the roots at soil depths 20 - 30 cm (L_2) and 40 - 50 cm (L_3) at greater depths (Figs. 3.2a -3.2d and 3.3a - 3.3d). Overlapping of roots would possibly have led to competition for water between cassia and maize, had the rainfall amount been below the average requirement for successful growth of Katumani maize variety (Mungai, in-prep). But there was in the two seasons during which the study was carried out no significant difference in the sufficient lateral soil moisture perpendicular to the cassia hedgerow (Netondo, in-prep.). However, a general, statistically not significant, pattern showed that percentage moisture content was higher near the cassia hedgerow than at distances further away from the cassia hedgerow. This may only support the argument used below for nutrients, that if competition between the cassia and maize for water would have occurred during the experimental period, this would have been higher at larger distances from the hedge, due to root overlapping differences.

4.5 Assessment of competition for nutrients, between cassia and maize roots, and maize yield

Overlapping of the roots and yield differences in maize suggest more competition for nutrients away from the hedge at greater depths. It was only at positions D_1L_1, D_2L_1, D_3L_1 and D_4L_1 that with only unimportant exceptions maize roots were always in the advantage over cassia in terms of greater root length densities (Figures 3.2a to 3.3d). So maize root length density was generally greater than cassia root length density at all distances from the hedgerow in combinations with depth 0 - 10 cm. However, there was a serious over lap of the roots of cassia and maize at all distances from the hedgerow in combination with the other depths 20 - 30 and 40 - 50 cm (Figures 3.2a to 3.3d). This spatial and temporal overlap was at the disadvantage of maize when cassia root length density was greater or near equal and both were relatively large. There are quite many of these cases in stages important to the ultimate yields, and most at distances D_3 and D_4, both for L_2 and L_3 (figures 3.2b, 3.2c, 3.3a and 3.3b).

An overlap of cassia and maize roots in the 20 - 50 cm soil space, especially at distances 135 and 180 cm away from the cassia hedge (feeding rhizosphere of maize plants in the middle row position) may have caused maize plants suffer somewhat more from nutrients deficiencies. This could possibly partly explain the relatively low maize grain yield in the middle row in the agroforestry in comparison to the rows bordering the cassia hedge (Tables 3.8a and 3.8b). Cassia roots tips are probably situated in the range 135 - 180 cm away from the hedge. This could further support the explanation of competition as reflected in reduced maize yields of the middle row. Therefore, even though the distribution of cassia root length was statistically the same at all distances from the hedge, an explanation of competition in the middle maize row could be more to do with where root tips (quality) are located as well as root length (quantity) of roots.

This reasoning of nutrient competition is strengthened by Mwangi's (1990) observation that nutrient requirements for maximum yields remain very much low irrespective of the quantity of mulch applied. Nevertheless, large parts of available nutrients come from the fertile top (0 - 10 cm) soil space, which is predominantly occupied by the active roots of maize. Since uptake of most minerals in maize takes place during the first half of the growth period

(Boyer and McPherson, 1975; cited by Mwangi, 1990), it may be expected that there was already a marked reduction in the anyway limited nutrient flux in corn 70 days after planting (DAP) (Mengel and Barber, 1974b). Katumani composite B being an early maturing cultivar, probably had effectively reduced absorbing nutrients by 70 DAS, which also covers the largest part of cassia mulch decomposition (Mugendi, 1990). This early absorption of nutrients by maize from the top soil space coincided with conducive environments of negligible or absent competition from cassia roots and non-limiting soil moisture. However, overlapping at other depths before 70 DAS shows a competition gradient remaining in favour of the rows closer to the hedge.

Mungai (in-prep.) who carried out experiments on the same site argues that the higher average temperatures near the surface of the middle row, R_{2AF}, could be a possible additional cause for these yield differences. Lower temperatures at the soil surface may possibly lead to reduced evaporation from the soil surface and reduced temperatures of the maize growing point. This may result in improved soil moisture status near the hedges and nearer to optimum growth temperatures in early stages and consequently be manifested in higher maize grain yield of plants next to the hedge. Yamoah *et al.* (1986) also observed that in their experimental plots, without N applications and prunings from cassia removed instead of being incorporated as mulch, maize plants near the cassia hedgerows performed better than those in the middle of the alleys. They explained that this was in their case probably due to the accumulation of litter, which was observed to be greater near the hedgerows than in the middle of the alleys, and consequent improvement in fertility near the hedgerows. In the plots with N application and prunings returned to serve as mulch, maize in the middle of the alleys had a double advantage in terms of improved fertility and undisturbed interception of incident light. Therefore, in this case of limiting nutrients, difference in maize grain yield with respect to distance from the cassia hedgerows may probably be a function of improved soil moisture (see end of 4.4) and fertility status near the hedges, due to differences in competition, leading to a somewhat better performance of maize rows next to the hedges. Maize plants in the middle rows are situated further from the hedges and do not gain from all of the improved micro-climate near the hedges, such as with respect to temperature, and consequently yielded possibly less grains due to these effects as well.

During the second season, maize yield in row R_{1AF}, as in the previous crop season, was still the highest among the three rows in the agroforestry system plots

(Table 3.8a). However, maize grain yield from row R_{3AF} was the least, but not significantly less than yield in row R_{2AF} (Table 3.8b), but significantly less than that of row R_{1AF}. Thus, there was a more or less similar trend of maize yield during the two seasons, and what applied to the first season appears to apply to the average of both seasons (Table 3.8b). Maize grain yield from rows R_{2AF} and R_{3AF} were statistically the same as was in the previous season (Table 3.8b). Maize yields per plant in a row from the other three rows in the NAF systems plots were comparatively lower than the yield from the corresponding rows in the AF system plots during the two crop seasons (Table 3.8a). Group mean comparisons showed that maize yield in the NAF system was less than maize yield in the AF systems. The difference in maize yield between AF and NAF plots was possibly for a small part due to soil moisture retention and plant moisture status, but must have been especially due to fertility differences (Netondo, in-prep.): whereas AF system plots were mulched with cassia prunings, NAF system plots were not.

4.6 Limitations in the experiment

There was a chance that a few rootlets of cassia and maize remained in the soil residue at the bottom of pails during the root washing operation, despite the great care taken to recover all the roots from soil suspension. The thin pores of the cheese cloths used for sieving the roots ensured that no roots passed through, but there was a chance that some very fine roots which were invisible to the naked eye could have been left on the sieve cloth. For the same reason of invisibility, roots could possibly not be separated completely from the debris. An error due to dividing roots by eye into different root diameter classes may have caused either an over-estimation, or under-estimation of the root lengths in various root diameter classes used. An over-estimation could have resulted when roots with diameters greater than 1.5 mm were mistakenly grouped with roots with diameters less than or equal to 1.5 mm. Similarly, an under estimation of root length could have resulted if roots with diameter classes less than or equal to 1.5 mm were omitted. However, precaution against biased root classification was taken by counter checking root diameters of some roots already classified by eye, by measuring with a vernier microscope. Roots were randomly selected in the course of root diameter classification and their diameters measured to regularly standardise the eye classification procedure. Unfortunately, accuracy of the method of dividing roots into different root diameter classes by eye could not be calculated.

The coefficient of variations (*cv*) in the analyses of variances of root length were high, especially for maize root lengths sampled at the start of the season (Tables 3.2a, 3.5a and 3.5b). Since *cv* is an index of reliability of an experiment, the higher the *cv*-values, the lower is the reliability of an experiment and vice versa (Gomez and Gomez, 1984). However, a comparison between *cv*-values in this experiment and values reported in similar experiments show that the former values are lower. For instance, Tardieu (1988b) reported *cv*-values of 80 - 90 and 125%, in the analysis of variance of maize root lengths sampled from non compacted and compacted soils respectively. Coefficients of variation also depend on soil depth from which the roots are sampled. For example, *cv* of 45 and 51% were calculated on maize root density data from roots sampled from soil layers, 0 - 30 and 30 - 60 cm soil layers respectively (Van Noordjwik *et al.*, 1985).

Higher *cv* of maize root lengths early in the season may have been due to non-uniformity in the germination of maize seedlings. Non-uniformity in the germination of maize seedlings resulted in isolated maize plants at early stages. Therefore, the heterogeneous distribution of the maize root lengths in the soil layers was reflected in high *cv*-values. The same explanation was also offered by Logsdon *et al.* (1987) and Pages *et al.* (1989). Other factors, such as soil texture heterogeneity and sampling positions may have also contributed to high *cv*-values calculated. Sampling positions were probably the main causes of high *cv*-values. Some maize roots were sampled from soil positions between two plants in a row. Other samples were taken from the inter-row spaces and from the space between cassia hedgerow and maize row. Also inherent heterogeneity of the plant root systems may have contributed to higher *cv*-values of cassia and maize root lengths. However, the results of this study were concluded to be reliable, taking into account that the *cv*-values (Tables 3.2a, 3.2b, 3.5a and 3.5b) were comparatively lower than the ones reported earlier based on similar calculations.

It was very difficult to either drill in the auger or remove soil cores when soil dried up. For instance, no sampling was done between 59 and 89 days after sowing of maize (DAS) of the first crop because the auger broke. There was a tremendous friction between the walls of bored holes and the auger tube despite the larger diameter of the latter.

4.7 CONCLUSIONS

Cassia siamea Lam. is apparently not a suitable alley tree/shrub to be intercropped with non artificially fertilized maize (*Zea mays* L. cv. Katumani composite B) under semi-arid conditions. Differences in grain yields observed between rows could be shown to be partly due to differences in root overlappings. Competition for water between maize and cassia roots was not observed during the study period, because rainfall amounts in the seasons was above the average requirement for the maize (Mwendwa, 1983). However, under limiting water conditions typical of semi-arid zones, cassia would out-compete maize for water and nutrients because of the overlap of the active roots of the two plants in space and time. Although maize and cassia roots are for a larger part separated in space and time in the top 0 - 10 cm soil space, under conditions of water stress maize would heavily rely on its active roots distributed within soil depths layers below 10 cm. Unfortunately, the observed overlap of the active roots would likely lead to serious competition for water and nutrients, and consequently reduce maize yield in the cassia alleys.

The choice of a suitable alley tree/shrub should be based on trees that also fix nitrogen and have their roots in fully separated horizons. In addition maize yields in AF should be higher to compensate for the area lost due to the presence of cassia hedgerows. These conditions were not, apparently, satisfied by *cassia siamea* in these experiments. Thus, precaution should be taken in recommending an association of this variety of *cassia siamea* and *Zea mays* L. (cv. Katumani composite B) for alley farming systems under semi-arid conditions.

4.8 Suggestions

Due to time limitation as is the case in most M.Sc. research thesis, the work reported in this text in not exhaustive and it is important that for further research in cassia and other root competition studies, the following be investigated:

a). Ways of making trees grow their fine (active) roots from below 30 cm downwards and the subsequent effects on the yields of maize rows. Lopping of cassia at heights greater than 50 cm should be tried out.

b). Effects of increasing the width of alley on the yield of maize, vis-a-vis root competition and amounts of mulch applications.

c). A more detailed study of nutrient and cassia root distribution across the alley in order to determine a lateral distance of optimal root activity.

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APPENDIX I

MEAN ROOT LENGTH DENSITY AND MEAN ROOT LENGTH FOR MAIZE

FIRST CROP SEASON 1989/1990

POSITION	32 DAS		46 DAS		59 DAS		89 DAS	
	DENSITY	LENGTH	DENSITY	LENGTH	DENSITY	LENGTH	DENSITY	LENGTH
D1L1	0.03	10.77	0.12	46.16	0.18	68.85	0.08	31.93
D1L2	0.10	36.54	0.07	25.39	0.07	25.77	0.10	39.62
D1L3	0.03	10.77	0.05	18.46	0.01	4.23	0.13	48.47
D2L1	0.05	20.00	0.20	76.93	0.41	156.94	0.17	64.24
D2L2	0.05	17.31	0.07	26.16	0.16	59.62	0.32	122.70
D2L3	0.01	4.23	0.12	44.23	0.21	81.93	0.48	182.71
D3L1	0.01	4.62	0.18	69.24	0.28	107.32	0.09	33.85
D3L2	0.00	0.77	0.15	56.93	0.19	71.93	0.10	37.70
D3L3	0.01	3.08	0.06	24.23	0.22	84.24	0.06	21.93
D4L1	0.05	18.85	0.14	55.00	0.19	71.16	0.23	88.85
D4L2	0.02	6.54	0.14	54.24	0.14	53.85	0.18	69.62
D4L3	0.01	4.62	0.08	31.54	0.27	104.24	0.15	57.31

SECOND CROP SEASON 1990 .

	36 DAS		56 DAS		70 DAS		89 DAS		98 DAS	
POSITION	DENSITY	LENGTH	DENSITY	LENGTH	DENSITY	LENGTH	DENSITY	LENGTH	DENSITY	LENGTH
D1L1	0.01	2.31	0.22	85.78	0.14	54.62	0.08	31.93	0.07	26.08
D1L2	0.00	0.77	0.13	49.24	0.08	31.16	0.00	1.15	0.02	8.85
D1L3	0.01	2.69	0.03	11.15	0.02	8.08	0.36	138.47	0.03	11.54
D2L1	0.06	23.85	0.49	190.02	0.08	31.16	0.24	90.39	0.07	27.31
D2L2	0.06	24.62	0.26	100.39	0.17	64.62	0.06	23.08	0.06	21.54
D2L3	0.01	4.23	0.41	157.32	0.09	33.08	0.24	93.09	0.06	22.69
D3L1	0.09	33.08	0.51	195.79	0.19	73.47	0.19	71.16	0.06	23.46
D3L2	0.03	10.39	0.19	71.54	0.11	40.39	0.25	94.62	0.04	16.54
D3L3	0.01	5.39	0.17	64.24	0.04	16.54	0.13	51.16	0.05	19.62
D4L1	0.15	55.77	0.20	75.01	0.37	142.71	0.42	163.09	0.37	143.47
D4L2	0.04	13.85	0.24	93.85	0.16	59.62	0.26	99.62	0.17	64.62
D4L3	0.01	5.39	0.24	93.47	0.16	62.70	0.13	49.62	0.15	56.54

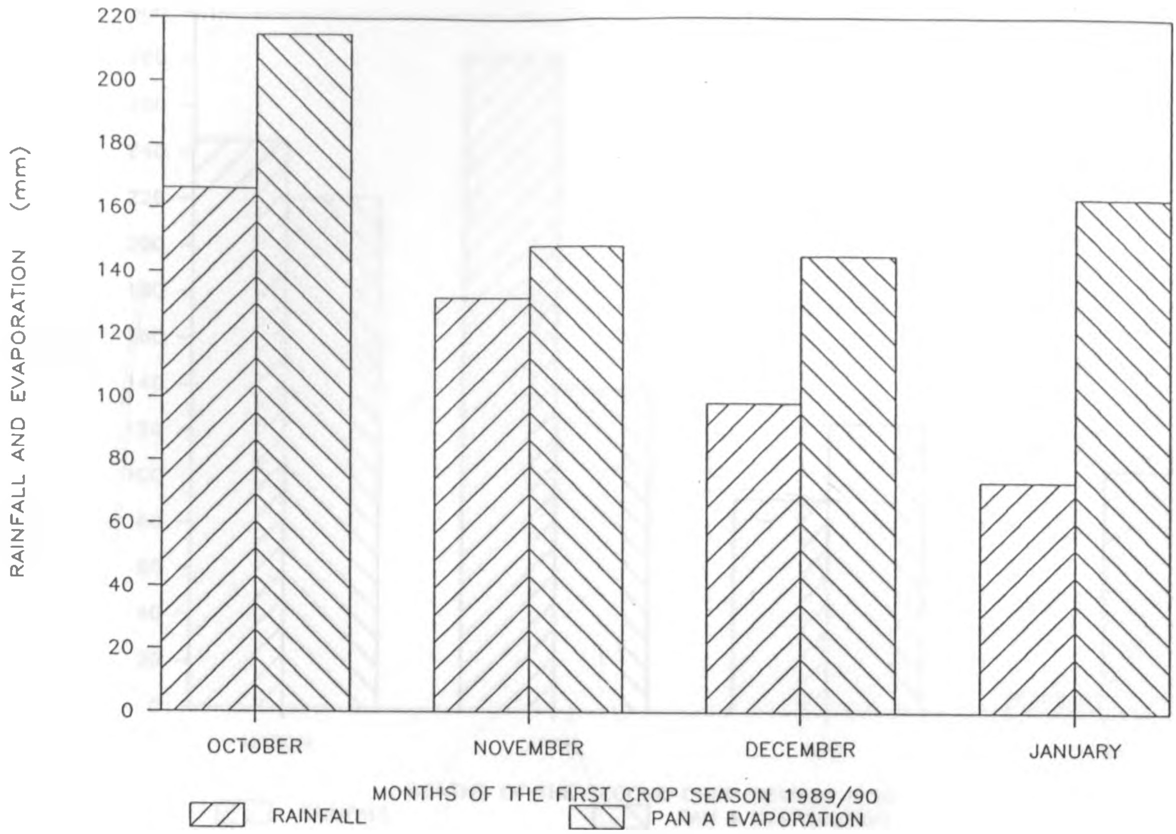
APPENDIX II

10 - DAY TOTAL RAINFALL AND CLASS A PAN EVAPORATION (MM).
DURING THE FIRST CROP AND SECOND CROP SEASONS.

MONTH	RAINFALL	EVAPORATOIN	MONTH	RAINFALL	EVAPORATOIN
OCTOBER	28	71	MARCH	163.8	108
	0	72		51	56
	138.3	72		30.8	57.2
NOVEMBER	22.5	59	APRIL	143	45
	29.8	44		113.8	48
	79	45		26.8	46
DECEMBER	68	41	MAY	78.5	55
	11.3	50		8.8	36
	19	53.9		4.5	34.1
JANUARY	60	49	JUNE	0	28
	1.3	58		0	37
	12	56.1		9.3	40.7

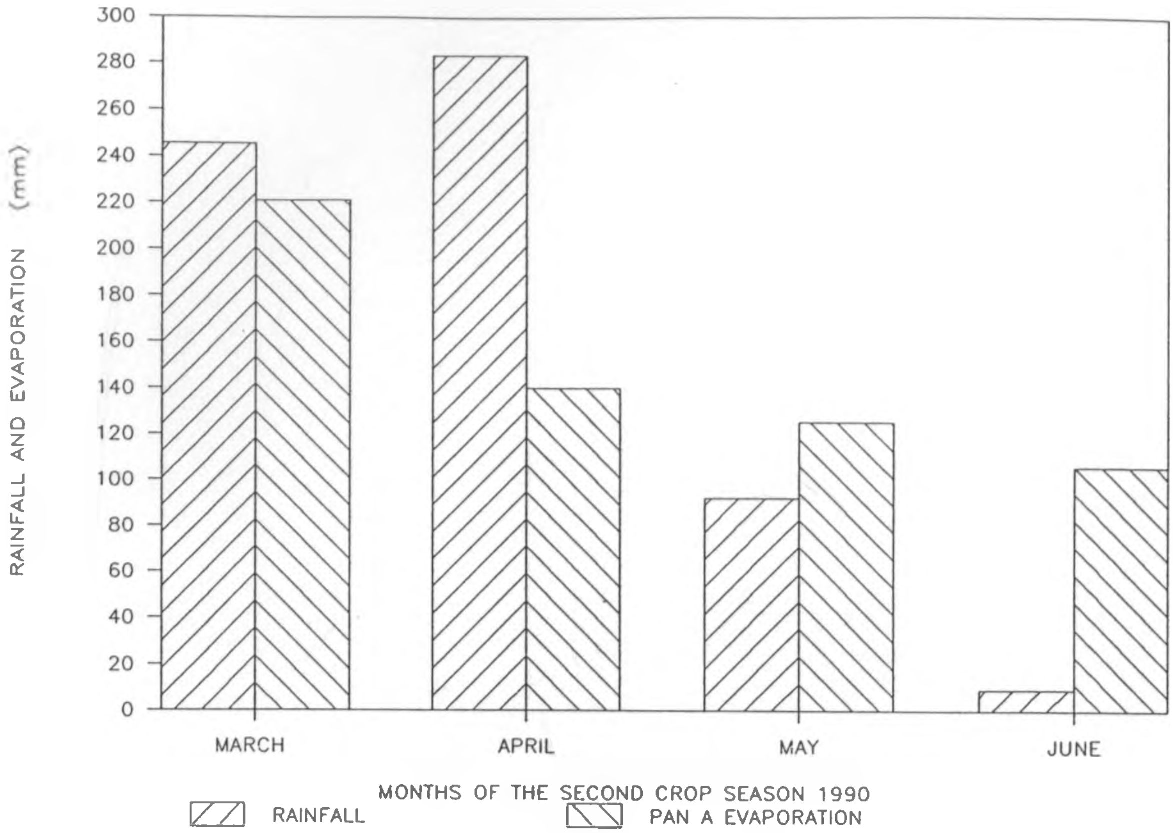
SOURCE: Adopted from ICRAF, Nairobi, Kenya. Machakos Field Station, Weather Bulletins for 1989-1990.

APPENDIX IIIa



Monthly rainfall and evaporation (mm) during the first crop season, 1989/1990

APPENDIX IIIb



Monthly rainfall and evaporation (mm) during the second crop season, 1990