BIOMASS, VOLUME AND NUTRIENT ACCUMULATION BY SIX-YEAR OLD *ACACIA ALBIDA* UNDER AGROFORESTRY AT MAFIGA, MOROGORO, TANZANIA

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DECLARATION

I, JOHN OKORIO, do hereby declare to the Senate of the Sokoine University of Agriculture that this dissertation is my own original work and has never been submitted for a degree award in any other University.

John Okorio

Date : 13/6/1988

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DEDICATION

"To my beloved parents whose constant inspirations made these all possible".

ABSTRACT

The study was conducted to evaluate the suitability of *Acacia albida* for fuelwood and fodder production using agroforestry in a semi-humid environment at Mafiga, Morogoro. The trial was planted in February, 1980 and arranged in a split - plot design with three main plots:

1) *Acacia* intercropped with maize,
2) *Acacia* intercropped with beans, and
3) *Acacia* monoculture cleanweeded.

Each main plot included four tree spacing subplots, no trees, trees planted at 4 x 4 m, 5 x 5 m and 6 x 6 m. The experiment had four replications covering an area of 4.32 ha.

In March 1986, thirty trees representing all the diameter classes in the trial were harvested and used to determine volume, biomass and nutrient content. In addition, eight root systems were excavated to determine root distribution, biomass and nutrient content. Seventy-two soil samples were collected from the different treatments and analysed for macro nutrients. Data on height, diameter growth and food crop yields (maize and beans) for the past six years was compiled from past records.

At the age of six years, the mean height and DBH for *Acacia albida* in the whole trial was 8.41 m and 10.7 cm respectively. Height growth was neither affected by intercropping nor tree spacing, but.diameter growth was affected by tree spacing.

Volume production varied from 9.9 to 24.9 m^3 ha^{-1} and total biomass values ranged from 19.6 to 43.1 tons ha^{-1} . Intercropping did not significantly ($p < 0.05$) influence the production of volume and biomass. Spacing, however, significantly ($p < 0.05$) influenced both volume and biomass production with higher volume and biomass under lower spacing and the lowest volume and biomass under the highest spacing.

Nutrient concentrations were high and comparable to other tree legumes. Generally, nutrient concentrations were highest in the foliage and brushwood, and least in the stem, with concentrations in the roots and branches being intermediate.

Except for N, the nutrient accumulations were highest in the stem, brushwood and roots, with the least amounts found in the foliage and branches. The highest inventory of N was concentrated in the foliage. The total nutrient accumulation in the aerial biomass at the closest spacing (4 x 4 m) in Kg ha^{-1} were 262.9, N; 39.4 P; 156.7, K; 97.4, Ca; 57.6, Mg and 73.8, Na. Corresponding values for the below ground biomass were 85.0; 8.1; 54.3; 23.5; 18.1; and 8.1 Kg ha^{-1} .

Although there were trends of increasing nutrients under the trees the presence of <u>Acacia</u> trees did not significantly influence the nutrient status of the soil.

Food crop yields varied from 143.2 to 409.7 Kg ha^{-1} for beans and 343.8 to 956.0 Kg ha^{-1} for maize. The yield of the food crops were not significantly affected by the presence of the trees. The *Acacia albida* root system developed a taproot with lateral roots growing downwards. At the age of six years, the mean taproot length was 2.84 m, and the mean diameter of lateral roots varied from 1.40 to 2.30 cm, while their mean length varied from 1.64 to 2.32 m. The root system is uniformly distributed within the soil profile, but with a higher proportion of lateral roots at depths greater than 20 cm. The fine roots, however, are concentrated in the top 30 cm of the soil.

The effects of *Acacia albida* on food crops and soil fertility, and the suitability of the species for village woodlots as a source of fuelwood and fodder are discussed.

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CHAPTER 1

INTRODUCTION

In the last decade, a lot of attention has been given to the shortage of fuelwood in developing countries (Arnold and Jongma, 1978; Noronha, 1981; Amor, 1982). The situation is especially serious in the dry lowland areas where close forests do normally not exist. FAO (1981) recently quantified and mapped the global fuelwood crisis and predicted that by the end of the century, 300 million people in the developing world will face an acute shortage of fuelwood.

Two main reasons have been given for this fuelwood shortage in these countries (Lundgren, 1985; Pimentel *et al*., 1986). People need new land for food production, and they need wood for a variety of different purposes. The largest share of forest clearing is, therefore, made for subsistence food production and subsistence cutting of wood for fuel and building material. This indiscriminate felling of trees leads to deforestation with the associated problems of fuelwood shortages, decline in soil fertility, soil erosion, floods and loss of medicinal and other values of the unexplored species and germplasm.

The fuelwood crisis has in recent years led to an unprecedented flow of international aid funds to fuelwood production in village and other social forestry programmes. The main aim of these projects being to improve the rural energy situation, conserve and improve soil conditions, enhance water resources availability and serve existing natural ecosystems.

The establishment of woodlots to address fuelwood shortages has received keen interest in Tanzania (Mnzava, 1980) and in many other developing countries (Gregersen, 1982; Wiersum, 1983). The main difficulties experienced in these tree planting programmes include:-

- the lack of tradition in growing man made forests among the people in rural areas;
- the percieved long term nature of returns from tree planting compared to fast returns from agricultural and other related economic opportunities;
- and the fact that tree planting has to take place at the same time as the planting of food crops (Skutsch, 1983) in the context of the shortlived and unpredictable rains (Kenworthy, 1964).

One approach to landuse which holds a great potential to address some of the main problems is agroforestry. Various definitions have been suggested for the term agroforestry (ICRAF, 1982). Agroforestry represents an intergrated landuse system involving a deliberate retention or planting of trees and other woody perennials in a crop or animal production systems so as to enhance the overall production of the land. The concepts and principles of agroforestry are now fairly well elucidated (King, 1968; King, 1979; Lundgren and Raintree, 1983; Torres, 1983). Similarly, the potential role of agroforestry under a variety of ecological conditions has also been examined by various authors especially in the amelioration of marginal environments (King and

Chandler, 1978; King, 1979; Chandler and Spurgeon, 1980); in soil conservation (Lundgren and Nair, 1983); in high - potential lands (Budowski, 1983); in areas with insufficient rural infrastructure (Lundgren and Raintree, 1982) and in combating deforestation (King, 1980).

Agroforestry is a means to solve a significant number of problems under specific site and social economic conditions but far from being a panacea (Maydell, 1985). A detailed evaluation of its structural components and associated functional features is therefore needed. This data will be important in extension efforts where agroforestry interventions are considered appropriate.

The tree component is undoubtedly the most important in the structural setting of an agroforestry system. Many fast growing fuelwood trees with potential for agroforestry have been identified (Felker, 1978; National Academy of Sciences, 1980; Nair, 1983; Forest Division, 1984; Lulandala, 1985). In addition, traditional agroforestry systems have recently been studied to identify the tree species involved (Fernandes *et al*., 1984; O'Ktang'ati *et al*., 1984). Sufficient evidence has accumulated to show that many tree species combine profitably with conventional agricultural crops in many tropical and subtropical enviornments. However, there is a general paucity of knowledge on the growth of the species and especially information on phytomass accumulation and nutrient relations when grown with food crops. This study was conducted to provide such information for *Acacia albida* which has been widely used in traditional agroforestry systems (Kerr, 1940; Seif-el-Din, 1981; Miehe, 1986; Poschen, 1986).

Acacia albida has been the subject of many studies both of a general and scientific nature (Wickens, 1969; Felker, 1978; Miehe, 1986; Poschen, 1986). Therefore, basic data is now available on its ecology and geographic distribution (Wickens, 1969). Regeneration and early growth of the tree has also been well studied (Maghembe and Redhead, 1982; Kiriinya, 1983). Data is, however, not available on growth and production of *Acacia albida* in a plantation setting especially where it is deliberately intercropped with food crops. This study presents data on the growth and biomass production in a six - year old plantation of *Acacia albida* intercropped annually with maize and beans at Mafiga, Morogoro. Specifically, the objectives of the study included:-

- estimation of volume production by *Acacia albida* monocultures and under intercropping with maize or beans;
- the estimation of biomass accumulation and nutrient distribution in the tree components under the different treatments;
- the assessment of the nutrient status of the soil in the stands;
- the assessment of the trend of food crop yields under the agroforestry system;
- and the assessment of the root distribution of individual trees within the soil profile.

CHAPTER 2

LITERATURE REVIEW

2.1 Acacia albida

Acacia albida is a deciduous tree growing upto 30 m high and having a massive root system (Wickens, 1969). At maturity, the crown is wide and rounded. The trunk is generally solitary and may attain a diameter of upto 2 m. The stem bark in mature trees is brown to dull - grey, rough, deeply fissured and scaly. The bark of the branches is reddish brown to white. The leaves are bipinnate and the leaflets are grey - green, each slightly obvate.

The flowers are sessile and yellow in colour. The fruit is a pod varying in colour from bright orange to reddish brown when ripe but somewhat purple when young. The seeds are light to dark - brown in colour and elliptic - lenticular in shape (Ross, 1966). There is considerable variation within the species with respect to height and girth at maturity, and presence or absence of spines. It is speculated that the large differences in growth rate could be attributed in part to seedling heterozyoisty (Anon, 1966).

Acacia albida is widespread in the drier parts of tropical Africa with a mean annual rainfall of 300-600mm (National Academy of Sciences, 1975). The range extends from Senegal to Ethiopia and Southwards through East Africa to Angola and Namibia. There is a northern extension from the main range via the Nile Valley north to Lebanon. It is also found in Israel and Syria and the Cape Verde islands (Wickens,1969).

Ecologically, it is a colonizer of newly deposited alluvial soils (Feeley, 1965) hence the frequent reports of occurence on river banks and flood plains. The altitudinal distribution ranges from sea level to 1800 m in East Africa but elsewhere from sea level to 2,500 m as on Jebel Marra in the Sudan (Wickens, 1969).

The timber of A. albida is used for joinery, interior fittings, shutters and structural purposes (Hughes, 1957). But its main use is for firewood. The wood is well suited for making house utensils such as mortars and food containers (Poschen, 1986).

In Nigeria, the stems of mature trees are fastened together to make dug-out canoes (Kerr, 1940). During the dry seasons, herdsmen in Senegal and Sudan lop the living branches of the tree for animal feed while in the Hararghe highlands of eastern Ethiopia, farmers let livestock eat the pods of A. albida from the fields during the dry season (Poschen, 1986).

The tree produces a good quality gum in West Africa and Tanzania (Irvine, 1961). In some parts of West Africa, the trees are ring-barked and the bark is used to make beehives. In the Nuba mountains of the Sudan, it is grown as live hedges. An extract of the bark is used for bathing and as a liniment for pneumonia in Senegal. In the Pare district of Tanzania and in Namibia an extract from the bark is used to cure diarrhoea, while the Masai use it to cure fever (Kiriinya, 1983).

2.2 Forest biomass and the energy situation in developing countries

The emergence and development of civilization has been closely associated with an increase in the per capita consumption of energy (Singh, 1984). Increasing supplies of energy are needed to maintain and improve human standards of living and for economic growth. It is known that coal, gas and oil reserves cannot meet the world's energy needs indefinitely. The development and use of renewable sources of energy is therefore being encouraged through research and development.

One of the important renewable sources of energy is biomass. In this discussion the word biomass will be used to refer to the vegetative material produced by plants. The most common and abundant form of this biomass is produced by forest trees and woody shrubs. The reserve of energy held by forests is more than twenty times the world current annual consumption of energy from all other sources (Earl, 1975). It is now well-known that one seventh of the world's fuel supplies are in the form of biomass (Hyman, 1980). Nearly 86% of the wood harvested in developing countries is used as fuel (Mnzava, 1981). About 50% of this fuelwood is consumed for cooking, 30% for domestic heating and 20% for other household purposes including processing of agricultural products and small scale industries (Patil, 1980). In recent years, forest biomass has therefore been recognized widely as an important source of energy for fuel production (Szego and Kemp, 1973, Grantham and Ellis, 1974; Garbutt and Van Breda, 1979).

On a regional basis, fuelwood accounts for 70% of the total energy consumption in Africa, 34% in Latin America and 30% in Asia (Mnzava, 1981). A review of literature accumulated over the last decade indicates that the per capita consumption of fuelwood in developing countries ranges from 0.01 to 2.50 m^3 per annum (Cabrido, 1984). In 1970, it was estimated that energy only absorbed about 2.5% of private consumption expenditure (PCE) of developing countries. By the late 1970's, however, this share had risen to 19%, with fuelwood accounting for between 4% and 5% of PCE. In Africa, the share of expenditure on fuelwood alone accounted for 10% of PCE, and for the least developed countries of Africa, this share was 20% (FAO, 1984). So with the ever decreasing forest resources, the share of expenditure on fuelwood in certain to increase over time in developing countries.

2.3 Rural dependence on fuelwood

Wood is the dominant fuel for rural communities in developing countries, and for many of the urban poor. About 2,000 million people use wood daily for cooking and for maintaining warmth in the home (Arnold, 1983; FAO, 1984). Wood is preferred because it can be acquired at little cost, often no more than the cost involved in gathering it.

For the people in rural communities in developing countries there is often no alternative to woodfuel or other locally available organic materials. Commercial fuels when available require cash outlays on related equipment. One consequence of growing rural populations is an inexorable growth in the pressures on locally available forest resources and other sources of woody material. The source of woodfuel extends progressively from collecting deadwood to the lopping of trees, the felling of trees, the total destruction of tree cover, and eventually to the uprooting of stumps and removal of shrubs.

The steady disappearance of wood in in the vicinity of the community means increased social hardship. Progressively more of the time of household members must be devoted to gathering fuel. It is estimated that a household uses 360 mandays annually to gather fuelwood in the Gambia and 250- 300 mandays in Central Tanzania (FAO, 1978). As the situation deteriorates and the household is forced to purchase its woodfuel, a heavy burden is placed on the household budget. Today, 15% of family income is spent on fuelwood in the Republic of Korea, 25% in the Sahelian zone of Africa (FAO, 1978) and 10 - 40% in the Philippines (Patil, 1980). Eventually, shortages of woodfuel affect the nutritional well-being of the people. In parts of West Africa, eating time has been reduced to one cooked meal a day. In the uplands of Nepal, emphasis in agriculture is placed on vegetables which can be eaten raw. In Haiti, a principal hinderance to the introduction of new food crops (with better nutritive value) into the wood poor hills is that they require more cooking (FAO, 1978).

2.4 The importance of forest biomass studies

As forestry and particularly forest utilization becomes more intensive, there is a need to improve our understanding of the relationships between forest organisms, forest environments, and multiple uses of forest areas (Ovington *et al*., 1967). These relationships influence the magnitude and the pattern of the four major functional ecosystem processes, namely the flows of organic matter, energy, chemicals and water. Comprehensive studies of these necessarily involve biomass determination.

Biomass studies are important because they assist in assessing the biological and commercial productivity of forests (Kushalappa, 1984). It also provides information needed for a thorough understanding of the structure and dynamic functioning of forest ecosystems (Ovington, 1962). Biomass is indicative of where the energy is accumulating in the system and the location of important nutrient reserves (Rencz and Auclair, 1978). Estimation of its distribution provides means for evaluating and comparing fuels (Barney _et al_., 1978).

Biomass studies also provide key data for the evaluation of the effects of forest harvest on future stand productivity (Aber _et al_., 1979). Forest biomass information also facilitates the assessment of weight yields that may be expected from forest harvest. Periodic forest biomass studies are therefore a prerequisite for the understanding of the forest wealth in our possession, for comparing it with forests elsewhere and for decision-making in the planning process (Karunakaran, 1984).

2.5 Methods of determining forest biomass

Because trees are so large, weight determinations of entire trees are laborious and the combined weight of all trees in a forest stand is normally determined from the weights of sample trees. Although the weights of sample trees are frequently estimated by sub-sampling, very little information on the accuracy and precision of existing methods is available (Whittaker and Woodwell, 1971). Overton _et al_. (1973) have discussed the physical problems of estimating weights of very large trees.

Three principal methods have been used to estimate stand weights (Madgwick, 1976), namely: the unit area method, the average tree method and the regression analysis technique. In the unit area method, all trees in a sample area, or a series of sample areas is collected and weighed. The tree biomass for the plot is determined by converting the sample area data to a plot area basis. The biomass Y is derived as:

$$Y = \sum_{i=1}^{n} wi \text{ ----------- } (1)$$

where wi is the weight of each harvested tree and n the number of trees in the sample area. Ovington et al. (1967) considers that errors may be introduced due to practical difficulties associated with accurate collection of material in the field. However, the errors can be reduced by increasing the number and area of the sample units. The method is laborious, time consuming and both less accurate and inefficient when compared with other methods.

In the average tree method, a tree or a number of trees considered to be of average biomass are selected for weighing from a knowledge of the linear dimensions of the trees in the plot (Ovington, 1957; Crow, 1971). The trees may be selected by subjective sampling of trees of known dimensions or by objective sampling from the whole population e.g. by systematic sampling. The tree biomass for the plot is determined by multiplication of the weight of the sample tree (or average of sample trees) by the number of trees in the plot. The biomass Y of the stand is estimated as:

$$Y = n\bar{w} \text{ ------------------- } (2)$$

where n is the number of trees per unit area and $\bar{w}$ is the weight of the average sized tree. As Crow (1971) points out, the difficulty with the "mean tree" techniques is the lack of a convenient measure indicating the degree with which a tree of mean dimension approximates a tree of mean biomass. In addition, a single tree or limited number of "mean trees" do not reveal differences in biomass distribution among tree components for trees of different sizes.

The third method is the regression analysis technique. A number of trees selected either randomly or systematically are weighed and the mathematical relationship between the weights of the whole trees, or tree components and one or more tree dimensions (tree height, crown volume and diameter, DBH) calculated. Diameter at breast height is commonly used because it gives relatively satisfactory relationships (Ovington _et al_., 1967). The models so developed are used to estimate the weights of individual trees and thus plot biomass.

Stand weight = Sum of weights from a regression - - - - - - - - - -(3)

The two most commonly used equations for relating tree size and weight are:-

$$\text{Log } Y = a + b \text{ Log } D \quad \text{-------- - (4)}$$

where Y is tree biomass, D is either DBH or DBH^2 x Height, and a and b are regression constants and:

$$Y = a + b D \text{ - - - - - - - - - - - - - - } (5)$$

where Y is tree biomass, D is either basal area or DBH^2 x Height, and a and b are regression constants. Equation 4 yields biased estimates (Meyer, 1938), a point which has been recently re-emphasized (Satchell *et al.*, 1971; Baskerville, 1972;Beauchamp and Olson, 1973). When equation 4 is used, less biased estimates of weight may be obtained using either the simple equations of Meyer (1938; 1941) or the more complex forms suggested by Finney (1941). The relative merits of equations 4 and 5 have been examined by Schreuder and Swank (1973). They conclude that a weighed regression of equation 5 is preferable to the logarithmic regresion (equation 4) for estimating leaf, branch, and stem biomass. However, the weighed regression requires at least five sample trees in each of three equally spaced diameter classes for satisfactory estimate of the weighing coefficient. This number of sample trees is necessary when many sample plots or large areas of forest are under consideration (Ribe, 1973).

Ovington *et al.* (1967) compared the known tree total ovendry weight obtained by summation of the measured weights of all trees that would have been obtained had the three sampling methods been used. Comparisons were made for the trees as a whole and for the component parts (leaves, cones, branches, boles and roots greater than 5 mm in diameter). They found that the unit area method gave significant overestimates for bole and branches. Results for the average tree method expressed in percentage errors of the known stand weights, decreased with increasing numbers of weighed trees.

In the regression analysis technique, whilst major tree components were related linearly to DBH, no significant relationship existed for minor components (cones and dead branches). Consequently, relatively large errors were obtained for estimates of these components, although this had little effect on total biomass estimates. When sampling is resticted to trees from a very small group of the population, regression analysis methods are not particularly appropriate and may give large errors. Average tree and regression analysis methods were therefore considered more satisfactory than unit area method particularly when estimations are made on major tree components. This is because DBH and tree weight were related linearly. The best of the average tree and of the regression analysis methods gave comparable accuracies for the same intensity of sampling.

Swank and Schreuder (1973) compared the three methods of estimating tree biomass. They point out that the average tree method involves the fewest assumptions. They also found that the average tree method gave both the lowest estimates of stand weights of foliage, branches, stems and the narrowest confidence intervals. The other two methods yielded stand estimates of foliage, stems and branches which were upto 9, 17 and 27% higher respectively.

Estimates of stand weight based on regression analysis and the unit area method have been compared by Satoo _et_ _al_. (1974). No consistent differences between the methods were found, the unit area method giving stand values of stem, branch and foliage biomass in the range of 93 and 114% of those from regression analysis. Madgwick and Satoo (1976) have compared stand estimates using logarithmic estimation equations, corrected for bias, with measured stand weights of folliage, stems and branches for nine stands. On average, standweight was overestimated by about 3%. Ribe (1973) also found that the logarithmic regression yields overestimates.

These results highlight the difficulties inherent in comparing methods. Only when measured values of total weight are available can reliable estimates of the bias associated with any sampling method be given (Madgwick, 1976). Based on the extensive literature reviewed, we consider that the logarithmic estimation equations are more appropriate for our stand of _Acacia albida_ and have therefore been used in this study.

2.6 Biomass production in forest stands

Numerous estimates of the biomass of individual stands have been published in the past few years (Table 1). Such studies frequently include information on the productive structure of the stand. Synthesis of this type of data have been made on a geographical basis (Basilevich _et al._, 1971; Jordan, 1971; Rodin _et al._, 1975), and by forest types on a local or international basis (Duvigneaud, 1971; Satoo, 1973; Baker _et al._, 1984; Karunakaran, 1984).

Several factors have been found to affect biomass production. These include stand age, genetic variation, elevation, moisture, thinning, tree population, and management practices.

Leaf amounts on young stands reach maximum values in a relatively few years, given adequate stocking. In _Prunus pensylvania_ regeneration, the maximum occured at age 6 (Marks and Bormann, 1972; Marks, 1974).

Forrest and Ovington (1970) found the maximum in Pinus radiata plantations at age 7; but Swank and Schreuder (1973) indicate age 12 for Pinus strobus. Current annual biomass increment tends to reach a maximum at an age similar to that associated with maximum foliage mass (Ewel, 1971; Marks and Bormann, 1972; Pollard, 1972; Forrest, 1973; Marks, 1974). The early attainment of maximum current annual increment implies an early attainment of maximum mean annual increment (MAI). Smith (1973) reports maximum MAI in Alnus stands at age 8 - 12 years, while in coppiced stands rotations of 3 to 5 years have been sugested for maximum production (Berry, 1971; Kormanik et al., 1973). Early culmination of MAI is supported by Carter and White (1971) and Singh and Sharma (1976).

Studies on two young Populus clones indicated that, within 2 years of planting, one clone had out-produced the other by a factor of two (Crist and Dawson, 1975). In addition, differences occur within species in the distribution of biomass between the woody components of stem and branches. Thus, in twenty half-sib families of Pinus virginiana stem wood accounted for 32 to 45% of the stem and branchwood and bark production in the first 8 years of growth (Mathews et al, 1975). Biomass accumulation also varies with varieties and ecotypes. Brewbaker (1975) observed that the Hawaiian variety of Leucaena leucocephala produced less than half the biomass produced by the Salvador type. While variation in growth distribution do not necessarily imply differences in total dry matter production (Bickelhaupt et al., 1973), a high heritability has important implications for tree improvement.

Leaf mass, total biomass and dry matter production per unit leaf mass decreased with elevation both in Fagus crenata (Maruyama, 1971) and in mixed beech - birch - maple stands (Whittaker et al., 1974). These

Table 1: Total biomass distribution in selected young tree plantations (3-18 years) from different countries

Plantation species	Age	Location	Stand density (trees/ha)	Total above-ground biomass (tons/ha)	Reference
Cupressus lusitanica	7	Tanzania	1680	224.0	Lundgren (1978)
Eucalyptus tereticornis	3	Tanzania	1600	31.4	Ahimana (1982)
Eucalyptus hybrid	3	India			
		a) Tarai Bhabar	992	11.5	George (1984)
		b) Pilibhit	1023	13.7	George (1984)
		c) East Dehradun	1133	12.0	George (1984)
Gmelina arborea	6	Brazil			
		a) Pacanari	639	122.0	Chijioke (1980)
		b) Sao Miguel	633	55.9	Chijioke (1980)
Gmelina arborea	6	Nigeria			
		a) Ubiaja area	667	63.4	Chijioke (1980)
		b) Omo Ajebandele	754	136.7	Chijioke (1980)
Gmelina arborea	10	Nigeria (Gambari)	1052	272.0	Nwoboshi (1985)
Gmelina arborea	7	Nigeria (Gambari)	1240	203.0	Nwoboshi (1985)
Gmelina arborea	5	Nigeria (Gambari)	1060	126.0	Nwoboshi (1985)
Leucaena leucocephala	4	Tanzania	1111	41.6	Lulandala (1985)
			625	27.3	Lulandala (1985)
			400	22.0	Lulandala (1985)
Leucaena leucocephala	5	Tanzania	1111	29.9	Maghembe *et al.* (1986)
			625	23.8	Maghembe *et al.* (1986)
			400	21.8	Maghembe *et al.* (1986)
Pinus caribaea	6	Brazil (Sao Miguel)	981	66.0	Chijioke (1980)
Pinus caribaea	10	Nigeria (Ibadan)	2866	144.0	Egunjobi & Bada (1979)
Pinus patula	7	Tanzania	1680	257.0	Lundgren (1978)
Pinus patula	10	India	-	51.21	Singh (1982)
Pinus radiata	15	Australia	-	162.0	Stewart *et al.* (1981)
Pinus radiata	12	Australia	1560	199.0	Forrest & Ovington (1970)
Pinus radiata	12	New Zealand	-	138.0	Will (1966)
Pinus radiata	18	New Zealanda	-	264.0	Will (1966)
Platanus occidentalis	5	Kentucky	-	27.0	Wittwer & Immel (1980)
Prosopis juliflora	6	Kenya	-	216.0	Maghembe *et al.* (1983)
Tectona grandis	10	Nigeria (Gambari)	1200	303.0	Nwoboshi (1980)
Tectona grandis	7	Nigeria (Gambari)	1186	115.0	Nwoboshi (1980)
Tectona grandis	5	Nigeria (Gambari)	970	56.0	Nwoboshi (1980)

effects of elevation on leaf mass are similar to those reported for temperature by Bray and Gorham (1964), and also reflect the changing productivities across temperature gradients as measured in terms of radiation (Rodin *et al*, 1975). Further studies of elevation effects have been reported (Kimmins and Krumlik, 1973; Krumlik and Kimmins, 1973; Whittaker and Niering, 1975) but these are confounded with changes in species composition.

Rodin *et al*. (1975) reviewing world literature, have documented the general increase in productivity with increased moisture supply. Such an analysis, however, confounds species composition and moisture supply. Ralwani *et al*. (1983) reported a doubling of biomass production by *Leucaena leucocephala* over 2-year period as a result of increased watering frequency. Moisture supply obviously affects growth, and drainage has increased biomass of *Pinus elliottii* (Mckee and Shoulders, 1974).

Heavy or repeated thinnings reduce stand foliage weight below values for unthinned stands (Madgwick and Olson, 1974; Siemon *et al*, 1976). In *Pinus radiata*, thinnings did not affect needle longevity but the production of stemwood per unit foliage weight was higher in thinned than unthinned stands (Siemon *et al*, 1976).

Biomass acccumulation is also reported to be dependent on tree density. Generally, per plant biomass accumulation is negatively related to population density (Savory, 1979). Per-hectare biomass, however, increases with tree population density (Ralwani *et al*., 1983; Visuttipitakul *et al*, 1983; Lulandala, 1985; Maghembe *et al*., 1986).

Besides climatic and environmental factors, plant biomass accumulation is related to management practices. When managed as a forage crop harvested frequently, *Leucaena* produced more dry-matter annually

(Krishnamurthy and Gowda, 1982). When established in stands in which the biomass is allowed to accumulate overtime, however, lower annual rates will be expected because of competition (Van den Beldt, 1982).

Biomass production figures for selected young plantations (3-18 years) for different tree species from various locations are shown in Table 1. These results show the variability in stand biomass production that is usually encountered even when considering a specific geographical region. These results further indicate that the biomass of an individual species tends to change with time and place. It is, therefore, difficult to make direct comparisons between data reported for various studies due to differences in stand age, stocking density, site, treatments applied and biomass determination methods employed (Alpizar *et al*, 1986; Maghembe *et al*., 1986). Several studies have shown that above ground biomass accumulation for most tree species decreases in the order of stem > branches > foliage.

The renewed emphasis on wood for energy and increased use of most of the tree components has led to the intensive culture of fast growing multipurpose tree species. Biomass studies on multipurpose trees are necessary in order to determine where most of the energy (biomass) is accumulating and the location of important nutrient reserves. Presently such information is lacking for most of these tree species. *Leucaena leucocephala* is probably the most studied in this respect (Brewbaker, 1975; Lu and Hu, 1981; Felker *et al*, 1982; Ralwani *et al*, 1983; Gowda and Krishnamurthy, 1983; Visuttipitakul *et al*, 1983; Lulandala, 1985; Maghembe *et al*, 1986). Other species that have been studied include *Prosopis spp* (Whisenant and Burzlaff, 1978; Felker *et al*, 1981; 1982; Maghembe *et al*, 1983; Chaturvedi, 1985), *Parkinsonia aculeata*

(Felker *et al*, 1982) and *Sesbania sesban* (Gutteridge and Akkasaeng, 1985).

Only two biomass studies hav been carried out on *Acacia albida*; one on seedlings (Kiriinya, 1983) and the other on a single *A. albida* tree (Jung, 1969). The results from this single tree were extrapolated to obtain a total standing biomass of 140 tons ha . Stocking density was assumed to be 43 trees ha . Roots were reported to constitute 41% of the tree biomass and the above ground parts the other 59%. The data presented in this study will, therefore, provide useful information on this widely used tree species.

2.7 Studies on nutrient distribution and accumulation in tree species

There are several reasons for studying plant nutrients. These include:-

- identification of deficiencies in plants;
- determining plant response to fertilizers;
- studying nutrient cycling in forest ecosystems;
- assessing the potetial of site productivity especially when using indicator plants;
- and assessment of nutrient levels in biomass production systems.

The level of supply of nutrients to plants is generally reflected in their concentrations in plant tissues. If that concentration falls below a certain level, the critical level, the yield will be restricted. In other words, the plant is deficient in that particular element (Hagin, 1982). Richards and Bevege (1972) have defined the critical level as the concentration which is associated with 90% of the maximum yield. Plant tissue analysis is a useful method for assessing nutrient deficiences and hence determining the fertilizer requirements of the plant in question. It is also used to determine plant response to fertilizers (Thornley, 1978). In addition, it is used to ascertain excess of micronutrients which may be toxic (Jones, 1970).

By plant analysis, the growing plant itself is the indicator of the nutritional status of the site. There are a few instances of species associated with nutrient - rich or nutrient - deficient site (Zottl, 1973). The analysis of indicator vegetation may, therefore, be a sensitive index to suitability of areas for reforestation where tree species are absent.

It has long been recognized that nutrients are not only withdrawn from the soil by trees, but that significant quantities are returned annually to the forest floor in litterfall. It is, therefore, important to know whether applied nutrients are cycled rapidly and reused many times, or whether they are leached or become immobilized in physiologically less active components of the system (Rodin and Basilevich, 1967). Nutrient cycling undoubtedly has an influence on the long-term effectiveness of any fertilizer (Stewart et al, 1981).

The importance of understanding the nutrient levels in biomass production systems has become highly relevant with the advent of intensive culture of fast growing multi-purpose tree species. There is usually a continuous removal of biomass in these systems. Such impact of intensive harvesting needs extensive understanding of nutrient distribution in different components of trees. Studies on nutrient content and distribution in tree species can aid in evaluating the potential drains resulting from short rotations and increased tree utilization (Kimmins, 1977; Leaf, 1979; Van Hook *et al*., 1982; Pehl *et al*., 1984).

Like biomass studies, numerous studies on nutrient content and nutrient dynamics of forest ecosystems have been made in many parts of the world. Studies have been carried out on plantation tree species (Attiwill, 1979; Feller, 1980; Hingston *et al*,1981; Cromer and Williams, 1982; Pehl *et al*, 1984; Van Lear *et al*., 1984; Zohar and Karschon, 1984; Lockaby and Adams, 1986) and on tropical forests (Greenland and Kowal, 1960; Stark, 1971; Golley *et al*, 1975; Zamierowski, 1975; Klinge, 1976; Grubb, 1977; Tanner, 1977; Lundgren, 1978).

Relatively few such studies have been carried out on multipurpose tree species. Data are widely available for *Leucaena leucocephala* (Hu and Shen, 1983; Van den Beldt, 1982; Lulandala, 1985; Maghembe *et al*., 1986). Others that have been studied include *Prosopis juliflora* (Maghembe *et al*, 1983), *Gmelina arborea* (Chijioke, 1980; Nwoboshi, 1985), *Erythrina poepigiana* (Alpizar *et al*., 1986), *Cordia alliodora* (Alpizar *et al*., 1986), *Acacia nilotica* (Grewal and Abrol, 1986) and *Acacia albida* (Giffard, 1964, Radwanski and Wickens, 1969).

Table 2 shows the nutrient content for tree components for tropical forests, whereas Table 3 shows that for multipurpose trees. These studies represent a wide range of soils, climates and species which explains in part the large variations in the results. However, some generazations can be made regarding the distribution of nutrients and accumulation in the tree components. Nutrients of a large number of tree species have been found to be highest during periods when they are fully leafy. The highest chemical element concentrations are found in the leaves and the lowest in the branches and stem, while levels in the roots are intermediate. In some cases, the amounts in the branches can be higher than that in the roots.

The nutrient levels in different tree components have to be monitored carefully because the nutrient requirements are unique for different species and varies with age and component developement (Young and Carpenter, 1967). Several workers also point out the need to carry out investigations with regard to the levels of nutrients not only in different components but also in different seasons. This would enable harvesting to be carried out at the time when the nutrients lockecd up in the harvestable components are at the lowest level. Additionally, it would give an indication of the levels of depletion of different elements. These will then be used to set guidelines for replacement of depleted nutrients through appropriate practices for sustained yield.

Table 2: Nutrient concentration (%) in different tropical forests

Forest type	Location	Tree	Nutrient content (%)					Reference
			N	P	K	Ca	Mg	
Semi decidous	Ghana	Leaves	1.88	0.13	0.76	.90	0.26	Greenland & Kowal (1960)
forest (several		Branches + stem	0.41	0.03	0.24	0.48	0.09	
species)		Roots	0.86	0.05	0.35	0.59	0.18	
Four different	Panama	Leaves	2.00	0.16	1.35	1.66	0.31	Golley *et al* (1975)
forest types		Branches + stem	0.50	0.12	0.90	0.96	0.11	
(several species)		Roots	0.80	0.11	0.66	1.36	0.26	
Lower Montane	Pueto Rico	Leaves	1.62	0.08	1.04	1.00	0.37	Ovington & Olson (1970)
forest (435		Branches + stem	0.48	0.32	0.45	0.55	0.12	
species)		Roots	0.49	0.24	0.33	0.43	0.13	
Lowland rainfall	Brazil	Leaves	2.29	0.18	0.75	0.30	0.26	Stark (1971)
forest (several		Branches + stem	0.42	0.02	0.18	0.13	0.04	
species)		Roots	1.61	0.10	0.22	0.10	0.15	
Lowland rainfall	Amazonas	Leaves	1.84	0.07	0.33	0.21	0.16	Klinge (1976)
forest (40		Branches + stem	-	-	-	-	-	
species)		Roots	1.02	0.02	0.08	0.14	0.08	
Highland	Tanzania	Leaves	0.10	0.97	0.97	0.97	0.29	Lundgren (1978)
forest		Branches + stem	0.40	0.12	0.37	0.43	0.08	
(several species		Roots	0.85	0.04	0.17	0.59	0.12	

Table 3: Nutrient concentration (%) in the various tree components for selected multipurpose trees

Species	Tree component	Nutrient concentration%)						Reference
		N	P	K	Ca	Mg	Na	
Acacia albida	Leaves	2.7	0.14	-	1.4	-	-	Giffard (1964)
Acacia albida	Leaves	-	0.10	-	1.8	-	-	Radwanski and Wickens, (1969)
Acacia nilotica	Leaves	-	-	10.3	12.1	-	0.8	Grewal and Abrol (1986)
	Stem	-	-	5.9	5.1	-	0.9	
	Roots	-	-	5.6	5.5	-	2.2	
Cordia alliodora	Leaves	2.79	0.24	2.28	1.72	0.82	-	Alpizar (1986)
	Branches	0.91	0.19	1.18	0.46	0.26	-	
	Stem	0.40	0.05	0.46	0.54	0.17	-	
	Roots	0.92	0.10	0.51	1.06	0.33	-	
Erythrina poeppigiana	Leaves	3.10	0.24	1.30	1.63	0.49	-	Alpizar (1986)
	Branches	1.19	0.14	1.33	1.24	0.42	-	
	Stem	0.54	0.06	0.76	0.72	0.24	-	
	Roots	1.23	0.13	0.99	1.08	0.26	-	
Gmelina arborea	Leaves	2.07	0.23	1.16	0.57	0.43	-	Chijioke (1980)
	Branchwood	0.27	0.04	0.43	0.21	0.15	-	
	Bark	0.55	0.06	0.59	0.69	0.22	-	
	Stemwood	0.16	0.02	0.37	0.17	0.03	-	
Gmelina arborea	Leaves	0.58	0.18	1.42	1.09	0.43	-	Nwoboshi (1985)
	Branches	0.29	0.11	1.08	0.47	0.16	-	
	Stembark	0.37	0.09	1.21	1.49	0.14	-	
	Stemwood	0.28	0.14	0.59	0.97	0.27	-	
Leucaena leucocephala	Leaves	2.31	0.13	1.96	1.14	0.40	0.08	Maghembe et al (1986)
	Branches	0.95	0.16	1.30	0.35	0.14	0.10	
	Stem	0.42	0.07	0.84	0.36	0.08	0.06	
Leucaena leucocephala	Leaves	2.60	0.13	1.25	1.32	0.41	-	Lulandala (1985)
	Brushwood	0.55	0.14	0.53	0.46	0.19	-	
	Branchwood	0.48	0.06	0.37	0.35	0.15	-	
	Stemwood	0.42	0.06	0.31	0.35	0.16	-	
Parkinsonia aculeata	Leaves	-	-	14.9	10.8	-	3.0	Grewal & Abrol (1986)
	Stem	-	-	6.5	2.9	-	1.0	
	Root	-	-	8.4	3.6	-	2.5	
Prosopis juliflora	Leaves	2.76	0.19	2.42	1.32	0.34	-	Maghembe et al (1983)
	Brushwood	1.60	0.10	1.11	0.60	0.60	-	
	Brarchwood	0.67	0.05	0.66	0.81	0.03	-	
	Stemwood	0.40	0.03	0.22	0.55	0.02	-	

Nutrient content data for Acacia albida are scarce. Only the nutrient content for leaves is reported (Giffard, 1964; Radwanski and Wickens, 1969). See Table 3. The data in this study may be the most comprehensive yet presented for the species.

2.8 Effect of trees on soil properties

2.8.1 Soil physical properties

Page (1968) suggested that the most significant changes in physical parameters of soil, as a result of forest planting, occur at or near the surface and are related to the supply of organic matter from leaf litter. However, observations on the effect of a forest cover on the soil are often conflicting (Chijioke, 1980).

Rennie (1962) and Page (1968) agreed on improved aeration and porosity in the upper horizons of forest soils as a result of afforestation. Hamilton (1965) reported increased bulk density and decreased organic matter in Pinus radiata soils converted from Eucalyptus forest in S. Australia. Challinor (1968) reported a change in the soil physical characteristics of compacted pasture to porous forest soil after planting the site with trees. Lundgren (1978) studying Pinus patula and Cupressus lustanica plantations on latosolic soils in the Usambara mountains of Tanzania indicated a trend towards an initial improvement in soil structure (increased organic matter and porosity, decreased bulk density) over the first 4-8 years, followed by a period of deterioration during the subsequent 10-20 years. Finally, as the stands grow older, soil structure again improved. No such trend was discernable in plantations of the same species on andosolic soils on Mount Meru. Removal of vegetative cover from the soil generally results in an increase in bulk density, decrease in porosity and a reduction in 34 infiltration rate (Weert and Lenselink, 1972; Wood, 1977). However, most structural deformations in forest soils are a direct result of compaction by heavy machinery in forest operations (Hatchell et al, 1970).

In undisturbed forest ecosystems, water movement under saturated conditions takes place in soils through macropores that dominate the pore space (Humbel, 1975) and, therefore, surface runoff is generally low. The honeycomb - like structure of the surface horizonas also favours high infiltratoin rates in such soils (Lal, 1975; Wolf and Drosdoff, 1976). Wilkinson and Ania (1976) reported high rates of infiltration and water entry into the soil (sandy soil, 10% clay) under tropical forest fallow in Nigeria, and the reduction of the rates after two subsequent years of maize cropping. Similar results on infiltration rates under various ecological and vegetation conditions in India are reported (Tejwani, 1979).

2.8.2 Soil fertility

Forest ecosystems contain large quantities of living biomass and therefore, a large inventory of chemical elements. About 20 to 40% of the total living biomass of trees is in roots (Rodin and Basilevich, 1968; Whittaker and Woodwell, 1971; Westman and Rogers, 1977; Armson, 1977), and there is a constant addition of organic matter to the soil through dead and decaying roots (Nye, 1961).

The major input of organic matter and so of nutrients to the soil from the trees (standing on it) is through litterfall (Brinson et al, 1980). The bulk of the organic matter and nutrients added to the soil in this fashion are found in the topsoil. Potassium, calcium and magnesium on the other hand, are concentrated in the biomass, except in high base status soils (Foelster *et al.*, 1976; Chijioke, 1980). That is why forest clearing leads to a considerable loss of nutrients. Those in the biomass are exported from the system, and those in the soil being lost by leaching and runoff.

A few reports have presented data to show that trees can deplete sites of soil nutrients. The most significant chemical changes associated with plantation forestry occur at or near the surface and are related to the supply of organic matter (Page, 1968). Changes in available nutrients can be brought about directly by their removal as harvested timber and indirectly through changes in pH and nutrient immobilization.

For tropical evergreen forests in Trinidad replanted to *Pinus caribaea*, Cornforth (1970) found that nitrogen was lost for four years after burning the original forest but increased to its original level after ten years. But phosphorus decreased for 7 years and never regained its original value. Increased levels of potassium, calcium, and magnesium reserves after burning were lost after 4 years.

As much as 74% of the original soil reserves were lost in 6 years. Lundgren (1978) found that, on the latosolic soils of the West Usambara mountains in Tanzania, soil P and K both in available and reserve forms showed clearly declining values with increasing age of *Pinus patula* and *Cupressus lusitanica* plantations. Trends in Ca and Mg were less clear and the pH was generally higher under Pine than under Cypress.

In Swaziland, Evans (1978a) as cited by Chijioke (1980) reported a comprehensive analysis of soil samples taken 9 years apart from the same soil pits in undisturbed *Pinus patula* stands and found slight increases in acidity, loss of most nutrients tested and considerable accumulation of litter. The rise in pH and drop in N, Ca, and Mg were all significant but there were no significant changes in P or K. Meanwhile, Holt and Spain (1986) observed that there was a decline of inorganic matter and associated nutrients in the soil after the replacement of a natural forest with a plantation of *Araucaria cunninghamii*.

There is sufficient evidence in the literature to justify the conclusion that trees and especially tree legumes improve the fertility of soil through additions of nitrogen added through biological nitrogen fixation (Nair, 1984). Estimates of such amounts of nitrogen fixed by trees are derived from the N content of sustained yield harvests or from differences in the N contents of soils that are adjacent to areas under such tree legumes. A few studies exist on nitrogen fixation by tree legumes under field conditions. The largest value (575 kg ha^{-1} yr^{-1}) for nitrogen fixed by tree legumes is reported for *Leucaena leucocephala* grown in Australia (Hutton and Bonner, 1960). Hogberg and Kvarnstrom (1982) calculated the amount of nitrogen fixed annually by a 4-year old stand of *L. leucocephala* at Mafiga, Morogoro (Tanzania) to be 110 ± 30 K ha^{-1}. Meanwhile Lulandala (1985) reported the amount of nitrogen fixed annually by 1 - year old and 2-year old stands of *L. leucocephala* on the same site to be 197 Kg ha^{-1}. Other reports show that nitrogen fixation by *L. leucocephala* can range from 70 to 500 Kg ha^{-1} yr^{-1} under different conditions (Vergara, 1982).

Other species reported to fix nitrogen include *Acacia mearnsii* which had nitrogen fixation rate of 200 Kg ha^{-1} yr^{-1} (Orchard and Darb, 1956), and *Prosopis tarmarugo* estimated to fix 198 Kg $ha^{-1} yr^{-1}$ (Pak *et al.*, 1977). Data presented by Felker (1978) on nitrogen fixation by *Acacia albida* growing in association with millet and groundnuts in West Africa was 21 Kg ha^{-1} yr^{-1}.

There is also evidence to indicate higher nutrient content in soils under scattered trees and shrubs. Kellman (1979) reported that trees show preferential enrichment of the soil below them in terms of Ca, Mg, K, Na, P and K in highly weathered and infertile utisols of the Mountain Pine Ridge Savanna of Belize. In some cases, the levels of these nutrients approached or exceeded those found in the nearby rainforest. Similar results of increasing nutrient content of soil under species of *Prosopis* growing in arid environments in India have been reported (Singh and Lal, 1969).

In West Africa, increase in nutrient content of soils under scattered Acacia albida trees have been reported. For total organic carbon and total nitrogen, the following workers reported the following increases: Dugain (1960), N-231%, C-269%, Dancette and Poulain (1969), N-33%, C-40%; Radwanski and Wickens (1969), N-600%, C-200%; Charreau and Vidal (1965), N-194%, C-192% and Jung (1966), N-110%, C-91%. These workers also reported increased soil water holding capacity and cation exchange capacities in soils under A. albida, which could be expected as a direct consequence of a higher soil organic matter content. A soil with a higher cation exchange capacity is important because cations like Ca^{++} and Mg^{++} (which arise from decaying leaf litter) are held in greater concentration by the soil where they can be absorbed by the plant (Felker, 1978). A soil with higher water holding capacity will have more water after rain available to the plant. This increase in nutrient content and water holding capacity is an advantage in agroforestry systems, because these nutrients and water become available to food crops. The results from this study do provide additional information on the soil improving aspect of A. albida.

2.9 The influence of multipurpose leguminuous tree species on food crop yields

There is a long tradition of growing pearl millet (Pennisetum glaucum) under Prosopis cineraria in the arid zones of India (Mann and Saxena, 1980). Prosopis cineraria supports good growth of understorey pearl millet and a large number of forage species, whereas grass growth under Prosopis juliflora was poor (Ahuja, 1980; Saxena, 1980). This influence on crop yields is attributed to the high amount of leaf litter P. cineraria adds to the soil. It is also due to the increase in soil organic matter and nitrogen content; an increased availability of micro nutrients (Zn, Mn and Cu), and higher moisture availability into the surface soil layer in comparison with soil under Prosopis juliflora or open fields (Aggarwal, 1980; Lahiri, 1980).

On the lower slopes and highlands of the Jebel Marra massif in the Sudan, subsistence crops such as bulrush millet (Pennisetum glaucum), groundnuts (Arachis hypogaea) and maize (Zea mays) are planted under stands of multipurpose trees dominated by Acacia albida, Cordia abyssinica and Ziziphus spina - christi (Miehe, 1986). The yields of these food crops are said to be sustained due to the presence of the trees. While in the Hararghe highlands of Eastern Ethiopia, a statistically significant increase in maize and sorghum yields was found for crops grown under A. albida canopies compared to those grown away from the trees (Poschen, 1986). This increase was higher for maize than for sorghum. Maize yields under the trees was 3.40 tons ha^{-1} against 1.92 tons ha^{-1} in the open, an increase of 76%. The figures for sorghum were 2.13 tons ha^{-1} and 1.57 tons ha^{-1} respectively, representing a 36% increase. This increase is said to be caused by the improvement in unit grain and an increase in the number of grains per plant, under the trees. This is an indication that the trees enhanced the fertility status of the soil. This improvement seems moderate compared to the published data from Senegal, where the reported increase in yields under A. albida trees were 250% for millet (Charreau and Vidal, 1965) and 100% for sorghum (Poschen, 1983).

In the Sahelian zone of West Africa, trees form an essential component of the farmland: Acacia albida, Adonsonia digitata, Borassus aethiopium, Parkia biglobosa, Parinari macrophylla, Combretum *micranthum*, *Balanites aegyptiaca*, *Acacia tortilis* and others are very commonly found on the farmlands (Seif-el-Din, 1981). One of the most comprehensive accounts of the farming practices involving such trees in the Sahelian region has been presented by Felker (1978) for *Acacia albida*. After an evaluation of available literature, he concluded that in the infertile sandy soils of the peanut basin of Senegal, crop yields of peanuts and millet increased from 500 ± 200 Kg ha^{-1} to 900 ± 200 Kg ha^{-1} directly under *Acacia albida* trees. In addition to a 50 to 100% increase in soil organic and nitrogen content, a marked increase in soil microbiological activity and waterholding capacity was also observed beneath the trees. Jung (1966, 1967) compared soil microbiological changes under and away from *A. albida*. Under *Acacia albida* he found a clear increase in invertase, dehydrogenase, asparaginase and respiratory CO_2. Bacteria counts under and away from the tree were the same but under the *A. albida* trees, there was a marked increase in fungi, and actinomycete populations, indicating that soil under *A. albida* supported more active rhizosphere populations. It is well documented today that higher rhizosphere activity is not only associated with fast decomposition rates, but also enhances site productivity. Increased soil organic matter, cation exchange capacity, water holding capacity and improved soil structure have also been associated with soils under trees (Charreau and Vidal, 1965). As a combined result of these effects, *A. albida* is known to increase soil productivity, a phenomenon which has been widely exploited by small farmers in the Sahelian zone of Africa.

Recently, experimental yield data have been available under intercropping of tree legumes with selected food crops. At Mafiga, Morogoro, Tanzania, different tree species were intercropped with maize, beans and sorghum (Redhead and Maghembe, 1982). In these studies it was found that maize, beans and sorghum could be grown successfully with Eucalyptus tereticornis in the first year at the close tree spacing of 2.5 x 2.5 m. Maize production was 1,280 Kg ha^{-1} in the first year but only 100 Kg ha^{-1} in the second year. Sorghum showed a similar trend. Beans yielded only 100Kg ha^{-1} in the first year and 150 Kg ha^{-1} in the second year. In the third year there was too much shade for any of the crops. Maize yields under intercropping with Leucaena leucocephala ranged from 1,337 to 1,736 Kg ha^{-1} . These yields were comparable with yields of the crop at University farm where maize was grown as a monoculture and was over double the national average of 670 Kg ha^{-1} . Bean crop yields (363-463 Kg ha^{-1}) were still an average value by peasant standards. Meanwhile the yield of maize intercropped with A. albida ranged from 950 to 1,000 Kg ha^{-1} .

Work at the International Institute of Tropical Agriculture (IITA) at Ibadan, Nigeria, has shown that the use of L. Leucocephala branches and leavaes as mulch sustained maize yields even with no additional nitrogen inputes (Kang et al, 1981). The effect of nitrogen contributed by Leucaena mulch on maize grain yield was equivalent to about 100 kg ha^{-1} for every 10 tons ha^{-1} of fresh prunnings.

2.10 Individual tree root systems-biomass and distribution within the soil profile

Knowledge of the morphology and habits of root systems is essential to an understanding of tree growth in relation to water and nutrient supply (Lyr and Hoffman, 1967). However, information on the rooting characteristics of many forest tree species is quite limited especially for tropical tree species (Kerfoot, 1963; Halle et al, 1978; Prasad and Mishara, 1984). This lack of information is doubtlessly related to the difficulty of studying underground structures, some of which may penetrate to considerable depths or extend long distances from the root stock (McMinn, 1963).

Nearly all early investigations on tree roots were confined to anatomical and morphological descriptions of roots. Gradually, investigations shifted towards studies relating to the ecological and physiological factors affecting root growth and distribution. Many of the papers pertaining to these two phases have been reviewed (Karizumi and Tsutsumi, 1958; Lyr and Hoffman, 1967). Recently, the growing interest in the dynamics and productivity of forest ecosystems has pointed out the need of a better understanding of roots as a part of the entire system (Santantonio et al., 1977). Results of these latest investigations have been summarized (Ovington, 1962; USSR Academy of Sciences, 1968; UNESCO, 1971; Herman, 1977).

The characteristics and extent of the root systems of individual trees have been revealed by manual excavation (Laitakari, 1929; Mensah and Jenik, 1968; Jackson and Chittenden, 1981; Prasad and Mishara, 1984), but the method is time consuming and often not very accurate. More rapid techniques, such as examination of the walls of trenches (Yeatman, 1955) or sampling soil blocks (Kalela, 1949; Karizumi, 1968) do not indicate the extent of invidual root systems. Although radioactive tracers do reveal the extent of root systems (Lott et al., 1950; Staebler and Rediske, 1958; Hough et al, 1965), other characteristics like root weight and root volume are not readily apparent. Hydraulic excavation on the other hand, is the only method adoptable to the study of all the characteristics of individual root systems (McMinn, 1963; Singer and Hutnik, 1965; Santantionio et al., 1977). Windfallen trees have also been used for studying root systems (Prasad and Mishara 1984).

The external factors which influence the morphology of a root system include soil type, soil mositure and planting techniques. Root systems are typically wide and deep in freely - drained soils and are usually flat when developed in a surface soil underlain by a more dense substratum (Lutz et al., 1937; Wilde, 1958; Savill, 1976). Large root systems are found in soils with high moisture levels, very deep root systems in areas subject to droughts and very flat root systems in soils where rainfall penetrates a short distance only (Wilde, 1958; Ponder and Kenworthy, 1976). Faulty transplanting can result in a deformed root system (Bergmann and Haggstrom, 1976) and ploughing prior to planting reduces the extent of a root system (Savill, 1976). Root systems may also be modified by competition between neighbouting trees (McMinn, 1963). Root distribution has also been found to be partly controlled by the concentration of nutrients, and the internal drainage-aeration conditions of the soil (Stark and Spratt, 1977).

For many tree species, the majority of roots are usually found in the upper 50cm of the soil and most of the fine roots are found within the top 20 cm (Kerfoot, 1963; McMinn, 1963; Kozlowski, 1971, Jenik, 1978; Berish, 1982; Nambiar, 1983). It has also been observed that occupation of soil by roots is nether uniform nor static (Harris et al., 1973; Ford and Deans, 1977; Persson, 1978), and the result of root amount measurements is a function of parameter chosen, that is, length, surface area, volume or weight (Santantonio et al., 1977).

Sampling of tree roots is tedius but reasonably reliable estimates of root biomass can be obtained (Newbould, 1967). The methods of root biomass estimation have been reviewed by Schuurmann and Goedenwagaen (1965) and Leith (1968). Normally, roots with diameters greater than 0.5 cm or over 1.0 cm may be dug, winched or hosed out and weighed. The estimate of fine roots (< 0.5 cm) can be obtained by excavation of soil monoliths or by taking soil cores down to a depth of at least 50cm and washing out the fine roots over a sieve (Will, 1966; Ford and Deans, 1977; Vogt et al., 1980, 1985). Roots larger than 0.5 cm are rejected from these samples as they will have been estimated by excavation.

Limited data exists on root biomass in forest trees. Estimates of root biomass for tropical tree species have made by Jenik (1971); Fittakau and Klinge (1973) and Berish (1982). Fine root biomass for conifer and hardwood forests have been compiled by Santantionio et al (1977). Overall, root biomass constitutes 20-40% of total tree biomass (Rodin and Basilevich, 1968, Whittaker and Woodwell, 1971; Young, 1971, 1973; Westman and Rogers, 1977).

In agroforestry landuse systems, mixtures of widely different kinds of species are grown together. If such associations are to be selected and managed optimally, then a detailed knowledge of the root distribution and root biomass of these species is necessary (Huck, 1983). It is important to know the distribution of roots within the soil profile because in mixed cropping systems some form of complementarity below ground is desirable. This can be achieved in space and/or time, and can alleviate competition for water and nutrients between the species. Meanwhile, an understanding of root biomass is important because both live and decaying root systems supply energy to meet the metabolic requirements of microbial populations whose activities aid in recycling of minerals in the system. The results of this study present information in this respect for *Acacia albida* under intercropping with maize or beans.

CHAPTER 3

MATERIALS AND METHODS

3.1 The study area

The experimental site is at Mafiga, Morogoro. It is located at 37° 38′E and 6° 50′S at 520 m a.s.l. The area lies on the flood plain of the Ngerengere river. Its geological formation has been described earlier (Hathout, 1983). The landform is almost flat, the slope being less than 5%. A detailed description of the soils at Mafiga has been given by Mpepo (1984). The soils are sandy loams, pH in water 6.5; Organic Carbon 0.7%; total Kjeldhal nitrogen 0.04%; Bray (1) available phosphorus 8.8 ppm and exchangeable bases 10.5 m.e./100 g. The area had been under sisal plantations for over 20 years when it was taken up for forestry research. The natural vegetation comprised small and medium sized trees and shrubs with a ground cover of assorted herbs and grasses.

The total annual rainfall for Mafiga varies between 500 to 1200 mm with a mean of 860 mm. The rainfall season is between December and May, and the dry season lasts from June to October. Monthly mean temperature maximas vary between 28° to 34°C and minimas 19° to 25°C. Temperatures are highest in January and lowest in June (FAO, 1984). Mean monthly relative humidity varies from 40% in October to 70% in April (Ahimana, 1982). In general values rise in December and reach a maximum level in April before declining to a minimum level in October.

3.2 Experimental design

Two local provenances of *Acacia albida* were used for the study (Morogoro provenance, 6° 52′S, 37° 39′E, 550 m a.s.l.; and River Msembe, Great Ruaha National Park provenance, 7° 40′S, 34° 40′E, 800 m a.s.l.). Container grown seedlings were planted in February 1980 in a ploughed and harrowed land that had been fallow for several years (Maghembe and Redhead, 1982).

The experiment was arranged in a split-plot design with food crops (maize or beans) and clean weeding forming the main plots and tree spacing forming the subplots. Four replications of the main treatments and subplots were used. The main plots consisted of three treatments planted with *Acacia albida* and intercropped or clean weeded as follows:-

1. *Maize* - Variety Ilonga composite planted (March, 1980, February, 1981, March, 1982, 1983, 1984 and 1985) at a spacing of 75 x 30 cm leaving a circle of 50 cm radius around each tree. Fertilizer was applied at every planting season at a rate of 400 kg ha^{-1} ammonium sulphate and 200 kg ha^{-1} triple superphosphate.
2. *Beans* - Variety Canadian Wonder planted (April, 1980, 1981, 1982, 1983, 1984 and 1985) at a spacing of 40 x 20 cm leaving a circle of 20 cm radius around each tree. Fertilizer was applied at every planting season at a rate of 200 kg ha^{-1} ammonium sulphate and 200^{-1} kg ha triple superphosphate.
3. *Acacia albida monoculture* - *Acacia albida* monoculture kept free from weeds by regular harrowing and hoeing around each tree.

Four tree spacing subplots were included in each mainplot. They included:-

1. Acacia albida planted at 4 x 4 m spacing,
2. Acacia albida planted at 5 x 5 m spacing,
3. Acacia albida planted at 6 x 6 m spacing,
4. And a treeless plot.

The subplots were 30 x 30 m square containing 56, 36, 25, and 0 trees for the 4 m, 5 m, 6 m spacing and no tree plots respectively. The whole experiment covered an area of 4.32 ha.

For each subplot with trees, the central core of 9 trees were clearly marked and regularly measured for height and diameter development. Initial diameter measurements were made at the root collar (height 15 cm) and starting in 1982, diameter at breast height (DBH) was measured. It was expected that trees surrounding the measurement unit would provide a sufficient buffer zone to overcome bias resulting from small plots (Zavitkovski, 1981). All plots were clean weeded by harrowing using a tractor and supplemented by hand hoeing. Pruning was carried out in 1983 and 1984 to facilitate tractor operations. The monoculture plots were not fertilized. Yields of maize and beans were recorded after every harvest.

3.3 Above ground biomass estimation

Above ground biomass was estimated from thirty sample trees carefully selected to cover the range of diameter classes present. The diameter classes were based on DBH. Each sample tree was cut at ground level, its height measured and then partitioned into foliage, brushwood (branches < 15 mm in diameter), branch wood and stem wood.

For each sample tree, fresh weights of foliage, brushwood, branch wood and stem wood were measured. Three stem discs (5 cm thick) were cut from each sample tree along the bole representing the stem base, middle and top. Samples of foliage (approximately 500 g), brushwood (approximately 1,000g) and branch wood (approximately 1,000g) were collected, weighed and taken to the laboratory for dry weight determination. The samples were ovendried at 75°C for foliage and at 105°C for woody materials to constant weights.

The ratio of dry weight to green weight was determined for each sample and used to estimate the oven dry weights of corresponding components of each sample tree (Alban and Laidly 1982). See Table 4. Regression equations between the tree component dry weights and DBH were developed for the simple linear model:

$$Y = A + BX \quad \text{-----------------------------}(6)$$

and the curvilinear model

$$Y = A X^{B} \quad \text{-----------------------------}(7)$$

Table 4: Mensurational data for the trees harvested for the study

DBH, cm	Ht, m	Dry weihts kg/tree				
		Foliage	Brushwood	Branchwood	Stem	Roots*
3.10	2.54	0.12	0.54	0.00	0.80	
3.50	3.44	0.05	1.24	0.18	0.89	2.90
3.90	3.92	0.07	0.47	0.00	1.73	
4.90	4.79	0.16	1.21	0.26	3.67	
5.20	4.64	0.15	0.92	0.52	1.75	2.90
5.30	4.92	0.17	1.17	0.00	2.87	
5.60	5.25	0.43	1.06	0.22	3.77	
6.20	5.00	0.45	3.82	0.24	4.63	3.81
6.90	5.69	0.44	1.64	0.51	3.96	
7.40	6.25	0.29	2.68	0.62	3.98	
9.20	6.68	0.48	3.11	0.61	7.75	
9.30	7.52	1.59	7.14	2.37	10.95	
9.30	7.95	0.36	2.59	1.15	6.49	
10.20	7.98	0.61	3.35	0.43	7.69	
10.50	8.75	0.16	3.44	1.86	7.81	7.21
10.60	8.96	0.16	8.71	1.77	8.97	
11.10	8.85	0.84	5.89	3.79	9.90	15.23
12.00	8.40	1.20	4.33	0.72	14.86	
13.40	8.53	2.03	18.01	5.25	23.06	
13.90	8.48	0.88	7.00	3.94	18.08	18.46
14.10	9.74	1.45	9.40	6.30	20.29	
14.10	9.68	1.35	9.08	4.62	16.85	
14.60	10.89	8.88	11.37	8.38	20.91	15.98
15.10	10.72	1.77	7.87	4.79	32.07	
16.90	10.92	3.00	10.50	13.09	31.74	
19.60	11.44	2.60	11.34	9.35	32.57	
19.20	11.36	1.43	19.29	11.29	38.58	
19.90	12.67	1.80	8.93	4.13	34.11	
20.00	12.28	1.67	15.58	8.35	33.03	
22.01	12.46	2.01	18.17	9.71	40.38	31.53

* = Only 8 trees were sampled for roots.

In each model, Y is the tree component dry weight, X is the tree DBH, and A and B are regression coefficients. Although there were very good fits between tree component dry weights and DBH in the simple linear regression model, the equations obtained could only be used for medium to large sized trees as they gave negative values for small sized trees. Negative dry weight values imply that as the tree DBH tends to zero, the dry matter tends to zero.

The linear regression model used to predict tree component dry weights was, therefore, the log-log allometric model:

$$\text{Ln } Y = A + B \text{ Ln } X \text{ ------------------(8)}$$

where Ln Y is the natural logarithm of tree component biomass, Ln X is the natural logarithm of DBH and A and B are regression coefficients. The regression equations obtained are shown in Table 5. The log-log transformation improved the R^2 values and reduced the standard errors of regressions. The model accounted for most of the variation in tree component weights as indicated by the high R^2 values for the equations. The analysis of variance of the regression equations showed all to be highly significant. The systematic errors associated with this model were corrected following the technique of Baskerville (1972). The correction factors so obtained were then multiplied with computed values of biomass of the respective tree components.

Table 5: Regression equations for predicting biomass and volume production by six-year old *Acacia albida* at Mafiga, Morogoro, Tanzania.

Parameter estimated	Equation	R^2	Standard error (Sy.X)	Correction factor (c.f.)	F - Value
Branch volume	$\text{Ln}\ (V) = -\ 7.669 + 2.423\ \text{Ln}\ D$	0.87	0.086	1.259	172.60**
Stem volume	$\text{Ln}\ (V) = -\ 4.711 + 1.529\ \text{Ln}\ D$	0.92	0.031	1.122	717.24**
Foliage biomass	$\text{Ln}\ (Y) = -\ 4.665 + 1.908\ \text{Ln}\ D$	0.77	0.100	1.413	90.24**
Brushwood biomass	$\text{Ln}\ (Y) = -\ 2.712 + 1.823\ \text{Ln}\ D$	0.88	0.082	1.259	197.33**
Branch biomass	$\text{Ln}\ (Y) = -\ 5.475 + 2.586\ \text{Ln}\ D$	0.84	0.105	1.413	129.11**
Stem biomass	$\text{Ln}\ (Y) = -\ 2.385 + 2.013\ \text{Ln}\ D$	0.96	0.058	1.122	722.00**
Corse root biomass	$\text{Ln}\ (Y) = -\ 1.345 + 1.559\ \text{Ln}\ D$	0.95	0.112	1.122	95.45**

** = Significant at $p < 0.01$

V = Tree component volume

D = Diameter at breast height

Y = Tree component biomass

Diameter at breast height squared x height (DBH^2 x H) has also been used as an independent variable in biomass estimation equations (Ogawa et al., 1965; Kira and Shidei, 1967; Post, 1970; Anderson, 1971), although the R^2 values obtained from this relationship do not represent much improvement over those obtained with DBH alone. The only advantage of the model being reduction of the error of estimate when the independent variable includes tree height (Whittaker and Marks, 1975). Nevertheless, measuring for DBH of individual trees in a stand is easier and more precise than measuring height. Therefore, equations using DBH proves more practicable than those using DBH^2 x H for estimation of stand biomass. For these reasons, tree height was not included in the model for biomass determination in this study.

For each treatment, the biomass of tree components for each tree was determined using the relevant component regression equation. The component dry weights were summed to obtain the tree component biomass for the 9 trees in each subplot and the values were then extrapolated to a hectare basis.

3.4 Estimation of volume production

The sample trees used for the above ground biomass determination were also used for determining stem and branch volume. All main stems and branches of each sample were cut into one meter lengths. The distal and proximal diameters of each one meter log were then recorded. All woody portions with diameters less than 15 mm were categorized as brushwood.

Volume was estimated from the different sections of each sample tree using Smalian's formula. Volumes of individual sample trees were obtained by summing the estimated volumes of all the respective small logs.

The regression model used to predict stem and branch volume of individual 9 trees in each subplot was the log-log allometric model:

$$\text{Ln } V = A + B \text{ Ln } X \text{ -------------- } (9)$$

where Ln V is the natural logarithm of tree component volume, Ln X is the natural logarithm of DBH, A and B are the regression coefficients.

For each treatment, individual tree stem and branch volumes were obtained separately using the relevant component regression equation. Plot totals for each component were obtained by summation. Data was corrected for systematic bias due to logarithmic transformation (Baskerville, 1972) and the values were then extrapolated to a hectare basis.

3.5 Maize and bean yields

Data for crop yields was compiled from past records (1980 - 1985). Yields were extrapolated to hectare basis to permit comparisons with data in the literature.

3.6 Root distribution of individual trees and determination of root biomass

Root systems of eight trees randomly chosen from those used for above ground biomass determination were excavated. The trees were chosen to represent the DBH range present as far as possible. Before digging out the root systems, two soil cores (size 15 cm depth and 10 cm in diameter) were taken around the tree stump (one meter radius) to obtain soil and fine roots at three soil depths (0-15 cm, 15 -30 cm and 40 - 45 cm). In all fourty-eight soil cores were collected.

The whole root system for each tree was then exposed by manual digging. Coarse roots (> 5 mm in diameter) were traced as much as possible upto their tips. Along the soil profile at 20 cm intervals, the number, diameters, lengths and fresh weights of coarse roots were determined. The small or fine roots (< 5 mm in diameter) were sorted from the soil cores and their fresh weights determined.

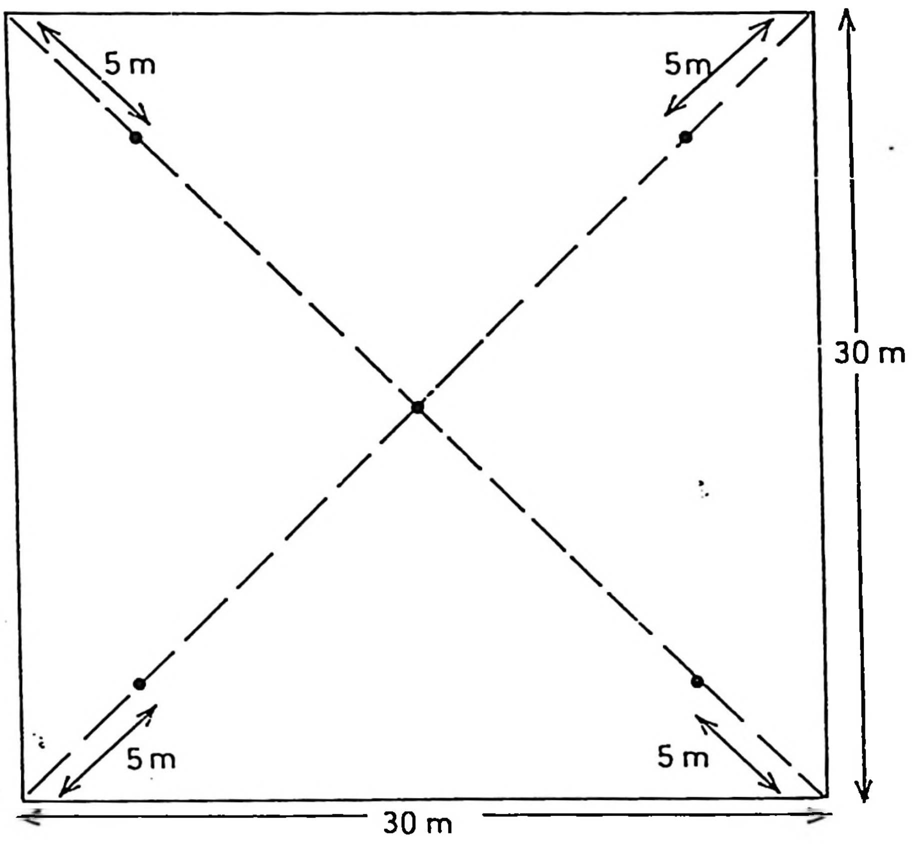
Samples of fine and coarse roots were carefully weighed and then taken to the laboratory for dry weight determination and nutrient analysis. Root samples were ovendried at 105°C. The ratio of dry weights to green weights were used to estimate the dry weights of the root systems separately for each of the eight sample trees.

The regression model used to predict coarse root biomass of the individual 9 trees in each subplot was the log-log allometric model (Equation 8). For each treatment, the coarse root biomass for each tree was determined using the regression equation so developed. Corrections of systematic error due to logarithmic transformation and plot biomass calculations followed the same methods outlined for other tree components. Fine root biomass was obtained by extrapolating the average dry weights obtained from the soil cores for each horizon to a hectare basis.

3.7 Soil sample collection

Soil samples were collected (using a soil auger) from two subplots in each mainplot for every replication. The subplots were:- the control subplot (without trees), and the subplot containg 36 trees (400 trees ha^{-1}). Soil samples were collected from five sampling points located in each subplot as shown in Figure 1.

At each sampling point, soil samples were taken at three soil depths (0-15 cm, 15-30 cm and 30-60 cm). Soil samples from each profile depth were bulked for each plot. In all, a total of 72 soil samples were collected. The soil samples were kept in plastic bags and taken to the laboratory for nutrient analysis. In the laboratory, the soil samples were air dried, ground and sieved to pass a 2 mm sieve. Portions of soil from each sample was used for nutrient determinations.



● Sampling points.

Figure 1 : The location of sample points in each subplot measuring 30 x 30 m.

3.8 Nutrient analysis

Preparation of plant material for nutrient analysis involved grinding foliage and brushwood in a Willey - Mill and sawing branch wood, stem wood and root samples repeatedly to obtain sufficient sawdust for nutrient analysis. Sample powder were then oven dried for 24 hours at 72°C prior to use.

For analysis of P, K, Ca, Mg and Na, 1 g of plant material was ashed at 475°C for three hours. The ash obtained was dissolved in 6 N HCl and the solution was made to 100 ml. Phosphorus was determined calorimetrically, while potassium, calcium, magnesium and sodium were determined by the atomic absorption procedure. For the determination of total nitrogen, the Macro-Kjeldhal procedure was used (Bremmer, 1965).

For soil chemical analysis, soil was ground and sieved to pass through a 2 mm sieve. Then, chemical analyses were carried out to determine total nitrogen, available phosphorus, exchangeable potassium, calcium, magnesium and sodium. In addition, soil pH and organic carbon were determined. Determination of organic carbon followed the wet combustion procedure of Walkley and Black (Allison, 1965). Soil pH was determined by a pH metter in a 1:2 soil to water paste. Total nitrogen was estimated by the Macro-Kjeldahl method (Bremmer, 1965). After extraction with ammonium fluoride solution, available phosphorus was calorimetrically determined using the Bray and Kurtz No. 1. Method (Bray and Kurtz, 1945). Potassium, calcium, magnesium, and sodium were determined by the atomic absorption procedure after initial extraction with ammonium fluoride solution.

3.9 Statistical analyasis of data

Analysis of variance for the split-plot design was performed on tree height, tree DBH, tree component biomass, plant nutrient concentrations, soil nutrient concentrations, volume production, crop yields, root lengths and root diameters to test differences between these variables among treatments. Duncan's New Multiple Range test was used to separate differing means (Alder and Roesler, 1972).

CHAPTER 4

RESULTS

4.1 Height and diameter development

Data on height development of the *A. albida* trees under the studied treatments are presented in Table 6 for the period 1980 to 1986. Neither intercropping nor tree spacing did significantly influence height growth of *Acacia* trees. Mean annaul height growth for the period was 1.42 m.

Table 6: Height growth (m) of *Acacia albida* trees for the growth period 1980 to 1986 at Mafiga, Morogoro, Tanzania

		Year						
Management regime	Spacing	1980	1981	1982	1983	1984	1985	1986
Acacia	4 x 4 m	1.30*	2.57	4.12	5.68	7.01	9.12	9.48
Monoculture	5 x 5 m	1.58	3.00	4.00	5.90	7.23	8.40	8.76
	6 x 6 m	1.50	2.64	4.24	5.69	7.10	8.43	8.79
Acacia	4 x 4 m	1.17	3.19	4.08	5.78	7.12	8.50	8.86
+ maize	5 x 5 m	1.28	2.84	4.31	5.64	7.32	8.43	8.79
	6 x 6 m	1.12	3.10	4.24	5.58	7.18	8.12	8.48
Acacia	4 x 4 m	1.16	3.02	4.13	5.68	7.04	8.31	8.67
+ beans	5 x 5 m	1.20	3.01	4.08	5.75	7.19	8.23	8.59
	6 x 6 m	1.33	2.73	4.23	5.59	7.23	8.17	8.53

* = Values in the same column and within each group do not differ significantly ($p < 0.05$).

+ = Measurements taken at the time of felling sample trees (March, 1986), three months after the 1985 measurements.

Similarly, intercropping with maize and with beans did not significantly influence diameter growth of Acacia trees. Tree spacing, however, significantly influenced diameter growth between 1982 to 1986 (Table 7). Spacings of 5 x 5 m and 6 x 6 m had significantly bigger diameters than 4 x 4 m spacing. The influence of spacing on diameter growth was apparent as early as 1982. Earlier on from 1980 to 1981, spacing did not significantly influence diameter growth of the trees. Mean annual diameter increment for the growth period was 1.6 cm.

4.2 Volume production

The effects of various management and spacing regimes on volume production by A. albida are shown in Tables 8 and 9. Total volume production ranged from 9.9 m^3 ha^{-1} for trees intercropped with maize at a spacing of 6 x 6 m to 24.9 m^3 ha^{-1} for trees intercropped with maize at a spacing of 4 x 4 m. The stem accounted for nearly 65% of the total volume, while the branches accounted for upto 35%.

4.2.1 Effect of intercropping on volume production

There were no significant differences in volume production between the trees grown in monocultures and the trees intercropped with either maize or beans (Table 8). Interactions between the management regimes and spacing were not significant for both stem and branch volume (Table 9). The results indicate that the number of trees per treatment was the most important factor governing yield in these studies.

Table 7: Diameter growth (cm) of *Acacia albida* trees for the growth period 1980 to 1986 at Mafiga, Morogoro, Tanzania

Management regime	Spacing	Year 1980	1981	1982	1983	1984	1985	1986+
Acacia	4 x 4 m	2.68a*	3.78a	4.34a	6.34a	8.51a	9.21a	9.89a
Monoculture	5 x 5 m	2.99a	4.12a	6.61b	8.25b	10.01b	11.45b	12.13b
	6 x 6 m	2.66a	4.23a	6.55b	8.40b	10.28b	11.68b	12.36b
Acacia	4 x 4 m	2.88a	3.75a	4.61a	6.53a	8.60a	9.24a	9.92a
+ maize	5 x 5 m	2.68a	4.00a	6.54b	8.14b	10.46b	11.25b	11.93b
	6 x 6 m	2.54a	3.95a	6.55b	8.49b	10.22b	11.72b	12.40b
Acacia	4 x 4 m	2.49a	3.59a	4.60a	6.21a	8.50a	9.04a	9.72a
+ beans	5 x 5 m	2.88a	4.28a	6.86b	8.32b	10.46b	11.23b	11.91b
	6 x 6 m	3.06a	4.04a	6.62b	8.64b	10.18b	11.87b	12.55b

* = Values in the same column and within each group with the same subscript do not differ significantly ($p < 0.05$)

\+ = Measurements taken at the time of felling of sample trees (March, 1986), three months after the 1985 measurements.

Table 8: Volume production by six-year-old *Acacia albida* in monocultures and when intercropped with maize or beans at Mafiga, Morogoro, Tanzania.

Management and spacing regimes	Volume production, m^3 ha^{-1}		
	Stem	Branch	Total
Main plot effects, Management			
Acacia monoculture	9.7a*	5.8a	15.5a
Acacia + beans	9.5a	5.6a	15.1a
Acacia + maize	10.8a	6.4a	17.2a
Sub plot effects, spacing			
4 x 4 m (625 trees ha^{-1})	14.7a	8.0a	22.7a
5 x 5 m (400 trees ha^{-1})	8.9b	5.5b	14.4b
6 x 6 m (278 trees ha^{-1})	6.5c	4.3c	10.8c

* = Values in the same column and within each group with the same subscript do not differ significantly ($p < 0.05$)

Table 9: The effect of intercropping and spacing interactions on volume production by six-year old *Acacia albida* at Mafiga, Morogoro, Tanzania.

Management and spacing regimes	Volume production, m^3 ha^{-1}		
	Stem	Branch	Total
Acacia monoculture			
4 x 4 m	14.0a*	7.7a	21.7a
5 x 5 m	8.5b	5.1bc	13.6b
6 x 6 m	6.8c	4.6c	11.4c
Acacia + beans			
4 x 4 m	14.0a	7.5a	21.5a
5 x 5 m	8.0b	4.9b	12.9b
6 x 6 m	6.6c	4.5b	11.1c
Acacia + maize			
4 x 4 m	16.0a	8.9a	24.9a
5 x 5 m	10.1b	6.6b	16.7b
6 x 6 m	6.2c	3.7c	9.9c

* = Values in the same column and within each group with the same subscript do not differ significantly ($p < 0.05$).

4.2.2 Effect of spacing on volume production

Tree spacing caused most of the observed differences between treatments (Table 8). Spacings of 4 x 4 m, 5 x 5 m and 6 x 6 m had significantly different volume production values. Tree spacing at 4 x 4 m showed the highest volume, while 6 x 6 m spacing showed the lowest volume production. Volume production at 5 x 5 m spacing was intermediate. The volumes under wide spacing (6 x 6 m) were based on a few large trees while the assortment of sizes in the lower spacing was much varied.

4.3 Biomass production

The distribution of biomass in components of *A. albida* monocultures and trees under intercropping with maize or beans at different spacings are presented in Table 10. Total tree biomass ranged from 19.6 metric tons ha^{-1} for trees intercropped with beans at a spacing of 6 x 6 m to 43.1 metric tons ha^{-1} for trees intercropped with maize at a spacing of 4 x 4 m. Intercropping did not cause significant effects on biomass production, the main variations emanating from tree spacing (Table 11). In general biomass distribution in components of *A. albida* was stem, 32%; roots, 35%; brushwood, 15%; branches, 12%; and foliage, 6%. The foliage biomass was considerably underestimated because sampling was done a few weeks after trees had started leafing.

Table 10: The effect of intercropping and spacing on the biomass of six-year old *Acacia albida* at Mafiga, Morogoro, Tanzania

Management and spacing regimes	Tree component biomass tons ha^{-1}					Total - biomass tons ha^{-1}
	Stem	Branches	Brushwood	Foliage	Roots	
Acacia monoculture						
4 x 4 m	12.4a*	4.8a	5.4a	2.5a	13.8a	38.9a
5 x 5 m	9.2b	3.5b	4.2b	1.8b	9.7b	28.4b
6 x 6 m	7.1c	2.7c	3.4c	1.4c	7.3c	21.9c
Acacia + beans						
4 x 4 m	11.7a	4.5a	5.3a	2.3a	13.3a	37.1a
5 x 5 m	9.1b	9.1b	4.1b	1.8b	9.6b	28.1b
6 x 6 m	6.3c	2.4c	2.9c	1.3c	6.7c	19.6c
Acacia + maize						
4 x 4 m	13.9a	5.3a	6.3a	2.8a	14.8a	43.1a
5 x 5 m	9.1b	3.5b	4.3b	1.8b	9.6b	28.3b
6 x 6 m	6.1c	2.3c	2.8c	1.2c	8.6c	21.0c

* = Values in the same column and within each group with the same subscript do not differ significantly (P = 0.05)

Table 11: Biomass distribution in components of six-year old Acacia albida grown in monocultures and when intercropped with maize or beans at different spacing at Mafiga, Morogoro, Tanzania.

Management and spacing regimes	Tree component biomass, tons ha^{-1}					Total biomass tons ha^{-1}
	Stem	Branches	Brushwood	Foliage	Roots	
Main plot effects, management						
Acacia monoculture	9.6a*	3.7a	4.3a	1.9a	9.8a	29.3a
Acacia + beans	9.0a	3.5a	4.1a	1.8a	9.4a	27.8a
Acacia + maize	9.7a	3.7a	4.5a	1.9a	9.9a	29.7a
Subplot effects, spacing						
4 x 4 m (625 trees ha^{-1})	12.7a	4.8a	5.8a	2.5a	13.9a	39.7a
5 x 5 m (400 trees ha^{-1})	9.1b	3.5ab	4.2ab	1.8ab	9.6b	28.2b
6 x 6 m (278 trees ha^{-1})	6.5c	2.5b	3.0b	1.3b	6.8c	20.1c

* = Values in the same column and within each group with the same subscript do not differ significantly ($p < 0.05$)

4.3.1 Effect of intercropping with maize and beans on biomass production by *A. albida*

The impact of intercropping with maize or beans on biomass production by *A. albida* was negligible (when compared to production by clean weeded *A. albida* monocultures). See Table 11. There were also no significant interactions between management regimes (clean weeding or intercropping) and tree spacing (Table 10).

4.3.2 Effect of tree spacing on biomass production

The effect of tree spacing on biomass production was highly significant (Table 11). Biomass production differed significantly between all the three spacings. Spacing the trees at 4 x 4 m produced the highest biomass and 6 x 6 m spacing the lowest. In all cases, biomass production at the 5 x 5 m spacing was intermediate.

For stem and root biomass, there were significant differences between all the three spacing treatments. For branches, bushwood and foliage biomass, however, there were no significant differences between the 4 x 4 m and 5 x 5 m on the one hand and between 5 x 5m and 6 x 6 m spacing on the other. In all cases, biomass production at the 4 x 4 m spacing significantly exceeded that at 6 x 6 m spacing.

4.4 Nutrient concentration and uptake

The percent concentrations of N, P, K, Ca, Mg and Na in the components of *A. albida* are shown in Table 12. The nutrient concentration values in this study are average values for all the trees analysed for biomass. Therefore, nutrient concentration values cannot be presented for each treatment. The average concentrations of the nutrients in the foliaage, brushwood and branches decreased in the order of N > K > Ca > Na > Mg> P, while for the stem, the order was N > K > Na > Mg > = Ca > P. For roots the order was N > K > Ca > Mg > Na > P.

Table 12: Nutarient concentrations for tree components of six-year old *Acacia albida* grown at Mafiga, Morogoro, Tanzania

Tree component	Nutrient element concentrations, %					
	N	P	K	Ca	Mg	Na
Foliage	3.50	0.22	1.00	0.69	0.30	0.49
Brushwood	1.08	0.17	0.79	0.59	0.26	0.34
Branches	0.89	0.16	0.53	0.46	0.23	0.24
Stem	0.55	0.13	0.48	0.19	0.19	0.24
Roots	0.94	0.09	0.60	0.26	0.20	0.09

Generally, nutrient concentrations were highest in the foliage and brushwood, and least in the stem, with concentrations in the roots and branches being intermediate. For individual elements; N and K concentrations in the tree components decreased in the order of foliage > brushwood > roots > branches > stem. But P and Na concentrations decreased in the order of foliage > brushwood > branches > roots > stem. Magnesium and Ca on the other hand decreased in the order of foliage > brushwood > branches > roots > stem.

The effects of management and spacing regimes on the accumulation of nutrient elements in the components of *A. albida* are shown in Tables 13 and 14, respectively. The impact of intercropping with maize or beans on nutrient accumulation in the *A. albida* trees was negligible when compared to nutrient accumulation by cleanweeded *A. albida* monocultures. Spacing on the other hand, did significantly influence nutrient accumulation in the trees (Table 15). As expected, the highest nutrient accumulations were recorded under the 4 x 4 m spacing (treatment with the highest biomass), and the lowest in the 6 x 6 m spacing. Accumulations in the 5 x 5 m spacing were intermediate.

From Table 15 it is observed that among the various nutrients, accumulation of N is highest followed by K, Ca, Na, Mg and lowest for phosphorus. However, except for N, the nutrient accumulations were highest in the stem, brushwood and roots, with the least amounts found in the foliage and branches (Tables 13 and 14).

For individual elements; N accumulation in the tree components decreased in the order of foliage > roots > stem > brushwood > branches, while for P, the order was stem > brushwood > roots > branches > foliage. Potassium and Mg acccumulations decreased in the order of stem > roots > brushwood > branch > foliage. Calcium was accumulated in the order brushwood stem roots branch foliage, while for Na it was in the order of stem > brushwood > foliage > branch > roots.

Foliage, brushwood and roots constitute about 67.5%, 58.7%, 59.0%, 61.6%, 53.5% and 48.6% of the total N, P, K, Ca, Mg and Na respectively, accumulated by *A. albida*. These proportions are the quantities of these elements that are likely to be left on the site after fuelwood and pole harvest. However, if foliage is harvested as fodder, then the figures drop to 42.0%, 37.2%, 47.0% 47.2%, 43.4%, and 33.5% of N, P, K, Ca, Mg and Na respectively.

4.5 Yields of maize and beans grown pure and intercropped with *Acacia albida* trees

Tables 16 and 17 show the yields of beans and maize respectively, grown in monoculture and when intercropped with *Acacia albida* trees for the growing seasons from 1980 to 1985. There were no statistical differences in the mean yields of maize or beans between the treatments studied. This indicates that neither the yields of maize nor that of beans were influenced by the trees under the study.

However, significant differences in the yields of maize and beans over the years were observed. Much of the variation in the yields of maize or beans over time was found to be closely related to the amount of total rainfall received during the growing season (Table 18). The total amount of rainfall received in the growing season (March to June) accounted for most of the variation in the yields of maize and beans observed over the years as indicated by the high R^2 values of the regressions.

Table 13: The effects of management regimes on the accumulation of nutrient elements in components of six-year old Acacia albida at Mafiga, Morogoro, Tanzania.

Management regime	Element, Kg ha^{-1}					
	N	P	K	Ca	Mg	Na
Acacia monoculture						
Foliage	67.1a*	4.2d	19.2c	13.2c	5.8e	9.4c
Brushwood	46.7b	7.3b	34.1b	25.5a	11.2c	14.7b
Branches	32.9c	5.9c	19.6c	17.0b	8.5d	8.9c
Stem	52.7b	12.5a	46.0a	18.2b	18.2a	23.0a
Roots	64.2a	6.1c	41.0a	17.8b	13.7b	6.1d
Acacia + beans						
Foliage	63.1a	4.0d	18.0c	12.4c	5.4e	8.8c
Brushwood	44.3b	7.0b	32.4b	24.2a	10.7c	13.9b
Branches	30.9c	5.6c	18.4c	16.0b	8.0d	8.3c
Stem	49.6b	11.7a	43.3a	17.1b	17.1a	21.7a
Roots	60.5a	5.8c	38.6a	16.7b	12.9b	5.8d
Acacia + maize						
Foliage	67.9a	4.3d	19.4c	13.4c	5.8e	9.5c
Brushwood	48.2b	7.6b	35.3b	26.3a	11.6c	15.2b
Branches	33.2c	5.9c	19.7c	17.2b	8.6d	9.0c
Stem	53.3b	12.6a	46.5a	18.4b	18.4a	23.3a
Roots	64.9a	6.2c	41.5a	18.0b	13.8b	6.2d

* = Values in the same column and within each group with the same subscript do not differ significantly ($p < 0.05$)

Table 14: The effects of spacing on the accumulation of nutrient elements in components of six-year old *Acacia albida* at Mafiga, Morogoro, Tanzania.

Spacing	Element, Kg ha $^{-1}$					
	N	P	K	Ca	Mg	Na
4 x 4 m						
Foliage	88.6a*	5.6d	25.3c	17.5c	7.6d	12.4c
Brushwood	61.3b	9.6b	44.9b	33.5a	14.8c	19.3b
Branches	43.4c	7.8c	25.8c	22.4b	11.2c	11.7c
Stem	69.6b	16.4a	60.7a	24.0b	24.0a	30.4a
Roots	85.0a	8.1b	54.3a	23.5b	18.1b	8.1d
5 x 5 m						
Foliage	63.9a	4.0d	18.3c	12.6c	5.5d	8.9c
Brushwood	45.3b	7.1b	33.2b	24.8a	10.9b	14.3b
Branches	31.3c	5.6c	18.6c	16.2b	8.1c	8.4c
Stem	50.2b	11.9a	43.8a	17.3b	17.3a	21.2a
Roots	61.1a	5.8c	39.0b	16.9b	13.0b	5.8d
6 x 6 m						
Foliage	45.6a	2.9d	13.0c	9.0c	3.9d	6.4c
Brushwood	32.5b	5.1b	23.8b	17.7a	7.8b	10.2b
Branches	22.4c	4.0c	13.3c	11.6b	5.8c	6.0c
Stem	35.8b	8.5a	31.3a	12.4b	12.4a	15.6a
Roots	43.5a	4.2c	27.8b	12.0b	9.3b	4.2d

* = Values in the same column and within each with group with the same subscript do not differ significantly ($p < 0.05$).

Table 15: The effects of management and spacing regimes on the accumulation of nutrient elements in six-year old *Acacia albida* at Mafiga, Morogoro, Tanzania

Management and spacing regimes	Element, Kg ha $^{-1}$					
	N	P	K	Ca	Mg	Na
- - - - - - - - - - -	Main plots effects, management - - - - - - - - - - - - - - - - - - -					
Acacia monoculture	263.6a*	36.0a	159.9a	91.7a	57.4a	62.1a
Acacia + beans	248.4a	34.1a	150.7a	86.4a	54.1a	58.5a
Acacia + maize	267.5a	36.6a	162.4a	93.3a	58.2a	63.2a
- - - - - - - - - - - - -	Subplot effects, spacing -					
4x4 m (625 trees ha $^{-1}$)	347.9a	47.5a	211.0a	120.9a	75.7a	81.9a
5x5 m (400 trees ha $^{-1}$)	251.8b	34.4b	152.9b	87.8b	54.8b	58.6b
6x6 m (278 trees ha $^{-1}$)	179.8c	24.7c	109.2c	62.7c	39.2c	42.4c

* Values in the same column and within each group with the same subscript do not differ significantly ($p < 0.05$)

Table 1b: The yield of beans in crop monocultures and when intercropped with *Acacia albida* trees at Mafiga, Morogoro, Tanzania during the 1980–1985 crop seasons.

Tree spacing	Crop yield, Kg ha^{-1}					
	1980	1981	1982	1983	1984	1985
4 x 4 m (625 trees ha^{-1})	168.0*	312.5	143.2	327.3	333.7	298.8
5 x 5 m (400 trees ha^{-1})	200.0	269.0	168.8	304.2	398.3	297.9
6 x 6 m (278 trees ha^{-1})	203.8	229.7	181.0	334.6	349.9	318.0
Control (No trees)	186.6	204.0	158.0	355.6	409.7	308.4
Seasonal rainfall (mm)+	327.0	365.0	305.0	427.5	430.6	417.5

* = Values in the same column do not differ significantly ($p < 0.05$)

\+ = Rainfall season, March to June.

Table 17: The yield of maize in crop monocultures and when intercropped with *Acacia albida* trees at Mafiga, Morogoro, Tanzania during the 1980 to 1985 crop seasons.

Tree spacing	Crop yield, Kg ha^{-1}					
	1980	1981	1982	1983	1984	1985
4 x 4 m (625 trees ha)	506.9*	551.0	343.8	715.2	881.4	689.7
5 x 5 m (400 trees ha)	450.0	571.1	338.2	769.4	894.8	632.2
6 x 6 m (278 trees ha)	442.7	546.0	303.6	758.8	884.4	675.1
Control (No trees)	480.0	539.4	318.8	775.0	956.0	666.6
Seasonal rainfall (mm)+	327.0	365.0	305.0	427.5	430.6	417.5

* = Values in the same column do not differ significantly ($p < 0.05$)

+ = Rainfall season, March to June

Table 18: Regression equations relating the yield of maize and beans with total rainfall (March-June) for the period 1980-1985 at Mafiga, Morogoro, Tanzania.

Tree spacing	Equation	Correlation coefficient (r)	R^2	Standard error (Sxy)	F
		Beans			
4 x 4 m (625 trees ha^{-1})	$Y = -277.5 + 1.4 X$	0.92	0.85	15.61	20.8*
5 x 5 m (400 trees ha^{-1})	$Y = -249.0 + 1.4 X$	0.92	0.85	14.77	21.6**
6 x 6 m (278 trees ha^{-1})	$Y = -232.1 + 1.3 X$	0.99	0.98	5.40	149.0**
Control (No trees)	$Y = -401.6 + 1.8 X$	0.95	0.90	14.94	35.0**
		Maize			
4 x 4 m (625 trees ha^{-1})	$Y = -607.4 + 3.2 X$	0.94	0.88	20.12	30.4**
5 x 5 m (400 trees ha^{-1})	$Y = -721.6 + 3.5 X$	0.94	0.88	31.87	30.1**
6 x 6 m (278 trees ha^{-1})	$Y = -828.0 + 3.8 X$	0.97	0.94	25.27	55.3**
Control (No trees)	$Y = -838.0 + 3.9 X$	0.93	0.86	38.04	25.5**

* = Significant at $p < 0.05$ ** = Significant at $p < 0.01$

Y = Crop yield, kg X = Total rainfall, mm.

In all cases, the yields of maize or beans were lowest in the 1982 growing season (total rainfall 305 mm) and highest in 1984 growing season (total rainfall 430.6 mm). See Tables 16 and 17. Bean yields ranged from 143.2 to 409.7 kg ha^{-1} and maize yields from 303.6 to 956.0 kg ha^{-1}.

4.6 Influence of *Acacia albida* trees on soil fertility

Tables 19, 20 and 21 show the concentration of soil elements in areas planted with and without *A. albida* trees in the different main plots. For all elements except Mg and Na, the concentration of the elements decreased down the soil profile. The soil pH also decreased down the soil profile.

For soil horizon 1(0-15 cm), significant differences did exist in the soil pH between areas that had been clean weeded (*Acacia* monocultures) and areas where intercropping with maize or beans had been done (Table 19). Intercropping with food crops tended to lower the soil pH. For all elements, however, there were no significant differences between the treatments.

In soil horizon 2 (15-30cm), there were significant differences in the soil pH between areas planted with and without trees, and also between *A. albida* monoculture and *A. albida* intercropped with maize or beans (Table 20). Intercropping lowered the soil pH, while areas planted with trees tended to have a higher soil pH. Areas planted with *A. albida* trees had significantly higher amounts of organic carbon and calcium when compared to areas without trees. For all the other elements no significant differences existed between the treatments.

In soil horizon 3 (30-60 cm), there were significant differences in the soil pH between areas planted with and without trees, and also between *A. albida* monocultures and *A. albida* intercropped with maize or beans (Table 21). Intercropping significantly lowered the soil pH, while areas planted with trees had higher soil pH. Soils in *A. albida* monocultures had significantly lower total nitrogen compared to areas where intercropping had been done. Concentrations of total nitrogen in areas intercropped with maize or beans did not differ significantly. Areas planted with *A. albida* had significantly higher amounts of calcium than those without *A. albida*.

Table 19: Elemental concentration of soils for a soil depth of 0-15 cm in areas with and without *Acacia albida* trees at Mafiga, Morogoro, Tanzania

Management regime	Element							
	pH	Organic carbon (g/100g)	Total nitrogen (g/100g)	p (ppm)	m.e/100g			
					K	Ca	Mg	Na
Acacia monoculture								
No trees	6.39a*	0.73a	0.07a	31.50a	0.55a	3.64a	1.16a	0.04a
Trees present	6.24a	0.78a	0.08a	31.75a	0.54a	3.77a	1.15a	0.02a
Acacia + maize								
No trees	5.74c	0.80a	0.07a	40.75a	0.60a	3.70a	1.07a	0.03a
Trees present	5.96c	0.85a	0.08a	43.50a	0.64a	4.00a	1.09a	0.04a
Acacia + beans								
No trees	6.00b	0.80a	0.07a	44.25a	0.63a	3.75a	1.18a	0.03a
Trees present	6.10b	0.83a	0.08a	40.25a	0.59a	4.06a	1.12a	0.03a

* = Values in the same column with the same subsript do not differ significantly ($p < 0.05$).

Table 20: Elemental concentration of soils for a soil depth of 15-30 cm in areas with and without *Acacia albida* trees at Mafiga, Morogoro, Tanzania.

Management regime	Element							
	pH	Organic carbon (g/100g)	Total nitrogen (g/100g)	p (ppm)	m.e/100g			
					K	Ca	Mg	Na
Acacia monoculture								
No trees	6.16b*	0.60e	0.05a	19.25a	0.41a	3.41b	1.06a	0.02a
Trees present	6.24a	0.68d	0.07a	28.25a	0.49a	3.76b	1.16a	0.02a
Acacia + maize								
No trees	5.72f	0.70c	0.07a	30.25a	0.45a	3.60b	1.08a	0.03a
Trees present	5.97d	0.73b	0.07a	32.50a	0.46a	4.22a	1.13a	0.03a
Acacia + beans								
No trees	5.88e	0.68d	0.07a	27.00a	0.43a	3.81b	1.15a	0.03a
Trees present	6.05c	0.80a	0.07a	32.25a	0.42a	4.20a	1.19a	0.03a

* = Values in the same column with the same subscript do not differ significantly ($p < 0.05$)

Table 21: Elemental concentration of soils for a soil depth of 30-60 cm in areas with and without Acacia albida trees at Mafiga, Morogoro, Tanzania.

Management regime	Element							
	pH	Organic carbon (g/100g)	Total nitrogen (g/100g)	p (ppm)	m.e/100g			
					K	Ca	Mg	Na
Acacia monoculture								
No trees	6.10b*	0.43a	0.04	18.00a	0.25a	3.14b	1.09a	0.04a
Trees present	6.17a	0.50a	0.04b	18.50a	0.27a	3.67a	1.28a	0.04a
Acacia + maize								
No trees	5.82c	0.53a	0.05	23.50a	0.32a	3.34b	1.18a	0.04a
Trees present	6.03b	0.50a	0.05a	31.00a	0.29a	3.97a	1.25a	0.04a
Acacia + beans								
No trees	5.89c	0.53a	0.05a	16.25a	0.26a	3.61b	1.38a	0.04a
Trees present	6.00b	0.55a	0.05a	24.25a	0.25a	3.93a	1.39a	0.04a

* = Values in the same column with the same subscript differ significantly ($p < 0.05$)

Generally, the trees did not show significant influences on the concentrations of the studied soil nutrients.

Tables 22 and 23 show the relationship between biomass production by _A. albida_ and the soil nutrients in the stand. A direct and significant relationship between stem and root biomass production and the concentration of K in the soil was found (Table 22). Increasing the concentration of K by 0.1 m.e./100g increased stem and root biomass production by 1.16 tons ha^{-1} and 0.80 tons ha^{-1} respectively.

Table 22: Simple regression equations relating soil nutrient elements to biomass production of six-year old _Acacia_ _albida_ at Mafiga, Morogoro, Tanzania.

Equation	R^2	F
Stem biomass = 4.03 + 11.60 K	0.42	7.2*
Root biomass = 3.00 + 8.04 K	0.42	7.2*

* = Significant at $p < 0.05$.

Multiple regressions showed the soil concentrations of P, Ca, N and Mg to be closely related to stem, branch, root, total above ground and total tree biomass production (Table 23). There were direct and significant relationships between P and Ca concentrations and stem, branch, root, total above ground and tree biomass. Increasing the concentration of P by 1 ppm, increased biomass production by 0.14, 0.05, 0.10, 0.28 and 0.38 tons ha^{-1} for stem, branch, root, total above ground and total tree biomass respectively. Likewise, increasing the concentration of Ca by 0.1 m.e./100 g increased biomass production by 0.32, 0.12, 0.22, 0.66 and 0.98 tons ha^{-1} for stem, branch, root, total above ground and total tree biomass respectively.

Table 23: Multiple regression equations relating soil nutrient elements to biomass production of six-year old *Acacia albida* at Mafiga, Morogoro, Tanzania.

Equation	R^2	t values
Stem biomass = 13.29 + 0.14 P + 3.15 Ca - 181.27N - 8.23 Mg	0.75	P = 3.772***
		Ca = 2.320*
		N = 2.609**
		Mg = 2.516**
Branch biomass = 5.09 + 0.05 P + 1.20 Ca - 67.97 N - 3.21 Mg	0.75	P = 3.742***
		Ca = 2.231*
		N = 2.522**
		Mg = 2.450**
Root biomass = 9.37 + 0.10 P + 2.18 Ca - 124.90 N - 5.70 Mg	0.75	P = 3.776***
		Ca = 2.318*
		N = 2.599**
		Mg = 2.522**
Total aboveground biomass =28.19 + 0.28P + 6.63Ca - 373.04N - 18.07Mg	0.75	P = 3.705***
		Ca = 1.929*
		N = -2.326**
		Mg = 2.476**
Total biomass = 37.504 + 0.38 P + 9.75 Ca - 535.36 N - 25.26 Mg	0.76	P = 3.889***
		Ca = 2.145*
		N = 2.524**
		Mg = 2.617**

* = Significant at $P < 0.1$

** = Significant at $P < 0.05$

*** = Significant at $P < 0.01$

On the other hand, an inverse and significant relationship existed between stem, branch, root, total above ground and total tree biomass, and the concentrations of N and Mg in the soil. Increasing the concentration of N by 1 g/100 g decreased biomass production by 1.81, 0.68, 1.25, 3,73 and 5.35 tons ha^{-1} of stem, branch, root, total above ground and total tree biomass respectively. While increasing the concentration of Mg by 0.1 m.e./100 g decreased biomass production by 0.82, 0.32, 0.57, 1.80 and 2.53 tons ha^{-1} for stem, branch, root, total above ground and total tree biomass respectively.

No clear relationship was found between foliage biomass, brushwood biomass, tree volume, and the soil nutrient concentrations.

4.7 Growth of roots of individual trees within the soil profile

4.7.1 The distribution of fine roots (< 5 mm)

The distribution pattern of the fine root biomass to a depth of 45 cm is shown in Figure 2. It is evident that most of the fine roots are found within the top 30 cm of the soil profile. The fine root biomass decreases with increasing soil depth. This is true for all the spacing treatments studied.

4.7.2 The distribution of coarse roots (> 5 mm)

Mean diameters and lengths of the lateral roots of six-year old *A. albida* are shown in Table 24. The distribution of the roots within the soil profile is shown in Figure 3. An additional illustration (Figure 4) presents the distribution of coarse root biomass in individual A. *albida* trees down the soil profile.

The mean diameters of the lateral roots varied from 1.45 to 2.36 cm and mean lenghts varied from 1.64 to 2.32 m. The mean length of the taproot was 2.8 m. No significant variations in mean diameters and lengths of the lateral roots were found between the various soil horizons. However, significant variations in the mean diameters and lengths of lateral roots between individual trees occured (Table 25).

The lateral roots were confined mostly to the top 200 cm of the soil profile. Generally, the root biomass decreased with increasing soil depth (Figure 4). The coarse roots accounted for about 67% of the total root biomass (taproot, 60%, lateral roots 40%), while the fine roots accounted for about 33%.

A. albida root system consists of a well developed taproot with fairly large lateral roots growing downwards (Figure 5). Few lateral roots occur near the surface, with a majority of them occupying the deeper soil layers (Figure 6). Most of the lateral roots extend more or less equidistantly around the tree and they branch though not frequently.

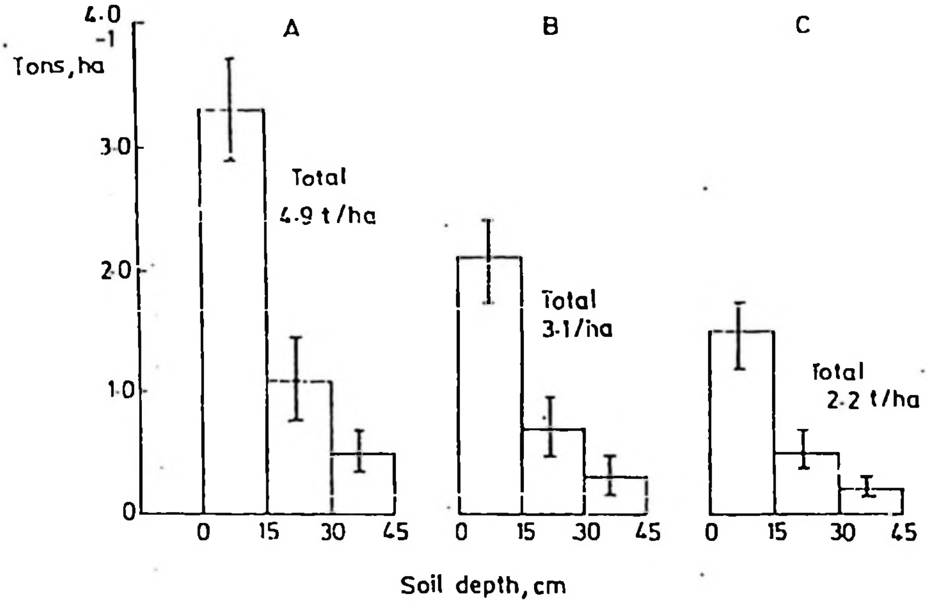


Figure 2 : Fine root biomass (< 5 mm) distribution down the soil profile for Acacia albida under (A) 4 x 4 m, (B) 5 x 5 m, and (C) 6 x 6 m spacing at Mafiga, Morogoro.

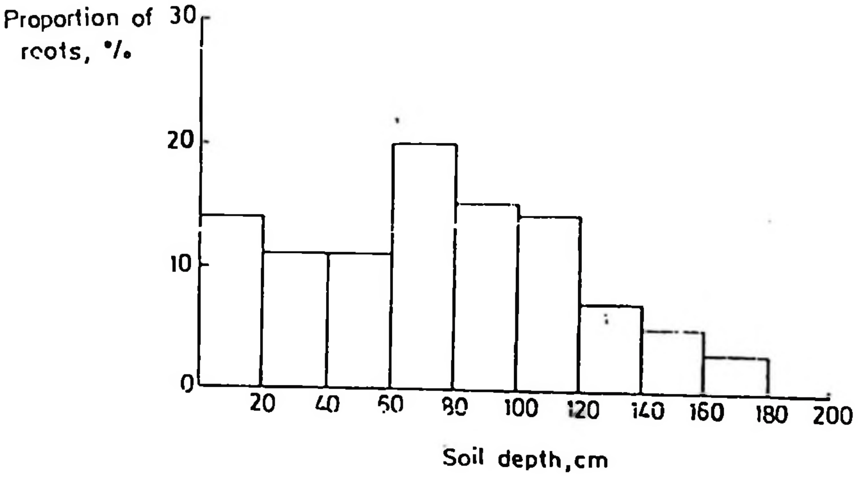


Figure 3 : Profile distribution of lat^e^ral roots in individual trees of Acacia albida at Mafiga, Morogoro

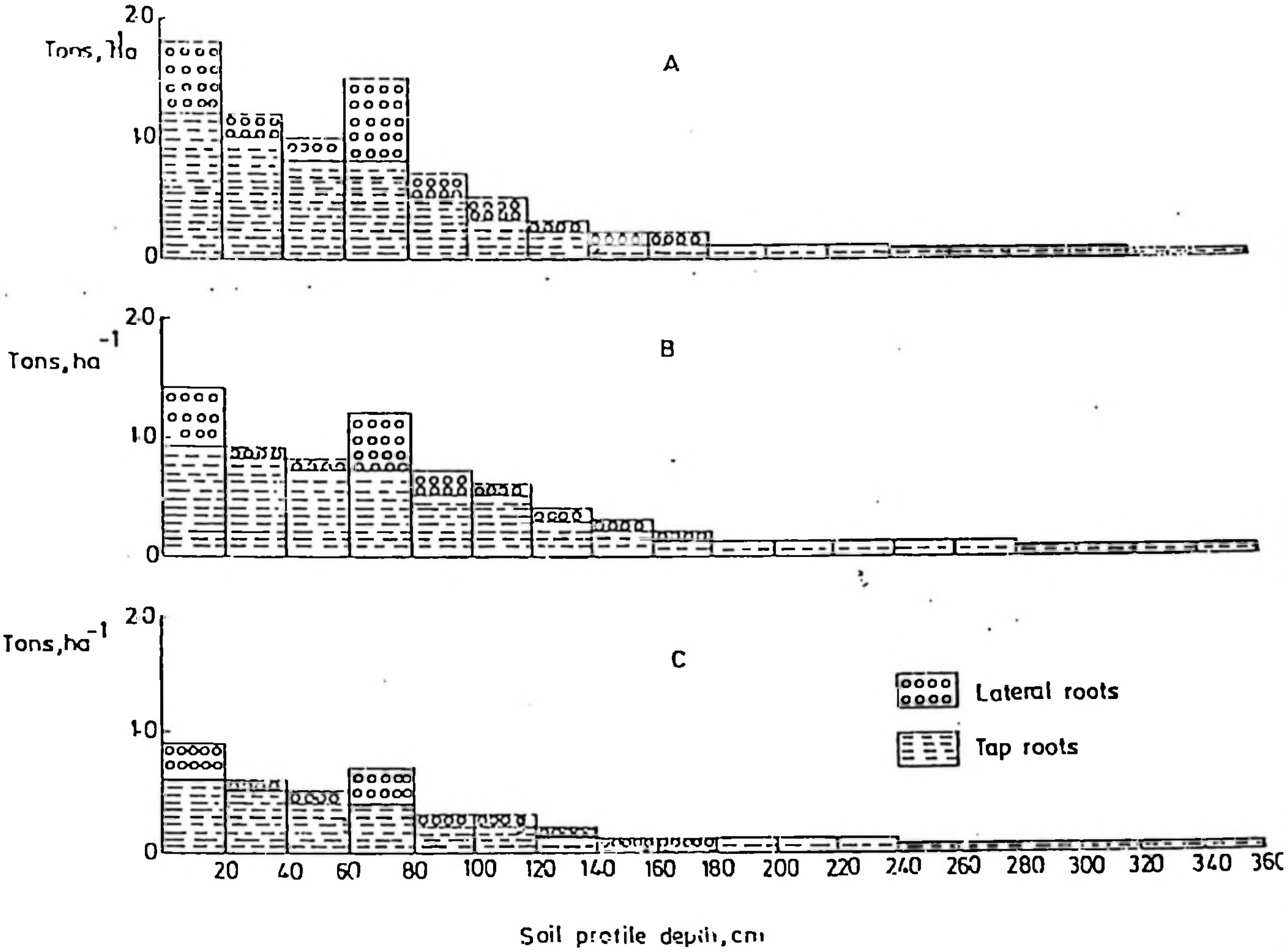


Figure 4 : Profile distribution of root biomass (> 5 mm) in individual Acacia albida trees planted at (A) 4 x 4 m, (B) 5 x 5 m, and (C) 6 x 6 m, spacing at Mafiga, Morogoro.

Table 24: Mean diameters and lengths of lateral roots (± standard deviation) at various soil depths for individual trees of six-year old Acacia albida at Mafiga, Morogoro, Tanzania.

Soil depth, cm	Lateral root diameters, cm*	Lateral root lengths, m
0 - 20	2.36 + 1.07	2.32 + 0.71
20 - 40	1.68 + 1.22	2.01 + 0.53
40 - 60	1.69 + 1.59	2.08 + 0.47
60 - 80	1.73 + 2.26	1.88 + 0.95
80 - 100	2.08 + 1.21	1.80 + 0.54
100 - 120	1.64 + 1.18	1.64 + 0.64
120 - 140	1.92 + 0.91	1.74 + 0.44
140 - 160	2.08 + 0.87	1.66 + 0.52
160 - 180	1.45 + 0.80	2.12 + 0.21

* = Diameters measured at the junction with the taproot.

Table 25: ANOVA for the mean diameters and lengths of lateral roots at various soil depths for individual six-year old *Acacia albida* trees at Mafiga, Morogoro, Tanzania.

i) Mean diameters of lateral roots

Sources of variation	DF	SS	MS	F
Trees	7	21.227	3.032	2.25*
Soil horizons	8	5.205	0.651	0.05 n.s.
Error	56	75.331	1.345	
Total	71	101.763		

ii) Mean lengths of lateral roots

Sources of variation	DF	SS	MS	F
Trees	7	5.977	0.854	2.996**
Soil horizons	8	3.434	0.429	1.50 n.s.
Error	56	15.945	0.285	
Total	71	25.356		

* = Significant at $p < 0.05$

** = Significatn at $p < 0.01$

n.s = Not significant

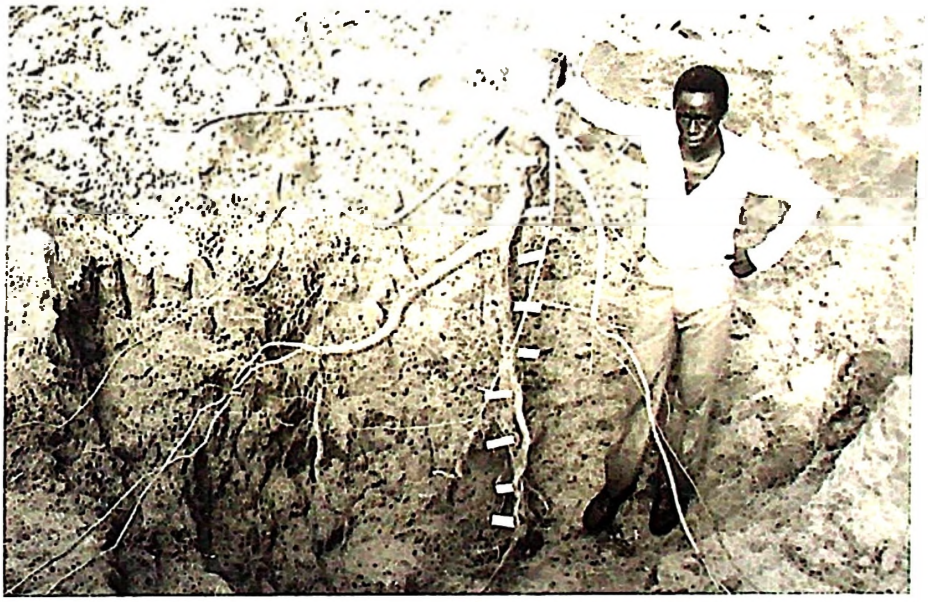


Figure 5: Root system of individual *Acacia albida* tree exposed by manual digging.

Figure 6: Root system of individual *Acacia albida* tree. exposed by manual digging.

CHAPTER 5

DISCUSSION

5.1 Height and diameter growth of *Acacia albida* at Mafiga, Morogoro

5.1.1. Height growth

Height growth of *A. albida* at the end of six years ranged from 8.1 m for trees intercropped with maize at a spacing of 6 x 6 m, to 9.1 m for trees which had been cleanweeded at a spacing of 4 x 4 m (Table 6). Neither intercropping nor tree spacing did significantly influence height growth of *A. albida* trees in the study. Mean annual height growth for the period ranged from 1.4 to 1.5 m. The growth rate at Mafiga was generally higher than that reported for the species in Namibia (Wickens, 1969), but was within the range reported for *A. albida* in Senegal (Anon, 1966). The mean annual height growth in Namibia was 1.0 m, while that in Senegal averaged 0.6 m (range 0.5 to 1.6 m).

In the same experimental site at Mafiga, Morogoro, a comparable mean height of 7.1 m (MAI 1.4 m) was reported for five-year old *Leucaena leucocephala* (Maghembe *et al*., 1986). But a three year-old *Eucalyptus tereticornis* growing in the same area attained an average plot height ranging from 6.4 to 8.9 m (MAI 2.1 to 3.0 m) (Ahimana and Maghembe, 1987). These values are much higher than those of *A. albida* reported in this study. These differences can be ascribed to the inherent differences between the species grown at Mafiga. Both *L. leucocephala* and *E. tereticornis* are relatively shorter-lived trees which grow and mature fast. At the relatively early age of 1-2 years they were already on seed and clearly at a mature stage. For *A. albida*, the trees were still at a juvenile stage at the time of the study.

In other semi-dry tropical climates, height growth data reported for other tree species are comparable to those of *Acacia albida* reported in this study. Annual height growth for *Acacia nilotica* at Uttar Pradesh and Rajastan in India was 1.1 m (Singh, 1982), while for fast-growing *Eucalyptus* species in dry sites in Africa, the annual height growth ranged from 1.5 to 1.8m (FAO, 1974). *Dalbergia sisoo* at the age of 7 years attained MAI of 1.8 m in Pakistan (Sheikh, 1986). Compared to these results, therefore, the height growth of *A. albida* at Morogoro was satisfactory. At this site, it grew as well as *L. leucocephala* although its growth rate was inferior to that of *E. tereticornis*. It is also apparent that height growth of *A. albida* under cleanweeding and intercropping at Morogoro is comparable with growth of the same and other species under similar conditions in semi-arid tropical climates. Since there was no significant difference in height growth between *A. albida* monocultures and *A. albida* trees intercropped with maize or beans, it is apparent that the trees were not suppressed by the food crops. This implies that a good yield of fuelwood can be obtained from *A. albida* wood lots despite the fact that trees are grown together with food crops. The absence of the influence of spacing on height growth is in general agreement with findings that height growth is influenced more by site conditions than by spacing (Smith, 1962), except at very high stocking (Van den Beldt, 1982).

5.1.2 Diameter growth

At the age of six-years, the average diameter of *A. albida* at Morogoro ranged from 9.0 cm for trees intercropped with beans at a tree spacing of 4 x 4 m, to 11.9 cm for trees intercropped with beans at a tree spacing of 6 x 6 m (Table 7). Intercropping with maize and with beans did not significantly influence diameter growth of *A. albida* trees in the study. Tree spacing, however, significantly influenced diameter growth. Wider spacings had significantly bigger diameters than closer spacings. The mean annual increment for the growth period was 1.6 cm. In other semi-arid climates in Africa, diameter growth rates of *A. albida* are reported to range from 0.61 to 2.90 cm annually (Mariaux, 1966), as well as 1.0 to 2.2 cm annually (Wickens, 1969) and from 0.3 to 2.2 cm annually (Anon, 1966). The mean diameter increment in *A. albida* at Mafiga, therefore falls within the ranges reported elsewhere. Part of the reason for the large ranges reported by these workers is in part attributed to site variability (Mariaux, 1966), but a major part of this variability, is attributable to genetic differences (Felker, 1978).

A comparable diameter growth of 1.5 cm (MAI) was obtained for a five-year old *L. leucocephala* growing in the same area (Maghembe *et al.*, 1986). A three - year old *E. tereticornis* also grown in the same area had a better diameter growth with MAI of 2.8 cm (Ahimana and Maghembe, 1987).

When compared with other species growing in semi-arid environments, diameter growth of *A. albida* at Morogoro was superior to that of *Acacia nilotica* in India with MAI of 1.3 cm (Singh, 1982). But it was lower than that for *E. citriodora* and *D. sisoo*, with MAI of 2.5 and 2.9 cm respectively reported in Pakistan (Sheikh, 1986).

As with height growth, diameter growth of *A. albida* at Morogoro was quite satisfactory. It grew as well as *L. leucocephala* at the same site but its growth rate was inferior to that of *E. tereticornis* growing at the same site. Diameter growth of *A. albida* under clean-weeding and intercropping at Morogoro is comparable with growth of the species under similar conditions elsewhere in Africa. Unlike *E. tereticornis* (Ahimana and Maghembe, 1987) and *E. camaldulensis* (Maghembe and Redhead, 1982) whose diameter growth was hampered by the presence of food crops, diameter growth in *A. albida* was not similarly affected. This is an advantage in agroforestry systems, since the ultimate yield from trees will not be affected. Therefore, maize and beans can be included in *A. albida* woodlots (at current spacing) without risking much in fuelwood yields. Since wider spacings favour diameter growth (Guevara *et al*, 1986), it would appear that wide spacings should be adopted when estabishing *A. albida* for uses requiring large diameters as in the case of timber production or making other domestic structures. As yield per hectare is increased significantly by the number of trees per hectare, the closest spacing (in this case 4 x 4 m) would be appropriate for maximizing on fuelwood yields.

5.2 Biomass and volume production in relation to fuelwood consumption in rural areas

5.2.1 Volume

Total volume production in the present study ranged from 9.9 m^3 ha^{-1} for trees intercropped with maize at 6 x 6 m spacing to 24.9 m^3 ha^{-1} for trees intercropped with maize at 4 x 4 m spacing (Table 9). The number of trees per hectare in the study ranged from 278 to 625. The stems accounted for nearly 65% of the total volume, while the branches accounted for 35%. There were no significant differences in volume production between trees grown as monoculture and those under intercropping with maize or with beans (Table 9). Tree spacing caused most of the observed differences between treatments (Table 8). Wider spacings showed the lowest volume, while closer spacings showed the highest volume production.

No volume production values for A. albida exist in the literature to compare with the data in the present study. However, in the same experimental site at Mafiga, Morogoro, comparable volume production values for other species have been reported. Volume production data for 5-year old L. leucocephala (Maghembe et al., 1986) intercropped with maize and with beans or in comparable monoculture at Mafiga, ranged from 21.8 to 32.8 m^3 ha^{-1}. The study involved 625 to 1225 trees ha^{-1}. In another experiment with Leucaena at Mafiga (Lulandala, 1985), the volume yield recorded was 25.1 to 52.1 m^3 ha^{-1} and the study involved 400 to 1,111 trees ha^{-1}. Data for a 3-year old E. tereticornis stand with 1,600 trees ha^{-1} in the same area was 24.8 to 37.8 m^3 ha^{-1} (Ahimana and Maghembe, 1987). For a spacing of 4 x 4 m therefore, volume production by A. albida at Mafiga, Morogoro, is comparable to those by L. leucocephala and E. tereticornis.

Intercropping with maize and with beans did not significantly affect volume production by A. albida. This is in strong contrast to reports for E. tereticornis (Ahimana and Maghembe, 1987) and L. leucocephala (Maghembe et al, 1986). Intercropping with maize and with sorghum significantly reduced volume production for both species. In the later studies, volume production was reduced by as much as 10-30% when compared to cleanweeded monoculture trees. The effects of the food crops on the trees have been ascribed to competition, adversely affecting height and diameter increment in the first year of tree growth. Such competition is thought to centre mainly on light and mineral nutrition (Maghembe and Redhead, 1982). These competitive effects are less pronounced in the case of A. albida because the trees are physiologically less active (as exemplified by leaffall) during the rainy season when food crops are growing. The trees resume active growth towards the end of the rainy season when the food crops are being harvested. Both maize and beans can therefore be successully included in A. albida woodlots for village forestry without significant losses in fuelwood and other wood product yields.

Volume production by A. albida at the present study was significantly influenced by tree spacing. Individual tree volume increased with increasing spacing, but volume production per hectare increased under close spacing because of a higher tree density. Similar results for other multipurpose tree species have been reported (Guevara, 1976; Guevara et al, 1978; Lulandala, 1985; Maghembe et al., 1986).

These results indicate that higher fuelwood yields from A. albida can be obtained by planting at close spacing when establishing village woodlots. Given the present shortages of fuelwood in the semi-arid areas of Tanzania and indeed the rest of sub-saharan Africa, village woodlots involving multipurpose trees like A. albida are one of the solutions to this problem. Assuming a fuelwood consumption level of 1-2 m^3 per person per annum and given an average family size of 6 people, one hectare of a six-year old A. albida at a spacing of 4 x 4 m and under intercropping with maize (24.9 m^3 ha^{-1}), would produce enough fuelwood for annual needs of 2-4 households. The benefit alone would save more than 500 mandays per annum used for the procurement of this resource. This is in addition to fodder and other benefits. The above mentioned figures are based on the fact that the trees are clearfelled at this stage. But fuelwood from A. albida is normally obtained through lopping of branches (Poschen, 1986). Yields obtained from loppings will obviously be less than the 8.7 m^3 accounted for by branch biomass. This approach provides for long term utilization of the trees and allows the other benefits of A. albida to be fully utilized. These include more efficient biological nitrogen fixation by large trees, production of younger foliage for fodder and at maturation the production of pods for fodder.

5.2.2 Biomass production

Biomass distribution in tree components of A. albida was stem, 32%; roots, 35%; brushwood, 15%, branches, 12% and foliage, 6%. This distribution of the aboveground biomass of A. albida is quite similar to that reported for other multipurpose trees (Lulandala, 1985; Nwoboshi, 1985; Maghembe et al., 1986). Jung (1969) reported biomass distribution of a single A. Albida tree to be 59% for the aboveground parts and 41% for root biomass. No indication was made as to how much of the aboveground biomass is constituted by stem, branches or foliage. So it is difficult to make any comparisons with data obtained in the present study. The proportion of root biomass reported in the present study (35 ± 5%) is comparable to that reported by Jung (1969), although his data were based on a single tree as opposed to eight trees used in the present study. In addition, foliage biomass was considerably underestimated in the present study because sampling was done a few weeks after leaf setting following a deciduous period.

The aboveground biomass values in the present study varied from 12.9 tons ha^{-1} for trees intercropped with beans at 6 x 6 m spacing to 28.3 tons ha^{-1} for trees intercropped with maize at 4 x 4 m spacing (Table 10). Intercropping with maize or with beans did not significantly affect biomass production in *A. albida*. The main variations in biomass production resulted from tree spacing (Taable 11). Biomass production estimates of *A. albida* are scarce in the literature. Jung (1969) reported biomass production by one six-year old *A. albida* tree to represent 140 tons ha^{-1} . As he was working with a single tree, he assumed the number of trees per hectare to be 43. Given that the number of trees per hectare in the present study ranged from 278 to 625, the value obtained by Jung (1969) is clearly too high. Other reservations on his data have been expressed by Felker (1978).

In the same experimental site at Mafiga, Comparable biomass production figures are reported for other tree species. The biomass production data for five-year old *L. leucocephala* ranged from 13.5 to 31.1 tons ha^{-1} for plots with 625 to 1,225 trees/ha (Maghembe *et al*., 1986). In another experiment with four-year old *Leucaena* at the same site (Lulandala, 1985), the biomass production figures recorded ranged from 21.8 to 44.3 tons ha^{-1} for plots representing 400 to 1111 trees ha^{-1} . Data for a 3-year old *E. tereticornis* stand with 1,600 trees ha^{-1} in the same area was 21.0 to 31.0 tons ha^{-1} .

Table 1 gives a summary of biomass production values for young tree plantations covering diverse climates and tree densities. When compared to values in Table 1, it is evident that biomass production values for A. albida in the present study are considerably lower than those reported for Cupressus lusitanica and Pinus patula at Olmotonyi, Arusha, Tanzania (Lundgren, 1978), Gmelina arborea in Brazil and in Nigeria (Chijioke, 1980), Prosopis juliflora at Mombasa, Kenya (Maghembe et al., 1983), Tectona grandis in Nigeria (Nwoboshi, 1980) and Gmelina arborea in Nigeria (Nwoboshi, 1985). These studies gave consistently higher values than A. albida at Mafiga, Morogoro because not only higher densities were involved but also they represent yields in the humid tropics.

In semi-arid zones similar to Morogoro, and in sub-tropical climates, biomass production by other tree species was comparable to that of A. albida. A typical example is biomass production by Eucalyptus hybrid in India (George, 1974). See Table 1.

The results of this study indicate that biomass production by A. albida under cleanweeding and intercropping at Morogoro is comparable to biomass production by other species in semi-arid and in sub-tropical climates. The results further indicate that intercropping with either maize or beans does not affect biomass production. These findings are in strong contrast to those reported for E. tereticornis (Ahimana and Maghembe, 1987) and L. leucocephala (Maghembe et al, 1986). Intercropping with maize and with sorghum significantly reduced biomas production for both E. tereticornis and L. leucocephala. Like for volume, biomass production values were reduced by a factor of 10-30% when compared to the cleanweeded treatments. The effect of maize and sorghum on the trees has been ascribed to competition, adversely affecting height and diameter increment in the first year of tree growth (Maghembe and Redhead, 1982). Maize intercropping seems also to reduce the production of multiple leaders in the case of *L. leucocephala* which in turn may have effect on stem and branch biomass. In other studies, the growth of young *Gmelina arborea* trees in Nigeria was adversely affected by intercropping with cassava and yams (Ojeniyi and Agbede, 1980). These competitive effects are less pronounced in the case of *A. albida* because the trees are physiologically less active (as examplified by leaffall) during the rainy season when food crops are growing. The trees resume active growth towards the end of the rainy season when the food crops are being harvested.

Regression models demonstrated positive correlations between biomass production and the amounts of available phosphorus and exchangeable potassium and calcium in the soil. Total nitrogen and exchangeable magnesium, however, were negatively correlated (Tables 22 and 23). A positive correlation indicates that the elements occur at sub-optimal levels, and that marginal increase in the level will positively affect growth. A negative correlation on the other hand indicates that at high levels, the element may affect growth negatively through phytotoxicity or by inhibiting the uptake of other nutrients (Jones, 1970; Thornley, 1978). Considerable inputs of N were made through fertilization of the plots intercropped with maize and with beans. This may have resulted in high accumulations of N in the soil. Since the fertilizer used was mainly ammonium sulphate, considerable acidification by the compound may also have had a bearing on the observed N correlation. The negative relationship between magnesium and biomass is more difficult to explain, especially in view of the addition of triple superphosphate during crop fertilization.

In this study, relatively high values of biomass were found to be associated with maize intercropping (Table 10). It is tempting to attribute this to the fact that the maize plots received more fertilizer than the bean plots. But the analysis of soils in both the maize and bean plots showed no significant differences in soil nutrient concentrations (Tables 18, 20, and 21). It therefore, appears that the bulk of the elements applied as fertilizer was taken up by the maize crop. Therefore, another possible explanation for this relative increase in growth in these plots might be due to the mulching effect of maize residues left in the plots after the harvest of the crops. It is possible that soil moisture is conserved by the mulch and that this moisture is later utilized by the trees for a considerably longer growth period during the dry season. This effect might not be felt in the bean plots due to complete removal of the bean residues during harvesting. Nevertheless, the results of this study clearly show that maize or beans can be successfully included in *A. albida* woodlots for village forestry without significant losses in fuelwood yields.

Biomass production by *A. albida* in this study was affected by tree spacing (Table II). Individual tree biomass increased with increasing spacing, but biomass production per hectare increased under close spacing of a higher tree density. Similar results for other tree species have been reported (Guevara, 1976; Wang, 1977; Guevara *et al*., 1978; Escalda, 1980; Lu and Hu, 1981; Van den Beldt, 1982; Lulandala, 1985; Yantasath *et al*, 1985). These results indicate that higher fuelwood yields from *A. albida* can be obtained by planting seedlings at closer spacing (4 x 4 m) when establishing village woodlots.

5.3 Nutrient concentration and content of *A. albida* tree components

Nutrient concentrations in tree tissues have been found to vary according to crown class (Madgwick, 1964), position in the crown (Verry and Timmons, 1976), age of tissue (Krueger, 1967), time of the year at harvesting the leaves (Alban, 1985) and external factors like soil nutrient status (MGee, 1963), moisture stress (Brix, 1972) and temperature (Miller, 1966). For diagnostic sampling in forestry research, foliage (Bevege and Richards, 1972), roots and sap (Smith, 1962) of trees haave been proposed. The number of trees to be sampled for reliable data will depend in part on the objective of the study and available resources. In the literature, studies have included samples taken from 3 to 60 trees (Van den Driessche, 1974). In this study, the nutrient concentration studies for each tissue were based on 30 sample trees for aboveground tree components. It was considered that 30 samples for each tissue studied (i.e. foliage, brushwood, branches and stem) have provided sufficiently reliable data for *A. albida* at Mafiga. Mean nutrient concentrations in root samples were based on eight samples of lateral roots and a similar number for taproot. These data also provide a useful guidance to the amount of nutrients held in the underground biomass.

The nutrient concentration levels in different *A. albida* tree components are illustrated in Table 12. As in other nutrient studies for tropical (Lundgren, 1978; Grubb and Edwards, 1982) and temperate ecosystems (Leaf, 1973; Francis and Baker, 1982), the highest concentrations for all nutrients studied were in the foliage. In terms of nutrients in the aerial tree components, the following decreasing order prevailed: foliagae > brushwood > branches > stem. Similar trends for other tree species have been reported (Woodwell *et al*., 1977; Madgwick *et al*, 1977; Maghembe *et al*., 1983; Nwoboshi, 1985). With regard to individual nutrient concentrations in all aerial tree components, the following was the order in a decreasing manner: N > K > Ca > Na > Mg > P. In the root tissues, individual nutrient concentrations decreased as follows: N > K > Ca > Mg > P = Na.

Magnesium, Ca and Na concentration showed little variation between the tree components, while N, P and K concentrations showed high variation (Table 12). This could be attributed to the fact that after uptake, N, P and K are normally redistributed to a considerable extent within the plant tissues, while Ca, Mg and Na are redistributed only to a very small extent (Hill, 1980; Grub and Edwards, 1982). Variation in the nutrient concentration between tree components also depends on the ratio of living to dead tissues in the tree components (Grubb and Edwards, 1982). That is why nutrient concentrations of most elements are highest in the leaves (with a lot of living cells) but low in the wood portions that contain little living tissue.

It is possible that the foliar concentrations of N, P and K reported in this tudy could be on the high side, while for the perennial tissues they could be on the low side. This is so because the sampling of tissues was done a few weeks after the leaf setting following a deciduous period. At this time, these elements are translocated out of the perennial tissues to the leaves (McColl, 1980; Alban, 1985). The concentrations of Ca, Mg and Na for both foliar and perennial tissues could be more reliable because these elements are not easily translocated within the plant.

For a deciduous species like A. albida, it is recommended that foliar sampling should be done several weeks prior to leaf fall (McColl, 1980; Alban, 1985). For N, P and K, this is a time of relative stability in concentration. Incase of the perennial tissues, the convenient time for sampling is during the leafless period (Alban, 1985). During this time, nutrient concentrations remain relatively constant and short term fluctuations due to translocation or environmental conditions are minimized.

Generally, little work has been done on the nutrient concentrations in A. albida, and we are unaware of information other than data on foliage nutrient content. Even then, the only concentratlions reported are for N, P and Ca. The N and P concentrations obtained for foliage in this study are higher than those reported by Giffard (1964), and Radwanski and Wickens (1969). But the Ca concentrations obtained in this study are lower than the values reported in those studies (Table 3). These differences can be attributed in part to sampling of the tissues at different times of the year.

When compared to other tree legumes (Maghembe et al., 1983; 1986; Lulandala, 1985; Alpizar et al., 1986) and other multipurpose trees (Chijioke, 1980, Nwoboshi, 1985), the nutrient concentrations of A. albida reported here are within the range of values reported in those studies (Table 3). These values are also comparable to those reported for tropical forest trees (Ovington and Olson, 1970; Stark, 1971; Golley et al., 1975; Lundgren, 1978). See also Table 2. The only exception is possibly the high N concentration in the foliage reported in this study.

The distribution of mineral contents according to tree components are shown in Tables 13 and 14. The quantities of nutrients associated with A. albida aboveground biomass at the closest spacing (4 x 4 m) are 262.9, 39.4, 156.7, 97.4, 57.6 and 73.8 kg $ha^{-1}$of N, P, K, Ca, Mg and Na respectively. The corresponding values for belowground biomass are 85.0, 8.1, 54.3, 23.5, 18.1m and 8.1 kg ha^{-1}. It is apparent that roots contain substantial amounts of mineral elements, especially N, K, Ca and Mg, when compared to the other components. The results also show that most of the elements in the aboveground biomass are accumulated in the stems and brushwood, with lower amounts in the branches and foliage. This distribution of elements is expected because the nutrient contents in biomass is directly related to both the nutrient concentration and weight of the component parts. In case of A. albida, much of the aboveground biomass (about 70%) is accounted for by the stem and brushwood.

In the present study, tree nutrient pools were not influenced significantly by the associated crops (Table 13). It has been widely believed that many forest species especially trees are deep rooted and would not compete with crops if they were put under intercropping in an agroforestry set up (NAS, 1977; Berendse, 1979). But evidence is building up to show that this is not true and that the fine feeding roots of both trees and crops are closely interacting in the top soil (Russell, 1977; Lulandala, 1985; Jonsson et al., 1987). It is therefore suspected that trees will compete strongly with food crops for nutrients and water. That competition is not apparent here is possibly because the soil nutrients were in sufficient supply. It could also be due to the fact that A. albida trees are less active physiologically when the food crops are growing, becoming only active during the dry season when crops have been harvested.

The overall concentrations, accumulation and distribution of nutrients in the various components of *A. albida* biomass observed in the present study (Tables 12, 13 and 14) are comparable to those reported for other multipurpose trees (Chijioke, 1980; Maghembe *et al.*, 1983; 1986; Lulandala, 1985; Alpizar *et al.*, 1986) and for tropical forest trees (Ovington and Olson, 1970; Stark, 1971; Golley *et al.*, 1975; Lundgren, 1978).

5.4 Nutrient budget and soil nutrient reserves in the stands of *A. albida*

Concern over possible site degradation resulting from nutrient depletion through frequent crop harvests under short rotations and coppice regenerations have been registered (Switzer and Nelson, 1973; Kimmins, 1977; Van Hook *et al.*, 1982). Applications of commercial inorganic fertilizers to replenish depleted nutrients and maintain productivity of affected sites has been suggested (Francis and Baker, 1982).

However, nutrient depletion through harvesting depends on what tree component is removed or left on the site. Two harvesting possibilities could be adopted for *A. albida*:-

- Complete aboveground biomass utilization involving removal of stems, branches and brushwood for fuelwood, and foliage for fodder;
- partial aboveground biomass utilization involving lopping of branches and brushwood for fuelwood; and foliage for fodder.

The frequency of harvesting for both options will depend on the coppicing ability of *A. albida*.

Table 26 shows the amount of available bases, phosphorus and total nitrogen at the study site to a soil depth of 180 cm (zone occupied by tree roots). The content for N may be considered a total soil pool of N, while the contents of P, K, Ca, Na and Mg are exchangeable quantities. A comparison of the quantities of elements that could be removed in a fuelwood and fodder harvest versus the quantities of the same elements found in the soil (i.e. removal versus supply) is also shown in Table 26. All calculations are based on a spacing of 4 x 4 m. For option one, element removals represent 2.3, 7.3, 4.9, 0.7, 2.3 and 5.4% of the N, P, K, Ca, Mg and Na soil quantities respectively. Corresponding values for option two are 1.7, 4.3, 3.0, 0.5, 1.3 and 3.2%. Obviously, option one is more intensive and is likely to result in the removal of more nutrients from the site. Overall, however, the quantities of nutrients removed are so small that they can be considered insignificant. It also appears that the combined harvesting of tree components and food crops from the site does not result in substantial losses of soil nutrients. Using nutrient concentration values for food crop (maize and beans) reported by Ahimana (1982), the combined harvesting of tree components (option one) and maize removes about 2.5, 8.5, 10.9, 1.0, 2.6 and 5.5% of the N, P, K, Ca, Mg and Na soil quantities respectively. Corresponding values obtained when beans are used as an intercrop are 2.4, 8.8, 5.4, 0.8, 2.3 and 5.4%. These calculations are based on the fact that crop residues are also removed during crop harvest. If this is not the case, then the quantities of nutrients exported from the site will be less than those quoted above.

Generally, export of nutrients from the site due to harvesting of tree components and food crops appears to be negligible. In case of A. albida these loses are further minimized because the species adds nutrients to the site through substantial amounts of litterfall and by its ability to fix nitrogen.

Losses of nutrients from the site can also be minimized by making sure that crop residues are left on site after harvest. However, nutrient improverishment will not only depend on the rate and frequency of harvest - export of nutrients but also on nutrient capital and additions through natural and artificial means (Alban, 1982; Francis and Baker, 1982; Lockaby and Adams, 1986). It will also depend on nutrient losses through leaching (Likens et al., 1977). Estimates from this study indicate that about 92% of nitrogen will still be in the soil pool after losses due to tree component and crop harvest; and leaching. The above calculations also took into account the amounts of fertilizer added to the stand from time to time.

5.5 The influence of Acacia albida trees on the yields of maize and beans

The crop yields in this study varied from 143 to 409 Kg ha^{-1} for beans (Table 16) and from 343 to 956 Kg $ha^{-1}$for maize (Table 17). It is apparent that in some of the years, the yields of both maize and beans were very low. This has been correlated to the low rainfall recorded during these years (Table 18). In some years, however, the maize and bean yields were comparable to mean peasant harvests which are at most 800 Kg $ha^{-1}$for maize (Maghembe and Redhead, 1982.)

Table 26: A comparison of the quantities of elements that could be removed in a fuelwood and fodder harvest versus the quantities of the same elements found in the soil (0-180 cm)*

Harvesting option	Element, Kg ha^{-1}					
	N	P	K	Ca	Mg	Na
1. Foliage + brushwood + branches + stem	262.9	39.4	156.7	97.4	57.6	73.8
2. Foliage + brushwood + branches	193.3	23.0	96.0	73.4	33.6	43.3
Soil nutrient reserves	11,340	540	3,168	13,500	2,527	1,368

* = Zone where most of the tree roots are concentrated.

The food crop yields reported here are much lower compared to reports elsewhere (Poschen, 1986). Maize yields reported by Poschen (1986) were in the range of 1,920 to 3,400 Kg ha^{-1}. In other studies, Felker (1978) reports a production of 700 to 1,100 Kg ha^{-1} of millet and Miehe (1986) harvested 650 to 900 Kg ha $^{-1}$. Differences in crop yields can be attributed in part to site differences. Mean annual rainfall figures reported by Poschen (1986) ranged from 600 - 1,000 mm, while those reported by Miehe (1986) ranged from 600 - 900 mm. Mafiga is considered outside the maize cultivation zone due to a generally low and unreliable rainfall usually 500 - 1,200 mm, with a mean of 860 mm and an estimated potential evapotranspiration in excess of 1,450 mm. This might be the reason for the low crop yields recorded in this study.

Six years of intercropping maize or beans with *A. albida* shows no reduction in crop yields attributable to the trees (Tables 16 and 17), even at the closest tree spacing of 4 x 4 m. There are various reasons for this. Because of its exceptional phenology, the competition for water by *A. albida* trees may be negligible during the rainy season when food crops are grown. At the sametime, the tree utilizes water reserves from deeper soil horizons by means of its deep taproot (Miehe, 1986). The other factor is the absence of shading of the food crops by the trees. The virtually leafless crowns of *A. albida* during the growing season means that the crops enjoy full sunshine and the shade cast on the crops is negligible. It has been found that a light shade increases the amount of radiation reaching the soil. This reduces competition for light and nutrients, and gives better light distribution and a lower humidity (Stigter, 1984).

These findings are in strong contrast to those reported for many tree species used in intercropping with food crops. Leucaena leucocephala at close spacing has been found to significantly reduce yields of cassava (Benge, 1977, Escalda, 1980), maize (Kang et al., 1981; Lulandala, 1985), cowpea (Kang et al., 1981) and beans (Lulandala, 1985). Verinumbe and Okali (1985) observed poor performance of maize among coppiced (Tectona grandis) regrowth. Similarly, King (1968) indentified teak (Tectona grandis) canopy to be responsible for a reduction in yield of interplanted maize.

The conclusions reached by these workers seem to indicate that the food crops were more affected by shading and competition for space more than competition for other growth factors chiefly water and nutrients. Verinumbe and Okali (1985) concluded that competition for light was a more critical factor than root competition in these intercropping mixtures, although this and the other trials did not include detailed studies on interspecific competition emanating from nutrient competition.

The other striking feature about the results of this study is the absence of increased food crop yields usually associated with A. albida trees. Several workers have reported increased yields of food crops grown beneath the tress (Robertson, 1954; Felker, 1978; Poschen, 1983; 1986; Miehe, 1986). In Ethiopia, Poschen (1986) reported a 76% increase in the yield of maize and a 36% increase in the yield of sorghum. Higher increases are reported from Senegal where Charreau and Vidal (1965) reported on an increase of 250% in the yield of millet and Poschen (1983) reported 100% increase in the yield of sorghum.

There are possible reasons for these differences. The trees in the present study were comparatively younger than those in other studies. Therefore, the associated rhizosphere benefits usually associated with large A. albida trees had not fully developed. Whereas the trees in this study were only six years of age, those of other studies were at least twenty years. Poschen (1986) stressed the fact that A. albida trees need 35-40 years to grow to a size which can significantly improve yields of underplanted crops. The food crops in the present study were grown in between rows of the trees as opposed to growing them directly beneath the tree canopies as reported in other studies. The other reason could possibly be that the trees used in other studies were isolated trees scattered throughout the farmlands. It is possible that in some of these cases, domestic animals concentrate around Acacia trees during the dry season to seek out and consume pods (Wickens, 1969). Consequently, the animals contribute to soil fertility around the trees with dung and urine.

Another reason could be that, unlike Leucaena leucocephala where N-fixation of 110-180 Kg ha^{-1} is attained at Morogoro (Hogberg and Kvarnstrom, 1982; Lulandala, 1985), relatively lower levels of N are fixed by A. albida at Morogoro (Kiriinya, 1983). However, results of the study indicate that the food crops, maize and beans, can be intercropped with Acacia albida trees without significant losses in yield.

5.6 The influence of *Acacia albida* trees on soil fertility within the stand

At the age of six years, *A. albida* trees had not shown any significant influences on the concentrations of the studied elements in the top soil (0-15 cm). See Table 19. But at the deeper soil layers (15-60 cm) areas with *A. albida* trees had significantly higher amounts of organic carbon, total nitrogen and calcium when compared with areas without trees (Tables 20 and 21). These observations support earlier reports that soils under *A. albida* trees tend to have more organic carbon and total nitrogen (Dugain, 1960; Charreau and Vidal, 1965; Jung, 1967; Dancette and Poulain, 1969; Radwanski and Wickens, 1969); and higher calcium concentrations (Anonymous, 1974; Felker, 1978).

But for all the other elements, no significant differences existed between areas with and without trees. However, in most of the cases, the concentrations of the elements in areas with trees were higher than those in areas without trees, although these differences were not statistically significant. The absence of a statistically significant difference in concentrations of these elements could be attributed to the buffering influences of the soil (Thornley, 1978; Hagin, 1982). It is possible that certain soil properties prelude rapid changes in chemical properties. Other factors which can account for this are:-

- the young age of the trees (six years) as compared to those reported in other studies;
- soil samples in the other studies were taken directly from beneath the tree canopies which was not the case in this study;
- and it is also possible that if the soil samples had been taken from plots with 4 x 4 m spacing instead of 5 x 5 m, a different picture might have emerged.

Nevertheless, it is apparent that the present values may be a trend which will undoubtedly show as the stand grows older.

5.7 Root distribution of individual *Acacia albida* trees in the soil profile

The fine roots of *A. albida* trees were found to be concentrated in the top 30 cm of the soil (Figure 2). This distribution pattern of fine roots is similar to those reported for other tree species notably *Pinus patula* and *Cupressus lusitanica* (Lundgren, 1978); *Pinus radiata* (Nambiar, 1983) and *Leucaena leucocephala* (Lulandala, 1985). Similar results are also reported by Jonson *et al* (1987) for four tree species and maize at Mafiga, Morogoro. They compared the vertical distribution of fine roots (< 2 mm in diameter) of four tree species (*Cassia siamea*, *Eucalyptus tereticornis*, *Leucaena leucocephala* and *Prosopis chilensis*) with that of maize. The trees were found to have a rooting pattern similar to that of maize, that is, a slow decline in fine root biomass with increasing soil depth. On average, the fine root biomass of the two-year old tree species were roughly twice that of maize. From this studies, it was apparent that the tree species are likely to compete with maize and other crops with a similar rooting pattern for nutrients and water. The observations in the present study, therefore, do not support the contention that trees have few roots, especially fine roots, in the top soil. Root competion between *A. albida* trees and the crops can, therefore, be expected since the fine feeding roots of both are closely interacting in the top soil.

Acacia albida root system consists of a well developed taproot with large lateral roots growing downwards. Few lateral roots occur near the soil surface, with a majority of them occupying the deeper soil layers (Figure 6). Most of the lateral roots extend more or less equidistantly around the tree. Certainly, the retention of the taproot seems desirable for a species like *A. albida* planted on poor sites. A deep vertical root system enhances utilization of dry sites because the lower soil profile represents a reserve of soil moisture available only to plants with a deep root system (McMinn, 1963). The uniform distribution of the root system of *A. albida* through the soil profile and the higher proportion of total root biomass at depths greater than 20 cm may reflect the ability to draw nutrients from deeper layers of the soil over a long period of time (Shukla and Ramakrishnan, 1984).

It, therefore, appears that the benefits of *A. Albida* trees to food crops intercropped with them could be attributed to the fact that the trees are physiologically less active at a time when the crops are growing. They resume active growth in the dry season long after the food crops have been harvested. There is, therefore, limited direct competition between the trees and the crops for nutrients and water. The benefits of trees to crops could also be attributed to other types of plant: plant interactions like exchange of metabolites in the soil via mycorrhizae, enhanced soil nitrogen via fixation and enhanced rhizophere activities.

CHAPTER 6

CONCLUSTIONS AND RECOMMENDATIONS

6.1 Conclusions

The principal results and conclusions of the study are as follows:-

1. At the age of six years, Acacia albida had attained a mean height of 8.41 m and a mean diameter at breast height of 10.7 cm.
2. Neither the growth of Acacia albida trees nor the growth of the food crops (maize and beans) were affected by intercropping.
3. Biomass and volume production of Acacia albida trees were not affected by intercropping with food crops, but were affected by tree spacing. The closest spacing gave the highest values for both parameters.
4. The yield of maize or beans were not affected by the presence of the trees, but seemed to relate more to climatic factors and especially rainfall.
5. The distribution of N, P, K, Ca, Mg and Na in the biomass was as follows; leaves, 15%, brushwood, 22%; branches, 14%; stem, 29%; and roots, 20%.
6. Removal of foliage for fodder, and brushwood, branches and stem for fuelwood removes about 80% of the nutrients immobilized in the tree. But removal of brushwood, branches and stemwood for fuelwood alone removes about 65%.
7. If clearfelled, branch and stem volume of one hectare of a six-year old Acacia albida at 4 x 4 m spacing and under intercropping with maize stands at 24.9 m^3 which is sufficient for annual fuelwood needs of 2-4 households.

8. At the age of six-years, Acacia albida trees did not show significant influences on the fertility of the soil in the stand. It is considered that at this age, the trees are too young to have had significant impacts on the soil.
9. Acacia albida root system consists of a well developed taproot with lateral roots growing downwards. The root system was uniformly distributed within the soil profile at Mafiga, but with a higher proportion of lateral roots at depths greater than 20 cm. The fine roots, however, are concentrated in top 30 cm of the soil.

6.2 Recommendations

The following recommendations are applicable:-

1. Demonstration plots growing Acacia albida with major staple food crops in selected areas of the country and elsewhere similar climatically to Mafiga can be established. These trials should be geared towards:-

- assessing the growth and yield of both the tree and the food crops,
- assessing the nutrient flow and long-term implications for site nutrient budgets and productivity in areas with varying soil nutrient reserves,
- and quantifying drains of nutrients due to Acacia albida growing in different climatic conditions so that patterns of variation in this characteristic can be identified and predicted on both regional and local scales.

2. Extend monitoring of Acacia albida growth and production for more years to enable a reliable projection of long-term growth and the influence of the trees on soil conditions.

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