EFFECT OF LEGUME INTERCROP MANAGEMENT PRACTICES AND INORGANIC NITROGEN APPLICATION ON GROWTH AND YIELD OF FINGER MILLET (*Eleusine coracana* L.).

BY

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DECLARATION

This thesis is my original work and has not been presented for a degree in any other University.

Akuja, Thomas Ekamais ------------ Date ---------- 25/7/1995

This thesis has been submitted for examination with our approval as University supervisors.

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DEDICATION

To my late father, Akuja Adokoro, my beloved mother, Mrs Lokuchei Akuja and my elder sister, Pauline Namase, who took me to school although they hadn't done so themselves.

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ABSTRACT

Two-phased field experiments were conducted at Kabete Field Station, University of Nairobi, Faculty of Agriculture, Kabete Campus and Field 3, Egerton University, Njoro Campus to investigate the effects of legume intercrop management practices and inorganic nitrogen application on growth and yield of finger millet (*Eleusine coracana*). In phase one, an indigenous vegetable legume (*Crotalaria brevidens*), a fodder legume (*Trifolium quartinianum*) were intercropped with finger millet and sole finger millet supplied with three rates (0, 20, and 40 Kg N/ha) of nitrogen in the form of urea (46% N) were laid out in a completely randomized block design with three replicates. Data collected included plant heights and biomass for the legumes and finger millet at various harvesting stages. During the last biomass harvest plants from half of an experimental plot were either uprooted or cut at ground level ensuring minimum soil disturbance. This procedure formed the basis for phase two of the study. In this phase finger millet was planted on all the last seasons plots. Considering the two harvesting methods there were eighteen plots which gave eighteen treatments which had been laid out in a split plot design. Data collected included plant heights, biomass, yield and yield components of finger millet.

Results from phase one indicated that intercropping promoted vigour in the growth of *Crotalaria brevidens*, whereas the performance of *Trifolium quartinianum* was unaffected, especially at Kabete. This was observed from the time of emergence where *Crotalaria brevidens* sprouted earlier than finger millet and *Trifolium quartinianum*. At Njoro, germination time was more or less the same for all crops but the vegetative and reproductive growths of *Trifolium quartinianum* were improved. At both sites results showed that inorganic nitrogen had a beneficial effect on the two leafy legumes. However, N enhanced both the vegetative and reproductive growth of sole finger millet.

Fresh leaf weight of *Crotalaria brevidens* at 56 (DAP) was 12.5% of the cummulative leaf fresh weight at 84 DAP, while that of *Trifolium quartinianum* was 10% of the final weight. In the case of of total leaf dry weight that for *Crotalaria brevidens*, 56 DAP was 11% of that at 84 DAP while that of *Trifolium quartinianum* was 18% of the final weight.

Plant heights increased proportinately with that of *Crotalaria brevidens* being higher than that of finger millet. *Trifolium quartinianum* was always shorter than finger millet at both sites. Biomass (stems and leaves) of legumes was significantly higher in plots where finger millet was intercropped with *Crotalaria brevidens* than where it was intercropped with *Trifolium quartinianum* at Kabete only. Total legume and finger millet biomass production was significantly higher at Kabete than in Njoro. Topdressing with N significantly increased the biomass of sole finger millet. Land equivalent ratios (LERs) were significantly lower in *Crotalaria brevidens*-finger millet intercrops than they were in *Trifolium quartinianum*-finger millet intercrops. In all plots The C:N ratios were higher in top soils than in subsoils.

In phase two, finger millet planted on plots in which plants had been cut germinated earlier than those on plots whose plants had been uprooted at Kabete. Intercropping had no significant effect of the growth of finger millet. It was the opposite at Njoro. Residual N and previous season's harvesting methods had a significant ($P<0.05$) effect on height but not on biomass, yield and yield components of finger millet plants at both sites. In this phase C:N ratios in all plots were lower in sub than top soils and the ratios were higher than those of phase one.

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CHAPTER ONE

1.0 INTRODUCTION

Increasing land pressure due to rapid population growth in many parts of the tropics has led to shortening of the fallow periods which used to restore soil fertility in many traditional farming systems (Torres, 1984). Agricultural output in the 1970s in Sub-Saharan Africa (SSA) decreased by 1.3%, while population rose by 2.7% (Meerman and Cochrane, 1982). Kenya's population growth rate was officially at 4% per annum (p.a) in 1979 (Stewart and Hash, 1981), but by 1989 it had reduced significantly to 3% p.a.(*Anonymous*, 1994).

Consequently, the high potential agricultural areas are now becoming more and more populated leading to soil degradation, depletion of soil nutrients and a decline in crop yields. The result of this is a rapid expansion of small holder farming in marginal areas of Kenya (Stewart and Hash, 1981). The new comers to marginal areas have no farming background of their new areas in terms of crop selection and the appropriate agronomic practises for food production in these areas.

Methods of improving productivity of traditional farming systems by the introduction of inorganic fertilizers have not been widely adopted by the poor small-scale farmers. This is because the inorganic fertilizers are expensive and their availability sporadic. The soils of SSA are deficient in many nutrients, but the lack of N is the most serious constraint to higher productivity from the soils (Meerman and Cochrane, 1982). Research over the past few decades has revealed the enormous potential of forage legumes for increasing both crop and livestock production (Meerman and Cochrane, 1982). In cropping systems, forage legumes are a cheap source of N whose presence in the soils boosts crop yields. The legumes, at the same time have high content of protein and thus can be used to supplement animal diets.

Intercropping, which is growing of two or more crop species simultaneously on the same piece of land, is a common practice that dominates tropical subsistence agriculture (Willey, 1970). Inter-cropping is widely practised among farmers in Asia and Africa (Andrews and Kassam, 1976; Harwood and Price 1976; Okigbo and Greenland, 1976). An economic survey by the Ministry of Agriculture (MoA, 1981) reported that almost all farmers researched practise mixed cropping in Kenya.

Mixed cropping has been practised by farmers for many centuries in the developing world. It is a system common with small scale farmers who manage to stabilize food production without costly inputs by just growing two or more crops together. In Kenya the traditional practise consists of either broadcasting seeds of intercrops between the rows of the base crop or drilling them between the rows of the base crops. The most prevalent system of mixed cropping is the random mixture (Masyaga, 1984).

Traditional intercropping is diverse and complex because the farmer attempts to satisfy multiple objectives simultaneously. In East Africa one can come across the following mixtures:-

- Subsistence crops raised mainly for self-provision of the family.
- Crops with different growth rates to spread labour peaks during harvesting e.g. maize and field beans, sorghum and pigeon peas.
- Drought tolerant and susceptible crops such as sorghum and maize or pearl millet and groundnuts.
- Food and cash crops such as sorghum and cotton.
- Legume and non-legume to maintain soil fertility and provide better diet for the

family e.g. maize and beans.

- Tree crops and other crops to make better use of land e.g. food crops and pastures at the coast.

Mixed cropping was for a long time regarded as a primitive practise that was to inevitably give way to sole cropping. This has never materialized in a large scale and now there is a great interest in intercropping as a means of increasing and stabilizing crop production. In fact food scarcity often observed in many tropical countries has led to the common belief that traditional food production systems of the tropics are inefficient. However, studies on productivity of traditional tropical systems have shown that in terms of energy return, these systems are more efficient than the mechanized sole crop systems of temperate regions (Cox, 1975). For a long time the value of mixed cropping systems was in doubt, but recent evidence has shown that in the tropics mixed cropping is usually more productive than sole cropping (Andrews, 1972; Fisher, 1976; Osiru and Willey, 1972; Nadar, 1984).

Reasons for the increased crop yield in intercropping systems may be summarized as follows: efficient use of solar radiation, unilateral benefits in crop growth and/or reproduction, reduction in the parent autotoxic effects of certain crops, favourable changes in the incidence of pests and diseases, and potential compensatory growth from vagaries of the environment (Akunda, 1989). Other benefits of mixed cropping are yield stability, spread of labour peaks, better diets, some income and sustenance when cash crops and food crops are mixed (Masyanga,1984).

In many parts of East Africa, the practise of intercropping has been carried out at the subsistence level, with cereals and legumes constituting the most frequent pattern. Although intercropping has been practised for a long time at subsistence level there has been in recent years a desire to evolve an intercropping system for both subsistence and commercial purposes.

Finger millet is a very important food crop in many parts of Kenya. It is consumed in large quantities in Eastern and Western parts of the country. The main areas are; Busia, Kakamega, Kitui, Machakos and Bungoma Districts (Acland, 1970). In East Africa finger millet occupies an important position among cereals. A well distributed rainfall of about 900 mm p.a. is required. Finger millet tolerates dry spells in early stages of growth. It grows at altitudes between 900 and 2000 metres above sea level (Acland, 1970; Purseglove, 1972; Kikafundwa-Twine, 1974). A variety of soils can support the crop (Acland, 1970; Purseglove, 1972).

The two groups of plants of greatest importance to World Agriculture are grasses e.g. wheat, maize, rice, millets and forage grasses and legumes eg. peas, beans, alfalfa, clovers and cowpeas. Legumes are extremely important for the high nutritive quality of the seeds for human consumption and animal feed and for their ability to fix atmospheric nitrogen in a form usable by plants (Hoveland, 1985).

A number of wild plant species are used as a source of leafy vegetables or pot-herbs by a large number of people in Kenya. It is not uncommon to find some of these plants being grown in home gardens. However, little attention has been given to these plants by agriculturalists (Chweya, 1985), mainly due to the fact that most of them grow wild in forests, in waste and arable lands. As a result, most emphasis has been laid on the production and consumption of exotic vegetables which are unfamiliar to majority of the rural people of Kenya.

Of late, however, attempts have been made to identify some of the wild plant species which could be cultivated for vegetables. This has been prompted by the current realization of the possible role these wild leafy vegetables are likely to assume in providing nutrients such as vitamins and minerals in the predominantly vegetarian diets of especially the rural Kenyans (Gomez and Mtotomwema, 1987).

Some of these wild vegetable plants could be leafy legumes whose contribution to the fertility of our soils is of immense value. This is through their ability to fix atmospheric nitrogen in the root nodules by associating symbiotically with *Rhizobium* bacteria. Especially information about intercropping involving minor cereals with indigenous leafy legumes whether edible or used as fodder is not documented.Two such legumes are *Crotalaria brevidens* and *Trifolium quartinianum*.

1.1. Justification of the Study

Of all plant nutrients, nitrogen is probably the most vital for cereal production. However, commercial inorganic nitrogen fertilizers are too expensive for most small scale farmers. This, therefore calls for spirited efforts to find out if there can be alternative sources of nitrogen.

Uses of indigenous legumes such as *Crotalaria brevidens* and *Trifolium quartimanum* which have different human and livestock uses can serve as sources of nitrogen . Agboola and Fayemi (1972) have documented evidence indicating that tropical legumes are capable of excreting nitrogen during growth or releasing it during decomposition of decaying roots and nodules (Janny and Kletter, 1965; De, 1980; Foth *et al.*, 1986). Nitrogen needs of a cereal intercropped with legumes have been reported to be less than for sole cropping due to transfer of some of the fixed nitrogen by the legume to the associated cereal during the growing season (Willey, 1979).

There is interest in the study of *Crotalaria brevidens* because it has multiple uses.

It is used widely as a leafy vegetable in most parts of Western Kenya and where it is not popularly used as a vegetable like in Central Province of Kenya it serves as a fodder legume in annual tillage systems. The fodder can then be harvested during dry season to supplement nappier grass in zerograzing. On the other hand *Trifolium quartinianum* is worth studying because it has been found to be a prolific nodule producer and hence has a place in the management of soil fertility (Akundabweni, 1984).

Preliminary studies have shown that finger millet and *Trifolium quartimanum* association may improve nutrient quality of finger millet than application of inorganic N fertilizer (Tothill, 1986). Further studies by Tothill (1986) showed that finger millet and *Trifolium quartinianum* are compatible as annuals since after harvest of the finger millet, animals may be allowed in to graze the stubble. However, these preliminary studies have not included the effects of inorganic N fertilizer on *Trifolium quartinianum's* growth and yield of finger millet.

The objectives of the study were therefore:-

1. To show the effect of intercropping finger millet with either *Crotalaria brevidens* or *Trifolium quartinianum*, on the biomass of the crops.
2. To investigate the effects of inorganic nitrogen application on the biomass of intercropped finger millet with either *Crotalaria brevidens* or *Trifolium quartinianum*.
3. To show the effect of harvesting methods and residual organic and inorganic nitrogen on biomass and grain yield of finger millet.

CHAPTER TWO

2.0. LITERATURE REVIEW

2.1. Finger Millet.

2.1.1. Botany.

Finger millet (*Eleusine coracana* L.) is a shortday-robust, free-tillering tufted annual grass which grows 0.4 to 1 metre tall. The race coracana resembles wild finger millet in having five to nineteen slender infloresence branches that are 6-11 cm long, digitally arranged and with the tips becoming slightly incurved or reflexed at time of maturity. The time the crop takes to maturity, 2½ to 6 months, is influenced by temperature as well as photoperiod. Some genotypes differ phenotypically from *subsp. africana* primarily in being unable to disperse their spikelets without the help of man (Rachie, 1975).

2.1.2. Distribution.

Among the millets of the world, finger millet ranks fourth after pearl millet (*Pennisetum americanum* L.), foxtail millet (*Setaria italica*) and proso millet (*Panicum miliaceum*). There are two regions of the world where finger millet is most intensively grown: immediate surroundings of Lake Victoria in East Africa and the South-eastern parts of Karnataka and parts of Tamil Nadu and Andhra Pradesh in Southern India. These regions account for nearly 75% of the Worlds Production of this cereal (Rachie, 1975).

In Africa, finger millet is produced principally in Uganda, Tanzania, Rwanda, Burundi, Eastern Zaire, Kenya and to a lesser extent in Ethiopia, Sudan and Somalia. It is also grown in Zimbabwe, Malawi, Zambia, Botswana, Madagascar, Central African Republic, Southern Chad and Northern Nigeria (Leonard and Martin, 1963; Rachie, 1975).

In Eastern Africa, finger millet occupies an important position among cereals. It grows at altitudes between 900 and 2000 metres above sea level. A well distributed rainfall especially during the later stages of growth of at least 900 mm per annum is required if good yields have to be obtained. Finger millet tolerates dry spells in early stages of growth (Acland, 1970; Purseglove, 1972; Kikafundwa-Twine, 1974). The crop can grow on a variety of soils (Acland, 1970; Purseglove, 1972) but reasonably free draining sandy loams are preferred. In India, finger millet grows on red lateritic loams. It grows best where average maximum temperature exceeds 27°C and the average minimum is higher than 19°C (Acland, 1970).

2.1.3. Cultural requirements.

Finger millet does well in a fine seedbed. Planting time depends upon the rains and the time taken to prepare the seed bed. Sowing is done by broadcast. Early planting is advisable because in most cases millet grown early in the season gives the highest yields (Esele, 1986). Plant density will vary with the spacing used by the individual farmers. Normally dense populations give poor yields while a widely spaced crop tillers more and bears larger heads (Esele, 1986).

Finger millet is usually weeded twice depending on the weed population. The first weeding is done 3-4 weeks after germination and the second weeding just before booting. However, most farmers weed only once because of scarcity of labour and other cultivation commitments. The weeding is normally done with small hoes, adzes and knives. Sometimes weeds are removed by hand. A weeding operation when done communally becomes faster where a few families join together to weed their fields in turns. During weeding, some thinning and transplanting may be done to reduce the plant density or gap fill as the case may be. The crop takes on average 4 months to mature (Mburu, 1986).

2.2. *Crotalaria brevidens* and *Trifolium quartinianum*

2.2.1. General

Crotalaria brevidens and *Trifolium quartinianum* are indigenous leafy legumes which are used as human food and animal feed, respectively. They are now attracting attention of researchers since there is a need to diversify food and feed resouces for the rapidly increasing human population (Akundabweni, 1984). Wild accesions of these crops are now being utilized in various studies in order to have a comprehensive information on their cultural practices.

2.2.2. Botany and distribution

Crotalaria brevidens is a bushy and shrubby, leafy leguminous indigenous vegetable. It grows up to about 1 m tall and branches extensively bearing compound leaves. The crop flowers at about 8 weeks after emergence (WAE). Pods containing up to 10 seeds are produced at the onset of the reproductive cycle. This crop is widely used as a vegetable in most parts of Western Kenya and where it is not used as a vegetable, like in the Central Province of Kenya, it serves as a fodder legume in annual tillage systems, where fodder can be harvested for dry season feed and to supplement nappier grass in zerograzing.

Trifolium quartinianum is a spreading leafy clover which hardly grows 30 cm above the ground. It bears numerous infloresences at the tips of its branches. Tiny seeds are borne on the flowers constituting the infloresences. It is a fodder legume native mainly in the highlands of East Africa, which has been extensively tested in agronomic experiments since 1982 (Akundabweni, 1984) and has been found to have promise in cultivation systems.

2.3. Effect of Intercropping on Growth and Yield of intercrops.

Cereal-legume intercrop performance has received considerable attention from several workers. Whereas most studies have shown substantial yield advantages of intercropping (Ahmed and Rao, 1982), there have been cases with no worthwhile advantage (Crookston and Hill, 1979; Wahua and Miller, 1978; Singh, 1981; Tarhalkar and Rao, 1981; Willey, 1981).

In studies on intercropping of sorghum with soybeans, Singh (1977) showed 84% yield increase in sorghum intercropped with soybeans as compared with sole crop. Cordera and MacCollum (1979) observed a 20% increase in total productivity from intercropping maize with soybeans. They attributed the high productivity to the longer leaf area duration of the intercrop system. Makena and Doto (1982) reported significant reduction in number of productive pods per plant, 200-seed weight and soybean yield as a result of intercropping with cereal crops. Nnko and Doto (1980) again found that intercropping maize or millet with soybeans, significantly reduced soybean yields.

Results of IITA (Ibadan) based on cropping system studies during 1972-1975 indicated that

(a) Maize intercrop with cowpea resulted in 15% higher maize yields in 1973 but not in 1974,

(b) intercropping of creeping plants such as melon and short leguminous plant such as groundnuts and determinate cowpea with taller plants such as maize at recommended spacings and densities always resulted in markedly depressed yields of the shorter crop species unless the taller plant was grown at very wide spacing,

(c) intercropping maize with cowpeas reduced cowpea branching, nodule weight and seed yields - the reduction being most pronounced when cowpea is planted later than maize

(d) preplanting cultivations, times of planting in relation to period of maturity, plant structure, height and plant populations affect performance of various crops in mixtures, and

(e) differential crop pest damage were observed with damage being always lower in mixtures as compared to sole cropping as evidenced by the fact that *Anaplocenus curvipes* which damages cowpea pods was found to exhibit greater preference for egg laying on maize than on cowpeas when both crops were intercropped.

Nadar and Faught (1984), found that intercropping maize with cowpeas without nitrogen fertilizer resulted in substantially better returns than those from maize alone. Further investigations by Nadar (1984) showed that maize yield in a maize/cowpea intercrop were reduced by 46% to 57%, mainly due to severe reduction in average ear weight. He reported that while the partial land equivalent ratios (LER) of the two cowpea varieties used in the study (Machakos 68 and a local climbing variety) were almost equal the maize partial LER was 0.54 when it was intercropped with the local variety, and 0.91 when intercropped with Machakos 68. He attributed this finding to the fact that different varieties perform differently under sole crop and intercrop conditions.

Kassam and Stockinger (1973) in their trial on mixtures of cereals at Samaru, Nigeria found that intercropping results in higher total yields per unit area than component crops even at improved levels of technology.

Under dryland conditions, finger millet is grown during the rainy season. In South

India, rows of finger millet are commonly intercropped with other crops like fodder, sorghum, field beans, niger, castor and pigeonpea. It is not uncommon to find mixtures of other millets like bajra or little millet in dryland finger millet fields (Hedge and Seetheran, 1985).

Hedge *et al* (1980) reported that traditional intercropping may not be profitable at high fertility levels but it is advisable under low fertility conditions. Further, the same studies indicated that inclusion of fodder intercrops like maize or pearl millet in wider intervals of 7:1 row proportion is better than putting them closer.

2.4 Plant Competition.

In plant populations, competition is defined as the situation in which each of two or more plants growing together in the same area seek the same growth factor, which is below their demands (Clements *et al.*, 1929; Donald, 1963).

Willey (1979) pointed out that the efficiency of production in cereal-legume intercrop systems could be improved by minimizing interspecific competition between the component crops for growth limiting factors. Growing component crops with contrasting maturities so that they complement rather than compete for the same resources at the same time is one way of achieving this. It is substantiated by the yield advantages reported from various studies: 85-day bean and 120-day sorghum gave a 55% total yield increase. (Willey and Osiru, 1972; Reddy *et al.*, 1980) obtained a 31% yield advantage with 82-day millet and 105-day groundnut; and Natarajan and Willey (1980a) found a 62% yield advantage with 82-day sorghum and 173-day pigeonpea. In contrast, lesser advantages have been reported in crop combinations in which interspecific competition is evident due to similar or almost overlapping growth durations. In this category, Wahua and Miller (1978a) obtained an 11% advantage with a sorghum-soybean combination; 11% advantage with 122-day maize and 116-day soybean (Dallal, 1977); and 8% with a maize-cowpea system (Wanki *et al.*, 1982). No yield advantages were found in maize-cowpea (Haizel, 1974) and sorghum-cowpea (Andrews, 1972; Rees, 1986) intercrop systems in which components were of similar growth durations.

Competition between component crops for growth-limiting factors is regulated by basic morpho-physiological differences and agronomic factors such as the the proportion of crops in the mixture, fertilizer applications and relative time of sowing (Harper, 1961; Trenbath, 1976). Where component crops are arranged in defined rows, the degree of competition is determined by the relative growth rates, growth durations, and proximity of roots of the different crops. The cereal component, with relatively higher growth rate, height advantage and a more extensive rooting system, is favoured in the competition with the associated legume. The cereal is described as the *dominant* component and the legume as the *dominated* component (Huxley and Maingu, 1978). In considering the relative yields of cereals and legumes in intercropping systems, a survey of 40 published papers shows that the yield of the legume component declined, on average, by about 52% of the sole crop yield, whereas the cereal yield was reduced by 11%. Thus the general observation is that yields of legume components are significantly depressed by cereal components in intercropping.

Regulation of the kind and amount of plant competition is an important ecological phase of crop production. Weeds are destroyed to keep them from competing with crop plants. Crops are spaced to obtain maximum yields of suitable quality. A moderate amount of competition between plants is not detrimental on an acre basis. A "struggle for existence" results when plants are grouped or occur in communities in such a way that their demands for an essential factor are in excesss of the supply. Competition is a powerful natural force that tends to eliminate or wipe out the weak competitors. It is chiefly a physical process, i.e., it is essentially a decrease in the amount of water, nutrients and light that otherwise would be utilized by each individual plant. Competition increases with the density of the plant population. Excessive populations often reduce the yield of seeds, while stimulating vegetative growth (Huxley and Maingu, 1978).

Numerous chemicals, called growth regulators, modify the growth rate, transpiration, height, branching, rooting, flowering or maturity of plants or plant parts (Audus, 1922).

In farm fields, crops often are confronted with serious competition with weeds. Success of the crop depends on the readiness and uniformity of germination under adverse conditions, ability to develop a large assimilation surface in the early seedling stage, the possession of large stomata and a root system with a large mass of fibrous roots close to the surface but with deeply penetrating main roots (Pavlychenko *et al.*, 1934).

Pasture legumes are weak competitors for soil N if grown with grasses (Walker *et al.*, 1956; Henzell and Vallis, 1977). If this finding can be extrapolated to cereals, then it follows that in soil which is deficient in N the cereal crop will absorb most of the mineral N. This will compel the legume to fix more N than in a situation in which it is grown alone, provided other factors, such as light and water are not limiting.

Competition is greatest between individuals of the same or closely related species because they make demands for moisture, nutrients and light at about the same time and at about the same level. Competition for moisture is especially important in dryland regions. In the grass crops competition for light reduces the number of heads, causes great irregularity in the number of tillers produced, diminishes the amount of dry matter formed, and reduces tillering, length of culm and number of kernels per head. Competition between different crop species may not be too severe because one plant has an opportunity to fit in among some others.

2.5. Effect of Fertilizer Application on Growth and Yield of Finger Millet.

Johnson (1968) reported that finger millet responds to both fertilizers and manures. Nitrogen increases tillering and number of ears per plant and tends to accelerate the growth of early and intermediate tillers more than that of late ones. In Malawi, application of Kraal manure to finger millet increased yields by 400 percent at Zomba in 1950 (Nyasaland, Department of Agriculture, 1952). Similar experiments carried out at Lusaka (Zambia) in 1954, resulted in yields of approximately 1600, 500 and 350 kg of grain per hectare from manurial treatment of 6, 2 and 0 tonnes of farmyard manure per hectare (Rhodesia, Department of Agriculture, 1955).

Agronomic studies during the 1960 to 1971 in Zambia showed that finger millet responds well to ammonium sulphate at the rate of 200 kg/ha dressed six weeks after planting. The response to phosphorus, in the form of single superphosphate, was less marked and gave significant results only on virgin land which had previously received no fertilizer. The residual responses to phosphorus was good when finger millet followed fertilized groundnut or soybean (Sarmezey, 1978).

Studies by Dhliwayo and Whingwiri (1984) of nitrogen and phosphorus on finger millet at Makoholi Experiment Station of Zimbabwe showed different responses of the crop to different nitrogen levels. 100 kg N/ha was suggested as the optimum level during 1980-1981 season. Inadequate nitrogen can limit yield in finger millet through a reduction in number of heads/m^2.

In Zimbabwe finger millet is grown in rotation with other dryland crops like groundnut, horsegram, sorghum, other millets, cotton, tobacco and simsim. Under irrigated conditions, it is usually grown after paddy in areas where water is not sufficient for a second crop of paddy. Finger millet is also grown after sugarcane, potatoes, onions, carrots, chillies etc. In such cases, the crop is usually transplanted under irrigation as a sole crop (Johnson, 1968).

In the eyes of the Nepalese hill farmers, finger millet is considered as a crop that can be cultivated with low input and grown under stressful conditions (Singh *et al.*, 1985). Fertilizer is generally not applied to the millet crop. If chemical fertilizer, farmyard manure or compost are used, they will usually be applied to the maize crop which is an intercrop with finger millet. If finger millet is grown as a side crop it is not uncommon for the farmers to apply farmyard manure at the rate of 5 to 10 tonnes per hectare.

2.6. Nitrogen Availability, Uptake and Utilization by Plants.

Soil nitrogen is classified either as organic or inorganic. The inorganic forms of nitrogen areNH_4^+, NO_3^-, N_2O, NO and elemental N. In terms of soil fertility NH_4^+, NO_3^- and NO_2^- have proved to be of significant use in crop production. The organic forms of soil nitrogen occur as consolidated amino acids or proteins, free amino acids, amino sugars and other unidentified compounds (Tisdale and Nelson, 1966). Upto 90% of the total nitrogen in soils is estimated to be in organic form, although in some cases significant amounts exist as NH_4^+ bound in clay colloids (Salisbury and Ross, 1986).

Plants absorb most of their nitrogen in the forms of NH_4^+ and NO_3^-. The amounts of these two ions available to the crop roots depends largely on the amounts supplied as commercial nitrogen fertilizer and released from the reserves of the organically bound soil N. Mineralization of organic matter plays an important role in supplying inorganic nitrogen to the crops. The first major step in mineralization is the conversion of organic nitrogen to NH_4^+ by heterotrophic soil microbes in a process known as ammonification. In warm moist soils, with near neutral pH, NH_4^+ is further oxidized by bacteria to NO_3^- within a few days of its formation or its addition as fertilizer in a process known as nitrification. Conversion of NH_4^+ into NO_3^- is a two step process in which ammonia is first converted to nitrite and then nitrate. Conversion to nitrite is effected largely by a group of obligate autotrophic bacteria known as *nitrosomonas* whereas conversion from nitrite to nitrate is effected by *nitrobacter* which is also a group of obligate autotrophic bacteria (Tisdale and Nelson, 1966; Salisbury and Ross, 1986).

In many acidic soils or poorly aerated soils, nitrifying bacteria are less abundant or active, so NH_4^+ becomes a more important nitrogen source than NO_3^-. Flora indigenous to such soils encounter little or no NO_3^-. When these species are cultivated they may still exhibit a distinct preference for NH_4^+ N (Pate, 1980) and display a marked intolerance to NO_3^- N (Pate and Farguhar, 1988). On the other hand, most cultivated soils have their available N in the form of ammonia released from decaying organic matter or ammoniacal fertilizer (Black, 1968; Salisbury and Ross, 1986). Many plants utilize NO_3^- and may also utilize NH_4^+, although they suffer various impairments when only ammonium furnishes nitrogen (Black, 1968).

Both NO_3^- and NH_4^+ are absorbed by inducible energetically dependent uptake mechanisms (Pate and Atkins, 1983). Whereas NH_4^+ is toxic and hence must be assimilated into inorganic compounds immediately upon absorption by the root, NO_3- can enter into the storage pools of root and shoot, or altenatively be reduced at or close to the site of uptake by an inducible nitrate reducing system. In non-photosynthetic tissues, NADH derived from glycolysis, mitochondria dehydrogenase, or the pentose phosphate pathway provides a reductant (Abrol *et al*., 1983) while in the light, NO_3^- may be assimilated at essentially no cost using surplus photosynthetically generated reductant (Smirnoff and Stewart, 1985). Nitrate reduction occurs in two steps, the first being mediated by nitrate reductase and nitrite reductase both nitrate inducible (Franco and Munns, 1982). Once ammonium has been produced it is assimilated via glutamine synthetase under normal low NH_4^+ concentration, and possibly via glutamase dehydrogenase under high NH_4^+ concentrations (Franco and Munns, 1982).

Nitrogen is a constituent of proteins, purines and many coenzymes and therefore an interference with protein synthesis and hence growth is the major biochemical effect of nitrogen deficienty (Epstein, 1972; Hewwit and Smith, 1974; Mengel and Kirkby, 1979). Lack of nitrogen leads to reduced photosynthesis which in turn causes a nitrogen deficient plant to lack not only amino acids but also the machinery for synthesis of the necessary carbohydrates and carbon skeletons. Plants deprived of nitrogen show decreased cell division, expansion and elongation, prolonged dormancy and therefore, delaying swelling of buds in some plants (Frank 1965; Bartholomew and Clark, 1965).

2.6.1. Nitrogen fixation by legumes.

Most legumes have the unique capacity to fix atmospheric nitrogen and make it available for plant growth (Hoveland, 1985). Nitrogen Fixation is a process by which atmospheric N_2 is reduced to NH_4^+. This process requires a source of electrons, protons and numerous ATP molecules in the presence of nitrogenase enzyme (Salisbury and Ross, 1986). About 15% of the nearly 20,000 species in the leguminosae family have been examined for N-fixation, and approximately 90% of these have root nodules in which N-fixation occurs (Salisbury and Ross, 1986).

Bacteria of the genus *Rhizobium* are responsible for N-fixation in legumes.

Rhizobia are aerobic bacteria that persist saprophytically in the soil until they infect a root hair or a damaged epidermal cell. After infection, they penetrate the cytoplasm and cause proliferation of tissues and eventually form a manure root nodule containing a non-motile bacterium (bacteroid) within which N-fixation occurs (Hubbel, 1981; Graham, 1984; Salisbury and Ross, 1986).

Ability to fix N_2 in legumes varies both between and within species. Variations are caused by host controlled traits like nodule initiation, development and function. Layzel *et al.*, 1982), found cowpeas to expend less energy in nodule maintenance and respiration than lupine, while Sen and Weaver (1980), found that the specific nodule activity of *Arachia hypogea* nodule was greater than that of cowpeas. Variations in ability to fix N_2 in symbiosis with *Rhizobium* between cultivars of the same species has been demonstrated in clover, soybeans, beans, cowpeas and vicia (Graham, 1984).

Nitrogen fixation requires a source of photosynthate and energy is also required for development and maintenance of nodules. In fact, recent studies indicate that photosynthate supply is the primary factor limiting nitrogen fixation by legumes (Havelka *et al.*, 1982). A number of traits each affect carbohydrate supply to nodules. Among them is the time varieties take to flower and mature. Hardy *et al.* (1973), demonstrated that early flowering soybean lines tended to fix less N_2 than those from later maturity group. This is presumably because of competition between developing pods and nodules (Graham, 1984). Nitrogen fixation has been significantly enhanced by a photoperiod-induced delay in flowering (Graham, 1982). Leaf area duration may also be important. Wynne *et al.*, (1982), in studies with peanuts found that 70 to 75% of the variation in nodulation and N_2 fixation found in eight peanut cultivars could not be attributed to differences in leaf area duration. In bean, high N_2 fixations were found to be associated with the late maturity and climbing habit (Remmie and Kemp, 1983).

Environmental factors which influence N_2 fixation include phosphorus, calcium, potassium, micronutrients, moisture content, temperature and acidity of the soil. P-defienciency is the most important single factor for N_2 fixation and legume production. It has been shown that plants dependent on N_2 require more P than plants using mineral N (Freire, 1984; Cadisch *et al*, 1989). This need reflects the vital role of P in energy transfer and the large quantities of energy required for reduction of N_2 to NH_4^+ (Salisbury and Ross, 1986). Most legumes dependent on N_2 fixation also have high requirements of Mo, S, Cu, Co, K and Ca (Collins and Duke, 1981; Salisbury and Ross, 1983; Cadisch *et al.*, 1989).

It has been reported that nitrogenase is inhibited reversibly by moderate deficits of water but severe water stress causes irreversible damages (Bergersen, 1977). Water stress was found to cause severe inhibition of nitrogenase activity and nodule respiration in *Soybean (Glycine max)*, and a number of other legumes (Bergersen,1977). Recovery of nitrogen fixing ability was found to be dependent on the severity of the stress, but complete recovery was not observed from severely stressed nodules. The degree of recovery was also related to nodule morphology (Venkatswarlu *et al.*, 1990).

2.7. Characteristics of forage plants.

A good pasture plant must be productive, aggressive so as to rapidly colonize the area in which it is sown, and be capable of persisting and retaining it's dominance despite invasion and competition by native flora (Lazier,1984). It must propagate easily, produce seed readily and in quantity, be adapted to the climatic and edaphic environment of the target area, be resistant to pests and diseases, persist and retain it's leaves under periods of drought and be resistant to cutting, trampling or grazing and yet have some degree of palatability. It should be productive under low fertility but also respond to fertile conditions. The ability to be used for other purposes than forage is an advantage e.g for human nutrition, thatching and fuel.

Plants for cut and carry or carefully managed grazing can have good palatability but in mixed grass-legume swards that are not carefully managed the legume should be no more palatable than the grass that it is not grazed in preference and thus , eliminated from the sward. Lower legume palatability is also an advantage in establishment when oversowing grass swards and in the conservation of fodder as standing legume hay for a dry season when it's high nutritional value will enable low-quality grass to be more efficiently digested by grazing animals (Lazier, 1984).

Tropical environments are extremely varied. Factors such as amount of rainfall, length of dry season, altitude, and soil pH, texture and fertility are all important when selecting areas for collection, or sites for testing accesions. Although most plants have some degree of adaptability and can grow in a range of environments, the range of environments in the tropics is so large that careful examination is required to determine in what part of the range of each factor a plant would be expected to be productive. Because of the large numbers of accesions currently in collections, it is important to pay attention to the environment of origin when collecting so that all accesions do not have to be tested in all enviroments and at least initially can be tested in environments in which they are likely to be successful.

Because newly cleared or ploughed areas are disturbed environments and grazing and cutting maintain swards in a subclimax or disturbed condition it is not surprising that the aggressive plants required as forages are commonly found in subclimax vegetation in contrast to the be less aggressive and persistent (Harlan, 1983).

2.8. Role of legumes in farming systems.

The call for integration of forage legumes with livestock has been accompanied by the suggestion that the key to increased livestock production in Sub Saharan Africa is intercropping legumes and cereals (Gryseels and Anderson, 1983). This is because of heavy reliance of livestock on crop residues during the long dry season. The advantages that have been advanced for such an intercropping system are:

(i) the possibility of N accretion from the legume to the cereal,

(ii) maintenance of continuity of feed supply during the dry season,

(iii) more efficient utilization of low quality cereals through the addition of high protein forage,

(iv) return of manure from livestock to the field

(v) greater dependability of return compared with sole cropping.

Annual forage legumes could fit into peasant farming systems either through intercropping or crop rotations. In large areas of the Ethiopian highlands where low-growing cereals , namely teff (*Eragrostis tef*) , wheat (*Triticum aestivum*), barley (*Hordeum vulgare*) and Oats (*Avena sativa*) are grown, clovers could be introduced through crop rotation. This is the system farmers are used to as is the case when they grow horse beans, (*Vicia faba)*, Chick-peas, (*Cicer arietinum)*, field beans, *(Pisum sativum*); and lentils, (*Lens esculentum)*. Intercropping could be introduced in those areas of the highlands with taller cereals such as Sorghum (*Sorghum vulgare*) and Maize (*Zea mays)*.

Work by ILCA in the subhumid zone (SHZ) of Nigeria has demonstrated that it is possible to improve nutritional quality of the animal diet by including a forage legume in the mixture (Mohamed-Saleem *et al*., 1985). Techniques for growing forage legumes with grain crops have been developed that require minimal inputs and are compatible with traditional cropping systems, but the identification of appropriate techniques needs careful study of the prevailing farming system.

There is no record of inclusion of forage legumes in traditional cropping patterns, and thus their use is novel to farmers in SHZ. Therefore forage legumes will have to be gradually introduced into the cropping systems, while preserving most of the traditional husbandry practises (Mohamed-Saleem *et al.*, 1985).

FAO (1983) noted that the major constraint to increased animal production is malnutrition caused either by overstocking or by low protein forage. The potential and use of forage legumes on farming systems and particularly in livestock nutrition has been summarized by Tothill (1986). However, research on indigenous wild legumes has been very limited compared to improved legumes. Tropical legumes which are used for forage have been cultivated during the last 50 years (William, 1983) yet the volume of unexplored genetic resource remains vast.

Research on the use of *Crotalaria* spp. as a feed for livestock is very limited. The limited data that is available does not give quantitative investigations to establish the potential of *Crotalaria* spp. as a fodder plant. The only work that gives some detail is that of Balaraman and Vankaterkrishman (1974) who determined the nutritive value of *C. juncea* by conducting a metabolism trial using rams.

Crotalaria ochroleuca locally known as " Marejea " is a well known leguminous plant in the southern part of Tanzania. As early as 1939, the legume was cultivated on small scale by Benedictine Fathers at Peramiho (Rupper, in press). It was mainly cultivated for the purpose of restoring fertility to the soil and to combat weeds. During shortages of fodder the legume was fed to dairy cows and calves. Although no quantified data was available, the performances of the animals were observed to be good.

Trifolium spp. introduction would find easier acceptance where farmers are already aware of its nutritive value and contribution to soil fertility. The Agaw Medir of Gojam is such a place. *T. decorum* grows there extensively in dense swards where it is grazed after flowering. The clover falls into a natural crop rotation with teff, barley, wheat, finger millet and nug. In this area, the clover plays a very strategic role in boosting grain yield through biological nitrogen fixation. Soil samples taken during seed collection from this area gave persistently high N levels. This confirms earlier observation where results of a comparative survey gave consistently high N values for soils from Agaw Medir of Gojam (Murphy, 1968).

That legumes have a role to play in farming systems has been overwhelmingly demonstrated in temperate zones, first in Britain and later in temperate Australia and New Zealand (Tothill, 1978). However, while legumes could play the same role in farming systems of the tropics, and particularly of sub-saharan Africa, their adoption has not yet had the revolutionary impact that it has had in temperate regions. The challenge is to find out the main limiting factors to an equally, or potentially more dramatic revolution in sub-saharan Africa. The role that legumes can play in farming systems has been covered by a large number of contemporary reviews, notably Wilson (1978), Mannetje *et al.*,(1980); Norman (1982), Crowder and Chheda (1982), Haque and Jutzi (1984) and Agishi (1985).

Haque and Jutzi (1984) reviewed the factors that may limit N fixation. Since N_2 fixation is the product of two symbiotically interdependent organisms (the host legume plant and the bacterium), it may be affected by the reaction of one or the other or both. As a broad generalization, fixation is proportional to the vigour of the host plant and therefore is affected by the factors that affect plant growth i.e. water, temperature, nutrients and light. This generalization may be upset by factors that specifically affect the activity of the *Rhizobium* rather than the host. These may be temperature, soil pH, nutritional status (particularly N and Mo) and genetic specificity.

Over a wide range of conditions, legumes can fix significant but varying amounts of N. However, these amounts need to be equated over time because varying proportions are cumulative in the soil compartments. This is also an important consideration because N may accumulate in the soil organic, biological and inorganic (NO_3^-, NH_4^+) forms (Salisbury and Ross, 1986). In some situations (e.g. heavy clay soils) total N fertility may increase steadily whilst available N might decline because of the build up of micro-organisms that compete successfully for available N. Eventually a situation is reached where the high-fertility soil becomes apparently as infertile as an inherently low-fertility soil. Studies by Mohammed-Saleem (1985) and others indicate that plant responses to the build up of soil fertility are not accounted for by N levels alone. It appears that they affect overall soil biology, in terms of lower bulk density, higher infiltration rate and more rapid nutrient turnover.

2.9.1. Effects of legumes on pasture quality.

Livestock obtain feed primarily from natural pastures, crop residues and to some extent from cultivated forage crops (Alemayu, 1987). One way of increasing livestock feed would be through pasture improvement. To this end Olayiwale *et al.*, (1986) recommended the inclusion of native clovers in natural pastures. However, periodic frosts, extended dry periods, high acidity, extensive areas of vertisols and nitosols each with its own peculiarities present special problems to legume introduction. On the other hand highland pastures are rich in legume composition particularly the *Trifolium* spp. (Gillet, 1952; Gillet *et al.*, 1971; Mengistu, 1975; Thulin, 1983). Evaluation of annual

Ethiopian clovers has shown that they have good potential for hay production (Kahurananga and Tsehay, 1984). In 1985 work was started in screening perennial clovers as research in Australia has shown that some have high potential for pasture production (Mannetje, 1964; Jones and Cook, 1981).

Among the solutions being advocated to reverse the declining productivity are the introduction of cropping systems that conserve moisture and soil fertility and the close integration of livestock and arable farming (Pratt and de Haan , 1979; Bouldin *et al.*, 1980; Oram, 1981). Okigbo (1984) observed that increasing agricultural output in SSA will require improved cropping systems, which will necessitate the integration of traditional and modern technologies as farmers are more likely to adopt modifications to existing farming systems than completely new ones.

In tackling the enormous shortfall in livestock feed resources, ILCA is focusing on the use of forage legumes. Not only do legumes provide highly nutritious forage, they also improve soil fertility through biological nitrogen fixation, thus creating an interphase between agriculture and livestock production in peasant farming through crop rotation or intercropping (Kahurananga *et al.*, 1984). ILCA's aim has been to collect forage germplasm from as many environments of the diverse Ethiopian highlands to evaluate their forage potential because initial observations elsewhere in Ethiopia had been favourable (CADU, 1972).

The *Trifolium* genus in Africa contains twice as many annuals as perennial clovers (Gillet *et al.*, 1971). Even though the growing period of the former is shorter than that of perennials the higher dry matter yield of the latter (Akundabweni, 1984) could be of greater use when harvested and conserved to overcome the seasonal feed-shortage. Furthermore, annual clovers could conveniently be integrated into the existing crop and livestock enterprises with greater management flexibility than might be the case with perennial lay meadows.

Preliminary screening of *Trifolium tembense* and *quartinianum* in Kenya have shown agronomic promise (Strange, 1958). The use of forage legumes as intercrops, relay crops or live-mulch cover crops relies on the ability of the legume to supply N to an association or subsequent crop. All of these applications are essentially still at early experimental stages (Powell, 1985; Mohammed-Saleem, 1985), although intercropping with pulse legumes is a common practise. Animal production can be integrated with some of these systems. The Australian-legume-ley farming model based on the sheep-wheat production system in temperate Australia is being investigated in northern Australia and East Africa and seems promising. Haque and Jutzi (1984) report several studies giving values of 40-100kg N/ha released following several years of forage legume cropping.

2.9.2. Role of legumes in crop rotation.

Crop rotation may be defined as a system of growing different kinds of crops in recurrent succession on the same land (Enlow, 1970; Johnson, 1927; Leighty, 1938; Throckmorton and Duley, 1932; Weir, 1926). A rotation may be good or bad as measured by it's effects on soil productivity or on it's economic returns. A good rotation that provides for maintenance or improvement of soil productivity usually includes a legume crop to promote fixation of nitrogen, a grass or legume sod crop for maintenance of humus, a cultivation or intertilled crop for weed control and fertilizer. Perennial legumes and grasses may leave 2 to 3 tons of dry weight per acre of root residues in the soil when ploughed down.

The reason for using leguminous cover crops in rotation and intercropping system is to obtain sustained and high crop yields with minimum N fertilizer input. Agboola and

Fayemi (1972) observed that intercropping Maize with *M. pruriens* reduced maize yield but intercropping *Colopogonium mucunoides* did not affect the maize yield. The same authors (Agboola and Fayemi, 1972) also showed that *C. mucunoides* intercropped with maize fixed 370 Kg N/ha but did not benefit the early crop. However, it was of benefit as a green manure for the late maturing crop.

CHAPTER THREE

3.0. MATERIALS AND METHODS.

Experiments were carried out between October 1993 and October 1994 at Kabete Field Station, Faculty of Agriculture, Kabete Campus, University of Nairobi and Field 3, Faculty of Agriculture, Egerton University, Njoro to study the effects of intercropping finger millet (*Eleusine coracana* L.) with indigenous legumes under various management practices on the growth of the crops. The study was done in two phases. The first phase (October 1993- March 1994) involved intercropping finger millet with *Crotalaria brevidens* and *Trifolium quartinianum* and growing sole finger millet, applying inorganic nitrogen (N) and harvesting the crops by cutting or uprooting. The second phase (April - October 1994) was to investigate the effects of previous legume intercrop, residual N and harvesting methods on the growth and yield finger millet crop.

3.1. Experimental Sites

3.1.1. Kabete

The site stands at an altitude of 1940 metres above sea level at latitude 1° 15' South and longitude 36° 44' East. It is located in a region that receives bimodal rainfall averaging 1000 mm per annum . Long rains start in March and stop towards the end of May, whereas the short rains last over October to December. During the study period mean monthly minimum and maximum temperatures were 12 and 23°C and total rainfall was 949.7 mm, respectively (Appendix 2).

The soils in this site are nitosols according to FAO/UNESCO (1974) soil classification. They are derived from deep well drained soil profiles with thick acidic topsoils that are resistant to erosion (Siderius, 1976). Soil samples were randomly taken within the experimental plots at 0-15 and 15-30 cm depths. The samples were air-dried, ground and sieved for analysis of soil pH, organic carbon and total nitrogen. Results of chemical analyses of the soils from the two depths were treated separately because disc ploughing was not used at the beginning of phase two (Appendix 1).

3.1.2. Njoro

The site is located at an altitude of 2225 metres above sea level, latitude 0°22' South and longitude 35° 55' East. It is also located in a region which receives mean annual rainfall of 1000 mm p.a. with a bimodal distribution. Long rains begin in March and end in May, while the short rains last from October to the end of December. Mean monthly maximum and minimum temperatures were 26 and 8°C and total rainfall 929.5 mm, respectively (Appendix 3) during the period of study.

The soils in the site are dark haplic phaezoems according to FAO/UNESCO (1974) soil classification. They are derived from tuff and ashes. The area has very deep moderately well drained profiles with slightly acidic topsoils. Soil samples from depths 0-15 and 15-30 cm were analysed as in Kabete site described above (Appendix 1).

3.2. Crops Used.

Finger millet was used as the principal crop throughout the study. In phase one,it was intercropped with either an indigenous edible legume (*Crotalaria brevidens* L.) or the fodder legume (*Trifolium quartinianum* L.). It was not easy to establish the exact local finger millet variety used by the Kenya Seed Company to prepare the seed used. A 140-day maturity finger millet (local variety) was used.The indigenous edible and fodder legumes used mature for biomass harvesting after 90 days.

Finger millet seed was obtained from the Kenya Seed Company depot in Nairobi. Seeds of *Crotalaria brevidens* and *Trifolium quartinianum* were obtained from the field station, Faculty of Agriculture, Kabete Campus, University of Nairobi.

3.3. Experimental Treatments and Design.

3.3.. Phase one: Effects of intercropping and inorganic nitrogen application on biomass production of crops.

Treatments included intercropping finger millet with *Crotalaria brevidens* or with *Trifolium quartinianum* and applying three rates (0, 20 and 40 Kg N/ha) of inorganic nitrogen. There were also sole finger millet plots supplied with the same inorganic nitrogen rates. These gave nine treatments which were laid out in a completely randomized block design with three replications. A plot for each sole legume was put seperately for comparative purposes. Each experimental plot measured 2 by 3 metres. Two guard rows were maintained around each experimental plot.

3.3.1. Phase two: Effect of previous legume intercrop, residual N and harvesting method on growth and yield of finger millet.

Treatments were the nine intercropped and N applied plots and the two harvesting methods. This gave eighteen treatments which were laid out in a split plot design with three replicates. The main plots were the previous cropping treatments, while the subplots were the previous harvesting method (uproot or cut). During the last harvesting of the crops half of the plants in each of the experimental plot were either uprooted or cut at ground level. Finger millet was sown in all the sub-plots to show the subplot effects on its performance. Two guard rows were maintained around each subplot.

3.3.2. Cultural practises.

Crops for each experimental plot were planted on the same date. At Kabete the crops were planted on the following dates: short rains:- 21 October 1993; and long rains:- 19 March, 1994. At Njoro the planting dates were: short rains:- 4 November, 1993; long rains:- 14 April 1994.

In the first phase of the study, plots were ploughed with a tractor and disc harrowed twice before sowing. Plots were not ploughed in the second phase. There crops were either cut or uprooted without any further disturbance of the soil. In both phases seeds were drilled into the soil and subsequent thinning done after 3 weeks of seedling growth and this continued until optimum population (267 000 plants/ha) for each crop was reached. The spacing within and between the rows was 10 cm and 30 cm, respectively.

All plots were kept weed free until plants reached weed growth suppressing canopy. Supplemental irrigation was applied when necessary to avoid water stress in plants.

3.4. Observations and measurements.

3.4.1. Observation

In phase one experiments, each experimental plot had eight rows of twenty plants each; four rows consisting of each of the two species in an intercrop in an alternate row pattern. For the intercrops, observations were made on the first and third rows, for the first crop and on the second and fourth rows for the second crop to avoid the border effect. The first crop was always a legume species while the second was the finger millet. The sole legume and finger millet plots had the six middle rows sampled. For each of the selected rows, ten plants were sampled for data collection. In phase one, plant heights of crops at flowering stages were taken and recorded. At 56 days after planting (DAP) upto 84 DAP on a weekly basis, fresh and dry weights of *Crotalaria brevidens* and

Trifolium quartinianum were taken and recorded. At 84 DAP above ground biomass of all crops were taken and recorded. Two harvesting modes were used. One half of each plot had plants cut at above ground using secateurs while in the other half plants were uprooted. Land equivalent ratios (LER) for crops involved were then calculated using the biomass (stems and leaves) harvested.

To calculate the LERs the following formula was used:

$$LER = L_A + L_B = Y_A / S_A + Y_B / S_B$$

Where L_A and L_B are the LERs for the individual crops, Y_A and Y_B are the individual crop yields in intercropping and S_A and S_B are their yields in sole crops.

In phase two experiments, finger millet plant heights, biomass, grain yield and yield components data were taken and recorded.

3.5. Phase two measurements.

3.5.1.1. Plant height.

Sampling for heights of crops started 6 WAE and continued every week until 13 WAE. At flowering stage of finger millet (10 WAE), 10 plants were selected for sampling. A metre ruler was used in taking the height. The measurements were taken by placing the tip of the calibrated ruler (cm) at the point the main stem touched the ground. The mean of the heights was recored.

3.5.1.2. Tillers per plant.

At flowering stage (10 WAE), a sample of 10 plants was selected and the numbers of tillers from each counted and the mean was recorded.

3.5.1.3. Ear numbers per plant.

Ear numbers per plant were taken at full maturity of finger millet. In each plot 10 plants were randomly sampled and the number of ears on each of them counted and the average was recorded.

3.5.1.4. Ear weight.

Ten plants were sampled at random, their ears cut and weighed for fresh weight and dried at 105°C for 48 to 72 hours for dry weights. The weights were recorded in grams.

3.5.1.5. Determination of dry matter.

Dry matter was determined by the AOAC (1984) recommended method. Plant samples were weighed fresh and after drying in an oven at 70° C for 48 to 72 hours to a constant weight.

3.5.1.6. Seed yield and yield components.

At the time of full maturity, three middle rows of finger millet per experimental plot were harvested for biomass, grain yield and yield components determination. 1000-grain weight was obtained by weighing 1000 dry grains from each plot. Biomass was calculated in g/plant, while grain yield was calculated as tonnes per hectare. This was done at 13% moisture content.

3.5.2. Determination of total nitrogen and organic carbon in the soil.

Total nitrogen was determined using the Macro-kjeldahl method, while organic carbon was determined using the Walkley-Black Method (Tisdale *et al.*, 1966).

Total nitrogen and organic carbon were determined before the experiments were done and after first and second phases.

(a) Total nitrogen

A sample containing 1g was placed in a dry macro-kjedahl flask, 40 ml of salicyclic acid-sulphuric mixture added and the flask swirled until the acid was thoroughly mixed with the soil. The mixture was allowed to settle for several hours (12 hours), 5 g of sodium thiosulphate was added through a dry thistle funnel having a long stem that reaches down into the bulb of the kjeldahl flask, and the mixture heated cautiously on the digestion stand until frothing had ceased. The flask was cooled and 20 ml of water was added, 10g of K_2SO_4, 1 g of $CuSO_4$ and 1 g of Se added.

After completion of digestion, the fask was allowed to cool, about 100 ml of water was added (slowly, and with shaking). Then the flask was cooled under a cold water tap, and the contents transfered to a 1-litre conical flask for distillation. Some sandy residue was retained in the digestion flask during this transfer, because sand could cause severe bumping during Kjeldahl distillation. Four washings of the sandy residue with 50 ml of water were used for adequate quantitative transfer of the ammonium digest.

To determine the ammonium-N liberated by digestion, a 500-ml Erlenmeyer flask containing 50ml. of H_3BO_3-indicator solution was placed under the condenser of the distillation apparatus so that the end of the condenser was below the surface of the H_3BO_3. Then the distillation flask was held at 45^o angle, a teaspoonful of pumice was added and 150 ml. of 10N NaOH down the neck so that the alkali reached the bottom of the flask without mixing appreciably with the digest. The flask was attached quickly to the distillation apparatus, the contents were mixed thoroughly by swirling and distillation commenced immediately. The heating was regulated to prevent suck-back of H_3BO_3 and to minimise frothing or bumping during distillation, and the flow was checked so that the flow of cold water through condenser was sufficient to keep the temperature of the distillate less than 35^oC. When about 150 ml. of the distillate had been collected, the receiver flask was lowered so that the end of the condenser was above the surface of the distillate; and, after rinsing the end of the condenser with water, the flask was removed and distillation stopped. Ammononium-N in the distillate was determined by titration with 0.05N H_2SO_4 using a 25-ml burette graduated at 0.1 intervals (1ml. 0.05 H_2SO_4 approx. 0.7 mg. ammomium-N). The colour change at the end-point was from green to pink.

Results were calculated using the following formula:

$$\%N = \frac{\text{Titre x normality of Acid (0.07N) x 0.014 x 100 x100}}{\text{Weight of soil (1g) x aliquot (10 ml)}}$$

(b) Organic carbon

The soil was ground to pass a 0.5 mm sieve, iron and steel mortars were avoided. 0.5 g of 0-15 cm and 1.0 g of 15-30 cm soil samples were transfered into a 500 ml wide-mouth Erlenmeyer flask. 10 ml of 1N $K_2Cr_2O_7$ were added and the flask was swirled gently to disperse the soil in the solution. 20 ml of concentrated H_2SO_4 were then rapidly added into the suspension. Immediately the the flask was swirled gently until the soil and reagents were mixed. The flask was allowed to stand on a sheet of asbestos for about 30 minutes. 200 ml of water and 5 ml of H_3PO_4 were then added followed by 3 to 4 drops of o-phenanthroline indicator. The solution was then titrated with 0.5 N $FeSO_4$. As the end point was approached, the solution took on a greenish cast and then changed to dark green. At that point, ferrous sulphate was added drop by drop until colour changed sharply from blue to red (maroon colour in reflected light agaist a white background). A blank determination was made in the same manner, but without soil, to standardise the $FeSO_4$.

The results were calculated according to the following formula, using a correction factor f= 1.33

$$\text{Organic-C\%} = \frac{(\text{m.e. } K_2Cr_2O_7 - \text{m.e. } FeSO_4) \times 0.003 \times 100 \times f}{\text{Grams water-free soil}}$$

m.e. = milliequivalents, which is

ml x normality of each solution used.

3.6. Data Analysis.

Analysis of variance (ANOVA) was computed in respect of the growth and yield parameters and mean seperations were done using the Least Significant Difference (LSD) test and Students t-test as described by Steel and Torrie (1981).

CHAPTER FOUR.

4.0 RESULTS.

4.1. Phase one.

4.1.1. Effect of intercropping and N application on:

(a) Leaf fresh and dry weights of *Crotalaria brevidens*.

Nitrogen application had a significant ($P<0.05$) effect on the fresh and dry leaf weights at Kabete and Njoro. Table 1 (a and b) gives total fresh and dry leaf yields harvested between 56 and 84 DAP. Leaf yields increased with increasing levels of N applied. Fresh leaf yields at 56 DAP were on average an eighth of the total yield , while the dry leaf weights were 11% at both sites.

Fresh and dry leaf harvests were higher in sole legume cropping than in intercrop of finger millet with legume as would be expected. Sole *Crotalaria brevidens* plants gave about 6% more fresh and dry leaf weights than the intercrop at Kabete . There was little change at Njoro. Intercropping therefore tended to curtail the growth and yield of the legume.

Table 1. Effect of intercropping and nitrogen application on (a) total fresh and (b) total dry leaf weight (t/ha) of *Crotalaria brevidens* (CB) intercropped with Finger millet (FM) at Kabete and Njoro during phase one (October 1993-March 1994) of the study.

(a)

	CB Fresh leaf weights	
Treatments	Kabete	Njoro
Sole legume	83.5	14.5
In intercrop at 0 Kg N/ha	71.8a	14.0a
In intercrop at 20 "	81.6b	14.9b
In intercrop at 40 "	82.5b	14.1a
Intercrop mean	78.6	14.3
LSD	8.84	0.73
CV(%)	6.1	2.8

(b)

	CB Dry leaf weights	
Treatments	Kabete	Njoro
Sole legume	12.6	4.5
In intercrop at 0 Kg N/ha	11.2a	3.8b
In intercrop at 20 "	13.0b	3.8b
In intercrop at 40 "	13.0b	3.8b
Intercrop mean	12.4	4.2
LSD	1.52	0.23
CV(%)	6.7	2.9

Within each column, intercrop means followed by the same letter are not significantly different at the 5% level of probability using the Least Significant Difference (LSD) Test.

(b) Leaf fresh and dry weights of *Trifolium quartinianum*

There was a significant (P<0.05) effect of N application on leaf and dry weights of intercropped *Trifolium quartinianum* at both sites (Table 2 a and b). The fresh and dry leaf weights of the crop increased from 54 to 84 DAP. Fresh and dry leaf weights of *Trifolium quartinianum* at 54 DAP were 10% and 18% of the final harvest, respectively.

Applying upto 40 kg N/ha to the intercrop significantly increased fresh and dry leaf weight of *Trifolium quartinianum*. Fresh and dry leaf weights of *Trifolium quartinianum* were unchanged between Kabete and Njoro. Sole legume yielded higher than the intercropped one at both sites. The yield of sole crop was about 5% more at Kabete than Njoro.

Table 2. Effect of intercropping and nitrogen application on the (a) total fresh and (b) dry leaf weights (t/ha) of *Trifolium quartinianum* (TQ) intercropped with Finger Millet (FM) at Kabete and Njoro, phase one (October 1993-March 1994) of the study.

(a)

	TQ Fresh leaf weights	
Treatments	Kabete	Njoro
Sole legume	2.05	13.92
In intercrop at 0 Kg N/ha	1.99a	13.52b
In intercrop at 20 "	1.63a	12.85a
In intercrop at 40 "	2.23b	13.01ab
Intercrop mean	1.95	13.12
LSD	0.44	0.39
CV(%)	12.6	2.2

(b)

	TQ Dry leaf weights	
Treatments	Kabete	Njoro
Sole legume	0.03	4.00
In intercrop at 0 Kg N/ha	0.27a	3.81b
In intercrop at 20 "	0.24a	3.64a
In intercrop at 40 "	0.36b	3.80b
Intercrop mean	0.29	3.92
LSD	0.09	0.14
CV(%)	17.6	2.4

Within each column, intercrop means followed by the same letter are not significantly different at the 5% level of probability using the Least Significant Difference (LSD) Test.

4.1.2. Effect of intercropping and nitrogen application on plant heights of crops.

Application of inorganic nitrogen had a significant ($P<0.05$) effect on height all crops at both sites. *Crotalaria brevidens,* however, invariably shaded finger millet. From seedling emergence, *Crotalaria brevidens* showed a more rapid growth than finger millet at Kabete but not at Njoro (Tables 3).

In intercropped plots *Crotalaria brevidens'* vigorous growth caused the growth of slender and weak finger millet plants. However, sole finger millet plants were healthy having almost the same height as *Crotalaria brevidens* at all N levels.

At Kabete following germination, finger millet showed a greater growth vigour than *Trifolium quartinianum*. At Njoro, *Trifolium quartinianum* was quite vigorous and germinated at the same time as finger millet. Visually the clover looked healthier at Njoro than at Kabete. Finger millet invariably dwarfed *Trifolium quartinianum* under intercropping. Sole *Trifolium quartinianum* grew only to a third of the height of finger millet at Kabete and to about half of its height at Njoro. The heights of all crops were higher at Kabete than at Njoro.

Table 3. Effect of intercropping and nitrogen application on heights (a) of *Crotalaria brevidens* (CB), or (b) *Trifolium quartinianum* (TQ) when intercropped with Finger Millet (FM) at Kabete and Njoro, phase one (October 1993-March 1994) of the study.

(a) Kabete

	Crop heights (cm)			
	CB-FM intercrop		TQ-FM intercrop	
Treatments	CB	FM	TQ	FM
Sole crop	43.90	41.96	14.8	41.20
In intercrop at 0 Kg N/ha	42.20ab	40.97b	14.00a	39.63ab
In intercrop at 20 "	42.10a	38.30a	14.40ab	40.83b
In intercrop at 40 "	43.43b	39.07ab	14.67b	40.83b
Intercrop mean	42.57	39.61	14.35	39.68
LSD	1.09	1.75	0.49	1.64
CV(%)	1.7	2.4	1.9	2.3

(b) Njoro

	Crop heights (cm)			
	CB-FM intercrop		TQ-FM intercrop	
Treatments	CB	FM	TQ	FM
Sole crop	27.40	30.00	12.20	25.23
In intercrop at 0 Kg N/ha	26.17a	28.97b	11.20a	23.70a
In intercrop at 20 "	28.20b	28.97b	12.67b	24.67b
In intercrop at 40 "	27.87b	27.76a	11.60ab	23.93b
Intercrop mean	27.41	28.56	11.82	24.10
LSD	1.60	1.01	1.10	0.75
CV(%)	3.2	2.0	5.2	1.7

Within each column, intercrop means followed by the same letter are not significantly different at the 5% level of probability using the Least Significant Difference (LSD) test.

4.1.3. Effect of intercropping and nitrogen application on biomass (stems and leaves) of the crops.

Nitrogen application had a significant ($P<0.05$) effect on biomass of all the three crops studied. At all N levels, *Crotalaria brevidens* had a higher biomass than finger millet, whereas the biomass of *Trifolium quartinianum* was slightly higher than that of finger millet. At Kabete finger millet intercropped with *Crotalaria brevidens* invariably performed worse than the one intercropped with *Trifolium quatinianum*. Intercropping created favourable conditions for the vigorously growing crops to outcompete the slow growing ones. At the same time the growth habit of *Trifolium quartinianum* made it suffer less competition from the tall and fast growing finger millet.

Nitrogen application enhanced the vegetative growth of *Crotalaria brevidens* and *Trifolium quartinianum* when intercropped with finger millet. Finger millet benefitted more from applied inorganic nitrogen where it was intercropped with *Trifolium quartinianum* than with *Crotalaria brevidens*. In general, biomass of intercrop legumes were higher at Kabete than Njoro (Table 4).

In plots where finger millet was intercropped with *Crotalaria brevidens* its biomass at Kabete was less than that at Njoro. However, the finger millet biomass at Kabete was more than that at Njoro when finger millet was intercropped with *Trifolium quartinianum*. At all N levels sole finger millet biomass was higher at Kabete than at Njoro.

Table 4. Effect of intercropping and nitrogen application on biomass (stems and leaves) in g/plant (a) of *Crotalaria brevidens* (CB), or (b) *Trifolium quartinianum* (TQ) when in intercrop with Finger Millet (FM) at Kabete and Njoro during phase one, (October 1993-March 1994) of the study.

(a) Kabete

	Crop Biomas (g/plant)			
	CB-FM intercrop		TQ-FM intercrop	
Treatments	CB	FM	TQ	FM
Sole crop	55.40	33.40	16.10	44.2
In intercrop at 0 Kg N/ha	44.72ab	11.20ab	16.15b	38.95a
In intercrop at 20 "	45.95ab	12.0b	13.10a	41.55ab
In intercrop at 40 "	50.65b	9.85a	12.95a	43.15b
Intercrop mean	47.10	11.0	14.06	41.22
LSD	4.98	1.61	2.67	3.14
CV(%)	5.4	8.1	10.5	4.2

(b) Njoro

	Crop Biomas (g/plant)			
	CB-FM intercrop		TQ-FM intercrop	
Treatments	CB	FM	TQ	FM
Sole crop	33.7	26.2	33.5	32.5
In intercrop at 0 Kg N/ha	31.98ab	14.72a	32.44b	31.87a
In intercrop at 20 "	31.30a	15.08ab	28.47a	31.98ab
In intercrop at 40 "	50.65b	9.85a	29.50ab	32.07b
Intercrop mean	32.06	15.05	30.13	32.0
LSD	1.20	0.46	3.05	0.15
CV(%)	2.0	1.7	5.5	0.2

Within each column, intercrop means followed by the same letter are not significantly different at the 5% level of probability using the Least Significant Difference (LSD) test.

4.1.4. Effect of intercropping and nitrogen application on the crops Land Equivalent Ratios (LER).

The biomass (stems and leaves) land equivalent ratios (LER) for *Crotalaria brevidens* and finger millet were 1.17 and 1.55 for Kabete and Njoro, respectively. Those for *Trifolium quartinianum* and finger millet for the same sites were 1.80 and 1.88, respectively.

4.1.5. Effect of intercropping and nitrogen application on soil C:N ratio.

Cut plots had more total nitrogen and organic carbon than uproot ones at both Kabete and Njoro (Tables 5-8). Top soil contained more organic carbon and total nitrogen than subsoil as expected. Magnitudes of the parameters were unchanged between intercrop and sole crop plots at the two sites. However, more total nitrogen and organic carbon were produced in Njoro than Kabete. The overall C:N ratios for top soils were higher than subsoils though the difference in uproot top and subsoil plots was negligible. The C:N ratios were lower at Njoro than Kabete.

Table 5. Soil C:N ratios of cut plots at Kabete (end of phase 1).

Plot	N-level (Kg N/ha)	Depth (cm)	%N	%C	C:N
FM+CB	0	0-15	0.261	2.31	11:1
		15-30	0.229	2.00	7.8:1
	20	0-15	0.261	2.63	11:1
		15-30	0.212	2.61	8.9:1
	40	0-15	0.245	2.24	11:1
		15-30	0.229	2.60	11:1
FM+TQ	0	0-15	0.229	2.14	11:1
		15-30	0.229	1.96	7.8:1
	20	0-15	0.245	2.50	11:1
		15-30	0.229	2.21	7.9:1
	40	0-15	0.245	2.67	11:1
		15-30	0.212	1.91	8.5:1
FM(sole)	0	0-15	0.261	2.66	11:1
		15-30	0.229	2.24	7.7:1
	20	0-15	0.261	2.31	11:1
		15-30	0.245	2.25	8.2:1
	40	0-15	0.261	2.49	11:1
		15-30	0.229	1.97	8.3:1

Table 6. Soil C:N ratios of uproot plots at Kabete (end of phase 1).

Plot	N-levels (Kg N/ha)	Depth (cm)	%N	%C	C:N
FM+CB	0	0-15	0.229	2.89	10:1
		15-30	0.212	1.79	9.4:1
	20	0-15	0.261	2.86	10:1
		15-30	0.294	1.89	8.9:1
	40	0-15	0.212	2.68	11:1
		15-30	0.245	1.88	8.8:1
FM+TQ	0	0-15	0.212	2.55	10:1
		15-30	0.212	1.79	9.2:1
	20	0-15	0.245	2.70	10:1
		15-30	0.245	1.80	9:1
	40	0-15	0.261	2.71	10:1
		15-30	0.212	1.81	9:1
FM (sole)	0	0-15	0.261	2.89	10:1
		15-30	0.245	1.77	9.1:1
	20	0-15	0.229	2.87	10:1
		15-30	0.245	2.00	9.2:1
	40	0-15	0.245	2.90	10:1
		15-30	0.212	1.91	9.3:1

Table 7. Soil C:N ratios of cut plots at Njoro (end of phase 1).

Plot	N-levels (Kg N/ha)	Depth (cm)	%N	%C	C:N
FM+CB	0	0-15	0.278	3.04	11:1
		15-30	0.261	2.22	8.5:1
	20	0-15	0.278	3.03	11:1
		15-30	0.212	1.83	8.6:1
	40	0-15	0.310	3.30	11:1
		15-30	0.212	1.91	9:1
FM+TQ	0	0-15	0.343	3.49	10:1
		15-30	0.245	2.15	8.8:1
	20	0-15	0.294	3.17	11:1
		15-30	0.212	1.85	8.7:1
	40	0-15	0.294	3.21	11:1
		15-30	0.245	2.00	8.2:1
FM (sole)	0	0-15	0.294	3.10	11:1
		15-30	0.245	2.03	8.3:1
	20	0-15	0.343	3.50	10:1
		15-30	0.261	2.16	8.3:1
	40	0-15	0.278	3.00	11:1
		15-30	0.212	1.78	8.4:1

Table 8. Soil C:N ratios of uproot plots at Njoro (end of phase 1).

Plot	N-levels (Kg N/ha)	Depth (cm)	%N	%C	C:N
FM+CB	0	0-15	0.261	2.61	10:1
		15-30	0.245	2.30	9.4:1
	20	0-15	0.245	2.52	10:1
		15-30	0.212	1.91	9:1
	40	0-15	0.278	2.81	10:1
		15-30	0.229	2.01	8.8:1
FM+TQ	0	0-15	0.278	2.83	10:1
		15-30	0.245	2.50	10:1
	20	0-15	0.245	2.51	10:1
		15-30	0.196	1.79	9.1:1
	40	0-15	0.294	3.01	10:1
		15-30	0.278	2.60	9.3:1
FM (sole)	0	0-15	0.294	3.00	10:1
		15-30	0.278	2.58	9.3:1
	20	0-15	0.310	2.94	9.5:1
		15-30	0.278	2.65	9.5:1
	40	0-15	0.261	2.67	10:1
		15-30	0.228	2.01	8.8:1

4.2. Phase two

4.2.1. Effect of previous intercrop management practices on growth and yield of finger millet.

(a). Plant heights.

The previous harvesting method had a very significant ($P<0.05$) effect on heights of finger millet at both sites. Table 9 shows heights at flowering stage (8 WAE). Plants which had previously been supplied with 0, 20 and 40 kg/ha and intercropped with finger millet, had heights increasing with the magnitude of N applied at Kabete. Where sole finger millet had been planted with the same rates of N, heights decreased with the respective residual N levels. Residual nitrogen benefitted finger millet plants that had been intercropped. Plants in plots where crops were uprooted were always shorter than those in plots where the crops were cut at Kabete. In Njoro, no distinct pattern was followed in terms of height under the various residual N levels. However, the plants in plots where crops were cut were shorter than those from plots where crops had been uprooted.

The differences in height between finger millet plants in previously uproot and cut plots at Kabete where 0, 20 and 40 kg N/ha were applied showed 8, 9, and 10 centimetres, respectively. However, the difference in Njoro was 2 centimetres in all plots. Under all residual N levels the height of finger millet plants at both uproot and cut plots, were higher at Kabete than at Njoro.

Table 9. Effect of previous harvesting method and residual nitrogen (rN) application on height (cm) of finger millet at flowering stage at Kabete and Njoro, phase two (April-October 1994).

Previous Cropping treatment	rN-level (kg/ha)	Area previously Uprooted	Kabete	t-test	Njoro	t-test
FM	0	Y	22.667	*	14.467	ns
	"	N	32.333		15.533	
	20	Y	24.17	**	20.500	*
	”	N	32.500		16.667	
	40	Y	24.367	**	19.433	ns
	"	N	33.333		18.433	
FM+CB	0	Y	25.267	***	22.033	ns
	"	N	36.267		22.200	
	20	Y	25.833	***	21.433	**
	"	N	36.267		18.400	
	40	Y	25.700	**	20.200	*
	"	N	36.800		18.133	
FM+TQ	0	Y	25.167	**	21.433	*
	"	N	35.667		18.467	
	20	Y	26.700	***	20.533	*
	"	N	35.533		18.200	
	40	Y	26.633	***	19.967	ns
	"	N	33.500		20.200	

FM=Finger millet; CB= *Crotalaria brevidens*; TQ= *Trifolium quartinianum*.
*= significant at 5% level of probability using students t-test.
ns= not significant; Y=yes; N=not.

(b) Biomass (stems and leaves).

The previous harvesting method had a significant ($P < 0.05$) effect on biomass of finger millet at both Kabete and Njoro sites (Table 10). All N levels showed a significant difference at Njoro, but only plots previously with sole finger millet supplied with 40 Kg N/ha, those which had finger millet and *Crotalaria brevidens* with 20 Kg N/ha and those with Finger millet and *Trifolium quartinianum* at 40 Kg N/ha showed significant differences.

At all N levels uproot plots at Kabete produced less biomass than cut ones. However, uproot plots had more yield than cut at Njoro. The difference in biomass of uproot and cut were lower in Kabete than Njoro.

Table 10. Effect of previous harvesting method and residual nitrogen (rN) application on the biomass (g/plant) of finger millet at Kabete and Njoro, season two (April-October 1994).

Previous Cropping treatment	rN-level (kg/ha)	Area previously Uprooted	Kabete	t-test	Njoro	t- test
FM	0	Y	79.427	ns	100.330	*
	"	N	71.433		65.067	
	20	Y	71.830	ns	64.900	*
	"	N	82.347		82.907	
	40	Y	100.597	**	100.683	*
	"	N	46.720		61.00	
FM+CB	0	Y	88.963	ns	82.080	*
	"	N	86.487		71.980	
	20	Y	70.117	*	90.503	*
	"	N	86.487		47.580	
	40	Y	67.973	ns	79.660	*
	"	N	59.210		54.273	
FM+TQ	0	Y	84.130	ns	100.360	*
	"	N	87.103		80.26	
	20	Y	64.903	*	102.873	*
	"	N	89.247		94.370	
	40	Y	116.363	*	100.730	*
	"	N	82.147		81.017	

FM=Finger millet; CB= *Crotalaria brevidens*; TQ= *Trifolium quartinianum*.
*= significant at 5% level of probability using students t-test.
ns= not significant; Y=yes; N=not.

(c). Grain Yield.

At both sites the previous harvesting method had no significant effect on the grain yield (Table 11). Finger millet grown on previously cut plots maginally outyielded those from uprooted plots at both sites. At both Kabete and Njoro, plots previously occupied by *Crotalaria brevidens* and finger millet, at all N levels, produced the highest grain yield, those with *Trifolium quartinianum* and finger millet gave intermediate grain yield, while those with sole finger millet gave the least.

At both sites, plots that had not received N, grain yield from uproot plots was higher than that from cut plots, whereas in plots that had received 20 and 40 kg N/ha, cut plots produced higher grain yield.

In general, grain yield produced at Kabete was more than that at Njoro. At Kabete, the difference between uproot and cut plots, in plots previously planted with sole finger millet was 0.3 t/ha, those planted with finger millet and *Crotalaria brevidens* was 0.2 t/ha and those planted with finger millet and *Trifolium quartinianum* was 0.1 t/ha. At Njoro, the values were 0.3, 0.1 and 0.25 t/ha, respectively.

Table 11. Effect of previous harvesting method and residual nitrogen (rN) application on grain yield (t/ha) of finger millet at Kabete and Njoro, phase two (April-October 1994).

Previous Cropping treatment	rN-level (kg/ha)	Area previously Uprooted	Kabete	t-test	Njoro	t-test
FM	0	Y	1.393	ns	1.097	*
	"	N	1.687		1.680	
	20	Y	1.580	ns	1.430	ns
	"	N	1.877		1.617	
	40	Y	0.883	*	1.307	ns
	"	N	1.570		1.437	
FM+CB	0	Y	2.15	ns	1.497	ns
	"	N	2.040		1.497	
	20	Y	1.667	ns	1.697	ns
	"	N	1.827		1.610	
	40	Y	1.850	ns	1.610	ns
	"	N	2.177		1.497	
FM+TQ	0	Y	1.323	ns	1.727	*
	"	N	1.447		1.507	
	20	Y	1.724	ns	1.373	ns
	"	N	1.617		1.413	
	40	Y	1.743	ns	1.363	ns
	"	N	1.710		1.747	

FM= Finger Millet; CB= *Crotalaria brevidens*; TQ= *Trifolium quartinianum*.
*= significant at 5% level of significance using the students t-test.
ns= not significant; Y=yes; N=not.

4.2.4. Yield components.

Previous harvesting method had no significant effect on number of tillers per plant, ear weight, ear number per plant, 1000 seed weight at both sites (Tables 12-15). The number of tillers per plant at Njoro was about twice that at Kabete. Plots that had not been supplied with nitrogen, produced the lowest number of tillers per plant, those that been supplied with 20 kg N/ha, intermediate and those with 40 kg N/ha the highest at Kabete, whereas at Njoro those that had received 40 Kg/ha, gave the highest number, then, 0, intermediate and 20 kg N/ha, produced the least. At Kabete, cut plots produced more tillers per plant than uproot ones and uproot did better than cut at Njoro.

Seed weights (1000) and ear weights were higher at Kabete than at Njoro. Uproot plots outyielded the cut ones at both sites. These parameters had highest value in plots previously planted with finger millet and *Crotalaria brevidens*, followed by those planted with finger millet and *Trifolium quartinianum* and lastly those planted with sole finger millet at all N levels.

The number of ears per plant were more in cut than uproot plots at Kabete at all residual N levels and the opposite was true for Njoro.

Table 12. Effect of previous harvesting method and residual nitrogen (rN) application on the number of tillers per plant of finger millet at Kabete and Njoro, phase two (April-October 1994).

Previuos Cropping treatment	rN-level (kg/ha)	Area previously Uprooted	Kabete	t-test	Njoro	t-test
FM	0	Y	4.667	ns	10.233	ns
	"	N	5.733		10.800	
	20	Y	4.467	ns	12.567	ns
	"	N	4.400		12.067	
	40	Y	4.200	ns	10.800	ns
	"	N	3.067		9.133	
FM+CB	0	Y	5.200	ns	10.900	ns
	"	N	7.067		8.967	
	20	Y	5.333	ns	10.167	*
	"	N	5.333		6.933	
	40	Y	5.067	ns	13.633	*
	"	N	4.800		6.233	
FM+TQ	0	Y	5.100	ns	12.567	ns
	"	N	6.400		10.767	
	20	Y	6.000	*	10.567	ns
	"	N	4.800		9.530	
	40	Y	4.200	ns	11.100	ns
	"	N	4.933		10.800	

FM= Finger Millet; CB= *Crotalaria brevidens*; TQ= *Trifolium quartinianum.*
*= significant at 5% level of probability using students t-test.
ns= not significant; Y=yes; N=not.

Table 13. Effect of previous harvesting method and residual nitrogen (rN) application on 1000 seed weight (g) of finger millet at Kabete and Njoro, phase two (April-October 1994).

Previous Cropping treatment	rN-levels (kg/ha)	Area previously Uprooted	Kabete	t-test	Njoro	t-test
FM	0	Y	3.877	ns	2.660	ns
	"	N	3.910		2.740	
	20	Y	3.750	ns	2.593	ns
	"	N	3.720		2.533	
	40	Y	3.410	ns	2.533	ns
	"	N	3.823		2.607	
FM+CB	0	Y	4.023	ns	2.840	ns
	"	N	4.087		2.693	
	20	Y	3.867	*	2.507	ns
	"	N	4.173		2.553	
	40	Y	3.920	ns	2.440	ns
	"	N	4.363		2.920	
FM+TQ	0	Y	4.153	*	2.920	ns
	"	N	3.797		2.760	
	20	Y	4.003	*	2.393	ns
	"	N	4.457		2.680	
	40	Y	4.017	ns	2.493	ns
	"	N	4.103		3.000	

FM= Finger millet; CB= *Crotalaria brevidens*; TQ= *Trifolium quartinianum*.
*= significant at 5% level of probability using students t-test
ns= not significant; Y=yes; N=not.

Table 14. Effect of previous harvesting method and residual nitrogen (rN) application on ear weight (g) of finger millet plants at Kabete and Njoro, phase two (April-October 1994).

Previuos Cropping treatment	rN-levels (kg/ha)	Area previously Uprooted	Kabete	t-test	Njoro	t-test
FM	0	Y	1.907	ns	1.993	ns
	"	N	1.883		2.023	
	20	Y	2.103	ns	2.007	ns
	"	N	1.530		2.177	
	40	Y	2.647	*	1.950	ns
	"	N	1.763		2.333	
FM+CB	0	Y	2.767	**	2.740	ns
	"	N	2.593		2.543	
	20	Y	2.097	ns	2.220	ns
	"	N	2.047		2.083	
	40	Y	2.170	ns	2.230	ns
	"	N	2.307		2.460	
FM+TQ	0	Y	2.517	*	2.723	ns
	"	N	2.723		2.663	
	20	Y	2.510	ns	2.073	*
	"	N	2.507		3.043	
	40	Y	1.970	*	1.903	*
	"	N	2.515		2.630	

FM= Finger millet; CB= *Crotalaria brevidens*; TQ= *Trifolium quartinianum*.
*= significant at 5% level of probability using students t-test.
ns=not significant; Y=yes; N=not.

Table 15. Effect of previous harvesting method and residual nitrogen (rN) application on the number of ears per plant of finger millet at Kabete and Njoro, phase two (April-October 1994).

Previous Cropping treatment	rN-level (kg/ha)	Area previously Uprooted	Kabete	t-test	Njoro	t-test
FM	0	Y	8.867	ns	9.567	*
	"	N	7.267		13.000	
	20	Y	9.433	ns	13.900	ns
	"	N	10.367		13.567	
	40	Y	8.833	*	12.233	**
	"	N	6.533		13.200	
FM+CB	0	Y	8.367	**	13.133	ns
	"	N	5.200		13.200	
	20	Y	5.700	ns	14.233	ns
	"	N	5.300		10.533	
	40	Y	7.333	ns	13.000	ns
	"	N	6.733		14.000	
FM+TQ	0	Y	4.953	*	11.767	*
	"	N	6.500		16.233	
	20	Y	4.600	ns	12.333	ns
	"	N	6.267		13.333	
	40	Y	5.133	*	12.433	*
	"	N	7.700		17.767	

FM= Finger millet; CB= *Crotalaria brevidens*; TQ= *Trifolium quartinianum*.
*= significant at 5% level of probability using students t-test.
ns= not significant; Y=yes; N=not.

4.3. Effect of previous intercrop management practices on soil C:N ratio.

At Kabete total nitrogen and organic carbon were higher in previously uproot plots than cut ones, but at Njoro organic carbon was more in cut than uproot plots, while total nitrogen was more in uproot than cut plots (Tables 16-19). Top soils had more total nitrogen and organic carbon at both sites. The C:N ratio was higher in the top than subsoil. The differences in the C:N ratios of top and subsoils in cut plots were higher than in uproot plots.

Table 16. Soil C:N ratios of cut plots at Kabete (end of phase 2).

Plot	rN-levels (Kg N/ha)	Depth (cm)	%N	%C	C:N
FM+CB	0	0-15	0.261	2.70	10:1
		15-30	0.212	1.86	8.8:1
	20	0-15	0.245	2.47	10:1
		15-30	0.229	2.20	9.6:1
	40	0-15	0.245	2.41	9.8:1
		15-30	0.212	1.96	9.2:1
FM+TQ	0	0-15	0.278	2.79	10:1
		15-30	0.212	2.01	9.5:1
	20	0-15	0.261	2.59	9.9:1
		15-30	0.212	1.98	9.3:1
	40	0-15	0.261	2.65	10:1
		15-30	0.212	2.02	9.5:1
FM (sole)	0	0-15	0.278	2.81	10:1
		15-30	0.212	1.99	9.4:1
	20	0-15	0.261	2.71	10:1
		15-30	0.229	2.11	9.2:1
	40	0-15	0.294	3.00	10:1
		15-30	0.212	1.93	9.1:1

Table 17. Soil C:N ratios of uproot plots at Kabete (end of phase 2).

Plot	rN-levels (Kg N/ha)	Depth cm	%N	%C	C:N
FM+CB	0	0-15	0.245	2.62	11:1
		15-30	0.245	2.20	8.9:1
	20	0-15	0.278	3.02	11:1
		15-30	0.261	2.48	9.5:1
	40	0-15	0.278	2.99	11:1
		15-30	0.245	2.19	8.9:1
FM+TQ	0	0-15	0.229	2.40	11:1
		15-30	0.245	2.17	8.9:1
	20	0-15	0.245	2.64	11:1
		15-30	0.229	2.01	8.8:1
	40	0-15	0.261	2.97	11:1
		15-30	0.261	2.42	9.3:1
FM (sole)	0	0-15	0.278	3.02	11:1
		15-30	0.245	2.45	8.8:1
	20	0-15	0.245	2.69	11:1
		15-30	0.229	2.03	8.9:1
	40	0-15	0.261	2.81	11:1
		15-30	0.245	2.11	8.6:1

Table 18. Soil C:N ratios of cut plots at Njoro (end of phase 2).

Plot	rN-levels (Kg N/ha)	Depth cm	%N	%C	C:N
FM+CB	0	0-15	0.245	2.71	11:1
		15-30	0.229	2.12	9.3:1
	20	0-15	0.278	3.01	11:1
		15-30	0.245	2.10	8.6:1
	40	0-15	0.245	2.69	11:1
		15-30	0.196	1.73	8.8:1
FM+TQ	0	0-15	0.278	3.02	11:1
		15-30	0.229	2.00	8.7:1
	20	0-15	0.261	2.85	11:1
		15-30	0.261	1.70	8:1
	40	0-15	0.278	3.05	11:1
		15-30	0.229	2.02	8.8:1
FM (sole)	0	0-15	0.294	3.22	11:1
		15-30	0.294	2.45	8.3:1
	20	0-15	0.245	2.65	11:1
		15-30	0.245	1.99	8.1:1
	40	0-15	0.245	2.67	11:1
		15-30	0.196	1.71	8.7:1

Table 19. Soil C:N ratios of uproot plots at Njoro (end of phase 2).

Plot	rN-levels (Kg N/ha)	Depth (cm)	%N	%C	C:N
FM+CB	0	0-15	0.278	2.75	9.9:1
		15-30	0.212	1.91	9:1
	20	0-15	0.261	2.64	10:1
		15-30	0.229	2.06	7.9:1
	40	0-15	0.261	2.59	9.9:1
		15-30	0.229	2.04	8.9:1
FM+TQ	0	0-15	0.229	2.31	10:1
		15-30	0.212	1.89	8.9:1
	20	0-15	0.261	2.62	10:1
		15-30	0.229	2.01	8.8:1
	40	0-15	0.229	2.33	10:1
		15-30	0.212	1.91	9:1
FM (sole)	0	0-15	0.196	2.00	10:1
		15-30	0.196	1.79	9.1:1
	20	0-15	0.245	2.48	10:1
		15-30	0.245	2.25	9.2:1
	40	0-15	0.294	2.91	9.9:1
		15-30	0.196	1.99	10:1

CHAPTER FIVE

5.0. DISCUSSION

5.1. Intercropping and inorganic N application.

In plant population, competition is defined as the situation in which each of two or more plants growing together in the same area seek the same growth factor, which is below their combined demands (Clements *et al.*, 1929; Donald, 1963). Both intercrop and intracrop competition are acceptable facts in plant population interaction. The higher the plant density, the higher the expected competition. The objective is to try to reduce the extent of this competition to a point where the highest possible economic benefit can be achieved.

Crotalaria brevidens germinated earlier and remained taller than finger millet at Kabete meaning that the legume had an advantage over the cereal in terms of accessibility to growth resources like light, nutrients, gases and water. These resources were limited and may on occasions have been insufficient to allow unrestricted growth (Black, 1960a). Furthermore individual plants may develop in such proximity that each lowers the availability of resources to the other or create a deficiency where they were adequate to support the growth of an isolated individual (Harper, 1977). Stress during germination and seedling establishment drastically affects crop stand and is often a major constraint especially in small millets with limited seed reserve (Paleg and Aspinall, 1981). *Crotalaria brevidens* shaded finger millet thus curtailing its photosynthetic potential as a result of being a superior competitor. At Njoro, both *Crotalaria brevidens* and finger millet seemed to have been affected uniformly by environmental and climatic factors, such that their plant heights were not significantly affected. On the other hand *Trifolium quartinianum* was dwarfed by finger millet at both sites by virtue of the legumes spreading growth habit.

The study showed that fresh and dry leaf weights of *Crotalaria brevidens* and *Trifolium quartinianum* were significantly influenced by application of various N fertilizer rates. In cereal-legume intercropping, the legume component is capable of fixing atmospheric N_2 under favourable conditions and this is thought to reduce the competition for N with the cereal component (Trenbath, 1976). In the absence of an effective N-fixing system, both cereal and intercrop legume compete for available soil N (Ofori *et al.*, 1987).

Average leaf dry matter of *Crotalaria brevidens* at Kabete was 12.4 t/ha, where N was applied and intercropped with finger millet; without fertilizer leaf dry matter yield was 11.6 t/ha. At Njoro, the yields were 4.23 and 3.58 t/ha. In Upper Volta, it has been reported that *Crotalaria juncea* produced 10 tonnes/ha of dry matter without fertilizer (Anon, 1965). In Surinam, when *Crotalaria quinquefolia* was grown for fodder, Ubels (1960) recorded an average of 17 tonnes/ha of dry matter. In the Southern part of Tanzania, Mukurasi (1986) harvested 12 tonnes/ha of dry matter from *C. zanzibari.* Comparatively, lucerne (*Medicago sativa*), which is one of the most important perennial fodders used in many regions of the world produces yields of 8-9 t/ha (Whiteman, 1980). Total dry matter is one of the factors which to a large extent determines the carrying capacity of a forage. In many selection programmes dry matter yield is a key criterion for selection (Whiteman, 1980). Since *Crotalaria* species are among the high nitrogen fixers, this partly explains their yield potential because total dry matter and nitrogen fixation in legumes are known to be positively correlated.

At Kabete, the biomass for sole and intercrop *Crotalaria brevidens* were, 55.4 and 47.1 g/plant; that of sole and intercrop *Trifolium quartinianum* were, 16.1 and 14.1

g/plant, respectively. On the other hand, sole and intercrop finger millet with *Crotalaria brevidens* gave 33.4 and 11.0; and sole and intercrop finger millet with *Trifolium quartinianum* gave 37.2 and 41.22 g/plant at this site. The above treatments gave 33.7 and 32.6; 33.5 and 30.13; 26.2 15.05 and 32.5 and 32.0 g/plant at Njoro, respectively. Thus intercropping depressed the yields of all crops.

The high LER; 1.80 and 1.88 at Kabete and Njoro, respectively, of *Trifolium quartinianum* - finger millet intercrop shows that this would be a better cereal-legume combination than the *Crotalaria brevidens*-finger millet association. It has been suggested that in density studies of cereal intercrop systems the sole crop yields used as standardization factors for estimating land equivalent ratios should at the optimum densities of the crops (1974; Huxley and Maingu, 1978). This avoids the confounding of beneficial interractions between components with a response to a change in density (Trenbath, 1976). The value of LER follow the density of the legume component rather than that of the cereal. Differences in growth durations of component crops affect the magnitude of the LER. The LER values in crops with similar maturities are usually less than in cropping combinations with contrasting maturities (Trenbath, 1976; Willey, 1979). The general trend in intercropping experiments is that the grain and stover yield of a given crop in the mixture are less than the yields of the same crop grown alone, but that the total productivity per unit of land is usually greater for mixtures than for sole crops. Shelton and Humphreys (1975c) reported that upland rice was 12% less when intercropped with *Stylosanthes guianensis* than when grown alone. Gardner and Boundy (1983) also observed yield depression of cereal lupins. Similar trends have been observed in the intercrops of *Dolicos lablab* with maize and sorghum at Debre Zeit, Ethiopia (Haque, 1984). Chetty (1983), in a review of work done over a 10-year period in India, noted little depression of yield of finger millet by fodder legumes, field beans, *Dolichos lablab* and lucerne.

The competitive ability of *Crotalaria brevidens* caused a greater accumulation of biomass than that of finger millet at Kabete, while at Njoro the biomass of the two crops differed slightly because the former crop was a better competitor. *Crotalaria brevidens* has a deep and extensive root system and produces large compound leaves which can trap a large proportion of phosynthetically active radiation (PAR). A larger, deeper or more active root system enables one plant to secure a larger amount of chresard (water avalable for growth) and the immediate reaction is to reduce the amount produced by the other (Clements *et a*l., 1929). The stems and leaves of the former crop grow in size and number and thus require more water, the roots respond by augmenting the absorbing surface to supply the demand automatically to reduce the water content further. At the same time the correlated growth of stems and leaves is producing a reaction on light by absorption, leaving less energy available for leaves of the competitor beneath it, while increasing the amount of food for further growth of absorbing roots, taller stems and overshadowing leaves (Clements *et al*., 1929). Biomass production is predominantly dependent on canopy photosynthesis. Though both leaf area and photosynthesis contribute to biomass production, increasing the photosynthetic efficiency is advantageous especially for crops grown under rainfed conditions (Paleg and Aspinall, 1980). The biomass of *Trifolium quartinianum* was higher than that of finger millet at both sites because the former crop is a spreader whose natural habitat is shaded environments. The presence of the latter crop did not interfere with its accumulation of biomass. The presence of a plant changes the environment of its neighbours and may alter their growth rate and form (Harper, 1977). Such changes in the environment, brought about by the proximity of individuals is referred to as "interference," a blanket term which does not define in any way the manner in which the alterations in the enviroment are produced and includes neighbour effects due to the consumption of resources in limited supply, the production of toxins, or changes in conditions such as protection from wind and influences on the behaviour of predators. Higher plants react to stress of density by plastic responses as well an altered risk of death. The population like structure of an individual plant fits it admirably to respond to stresses by varying the birth rate and the death rate of its parts, leaves, branches, flowers, rootlets etc. (Harper *et a*l., 1970).

Unlike intercrops, sole crops had higher biomass because they never experienced any competition or interference. At Kabete, *Crotalaria brevidens* produced the highest biomass, followed by *Trifolium quartinianum* and then finger millet. The order at Njoro was *Trifolium quartinianum*, *Crotalaria brevidens* and finger millet. Clements *et al.* (1929) stated that the beginning of competition is due to reaction when the plants are so spaced that the reaction of one affects the response of the other by limiting it, the initial advantage thus gained is increased by accumulation, since even a slight increase in amount of energy or raw material is followed by corresponding growth, and thus by a further gain in response and reaction.

The fact that the crops were taller, had higher leaf yields and had more biomass (stems and leaves) at Kabete than Njoro could be attributed to the more suitable climatic conditions which prevailed at Kabete than at Njoro during phase one. Another factor that could have given the crops at Kabete an advantage over Njoro was that the nitosols found in Kabete retain water for a longer time than the haplic phaezoems prevalent at Njoro (FAO/UNESCO, 1974). Layers of haplic phaezoms dry out too rapidly for the seed to germinate or for the seedling to extend its roots down into the deeper layers where available moisture can be found (Hsiao, 1973). It is possible that, at Njoro, apart from leaching of NH_4+ and NO_3- to lower horizons, the relatively high maximum temperatures under irrigation facilitated volatilization of some of the N applied (Tisdale, 1966). Periods of drought, however short, during some stages of growth markedly reduce yield (Hsiao,1973). Analysis of the constraints of growth and productivity suggests that the following are the major factors: (a) Stress after sowing has effect on seedling emergence and crop establishment, (b) Early season stress has effect on early crop growth, (c) Mid-season stress has effect on sink development and sink number. Nitrogen is lost from cropping systems through harvested crop products, gaseous N, and leaching of nitrates from soil beyond the root zone (Greenland, 1977). The complexity of the processes involved in gaseous N losses, namely, denitrification and volatilization, and the paucity of direct measurements that vary widely with environmental conditions, especially temperature and water content, has generally limited an accurate assessment of the magnitude of N losses under field conditions (Vlek *et al.*, 1981). Legumes and Finger millet left residues in the soil thus causing a higher C:N ratio on the cut than the uproot plots.

5.2. Effect of previous legume intercrop management practices.

Seed placement was rather poor in both uproot and cut plots at Kabete and Njoro because of the different previous seasons harvesting methods. Plants on the cut plots emerged earlier than those on uproot plots at Kabete. For Njoro's haplic phaezoems, since there was some form of soil disturbance in the uproot plots, plants germinated earlier than those in cut plots.

There were taller finger millet plants, more biomass, higher grain yield at Kabete than at Njoro. This could be probably explained by the fact that favourable climatic conditions prevailed in the former site. There had been more crop residue left in the soil after harvest. It is also possible that the legumes could have shed more nodules at Kabete than at Njoro. Furthermore, nitosols at Kabete are friable, easy to work and have a high moisture holding capacity (FAO/UNESCO, 1974). The seeds in the cut plots at Kabete were also placed at a depth that facilitated easier and earlier germination than on the uproot plots which was too deep for easy seed germination. At Kabete the situation of seed placement and germination was worse in plots which were previously occupied by *Crotalaria brevidens* and finger millet than those with *Trifolium quartinianum* and finger millet. This was because *Crotalaria brevidens* is more deeprooted than *Trifolium quartinianum* and hence deeper trenches were left when the former crop was harvested than when the latter was. At Njoro, the haplic phaezoems were compact when dry and difficult to work. Therefore, since ploughing of the soil was not done, the cut plots plots remained highly crusted such that the seeds were placed just below the surface. The previous season was fairly dry at Njoro and irrigation supplemented rains at times. As soil water potential in the surface layers decreases, water retained in the deeper layers makes a larger contribution to evapotranspiration (ET) Levitt (1980). Often in shallow rooted crops like the small millets, when most of the moisture from the upper layers is exhausted, the plant is unable to extract water to satisfy the ET demand even though the soil water available in the deeper layer is still high. Under these conditions, a deeper root system may have an advantage . On the cut plots, only a thin layer of soil covered the seeds. This, therefore, exposed the seeds to vagaries of nature as opposed to seed on the uprooted plots which was placed at an optimum depth and hence better germination. Drought stress severely limits the yield of finger millet although it is reputedly one of the most tolerant to drought (Hsiao, 1973).

There was no significant difference in grain yield between plots previously planted with intrecrops. Grain yield was higher at Kabete than at Njoro. The differences in yield at 0, 20 and 40 residual N levels were on average 0.7, 0.3 and 0.3 t/ha, at the two sites. The contribution of N by a forage legume to a subsequent crop is less controversial than current transfer of N. It is generally agreed that some quantity of N will result from root and nodule decay (Henzell and Vallis, 1977). Waghmare and Singh (1984b) in India reported that the N requirement of a non-legume can be considerably reduced after intercropped fodder legume. However it is not clear whether the presence of legume roots could increase mineralization of cereal roots and native soil organic matter by decreasing the overall C:N ratio.

Tillers and ears per plant were more at Njoro than at Kabete because the crops at the former site took a longer time to mature. That meant that most of the photosynthate produced was utilized in vegetative growth. Inspite of the inbuilt mechanism for low transpiration quotient in finger millet, the crop experiences severe moisture stress in many locations during the early stages of growth even with a good degree of soil moisture conservation practises (Hsiao, 1973). Stress induced plasticity in postponing the flowering and development of new tillers on stress alleviation are often suggested as adaptive mechanisms under such situations (Paleg and Aspinal, 1981). Medium duration cultivars have better plasticity both in terms of postponement of flowering during stress and production of new tillers on stress alleviation as compared to early cultivars.

Mid-season drought stress effect on overall productivity has been shown to be less in tillering genotypes with an ability for tiller development on alleviation of stress

(Algarwamy, 1981). However, in finger millet, the specific advantage in tillering types under stress situations has not been elucidated so far. In many genotypes of finger millet, this productivity of successive tillers reduces drastically and the late formed tillers and nodal tillers formed after stress alleviation contribute very little to grain weight (Sastry, 1982).

In spite of the early germination of finger millet on the cut plots at Kabete and uproot plots at Njoro the late emerging plants underwent compensatory growth such that by the time of maturity the crops were the same in stature and height. 1000 seed weight and ear weight were higher in on cut than uproot plots at both sites because finger millets in the former plots germinated earlier, hence underwent vegetative and reproductive stages within the crops normal growth cycle. The plants on the uproot plots spent most of the time in the vegetative stage. In finger millet, a relationship exists between productivity and mean ear weight, but not ear number per plant (Anonymous, 1986). In finger millet, ear photosynthesis constitutes nearly 5 to 30 per cent the grain dry weight (Perumal, 1982). The advantage of high glume size for higher ear photosynthesis and grain development by virtue of greater translocation has been shown in some collections of finger millet from Malawi (Sashidhar, 1984).

Cut plots had higher C:N ratios than uproot at the top soils. The differences in the subsoils were negligible. In fact the C:N ratios in the second phase were higher than the first phase because there was negligible nitrogen left in the soil at the end of the experiment.

CHAPTER SIX.

6.0. CONCLUSIONS AND RECOMMENDATIONS.

In this study intercropping favoured the growth of *Crotalaria brevidens* and had no effect on the performance of *Trifolium quartinianum*, but it depressed the growth of finger millet. That means finger millet did not benefit from N fixed by the legumes. Therefore when intercropped with finger millet, *Trifolium quartinianum* could be a better legume than *Crotalaria brevidens* in a legume-based intervention in a predominantly cereal-farming system. This is because *Trifolium quartinianum* does not cause much competition to the finger millet crop while at the same time giving good yields. Applying N was beneficial to sole finger millet and when in intercrop with *Trifolium quartinianum* where no competition for growth factors was experienced. The applied N enhanced the vegetative growth of the legumes thus boosting the idea of including them in mixed cropping systems.

Residual organic and inorganic N was beneficial to finger millet. The two harvesting methods used could make a difference if the main interest is biomass production but not grains. Therefore different harvesting methods could be useful for fodder but not for grain production purposes.

Recommendations for further research work are:

1. *Trifolium quartinianum/Crotalaria brevidens* should not be intercropped with finger millet.
2. Work on the legume-cereal intercrops be done in warmer areas.
3. Growth and yield components should be investigated for all crops within the two phases.
4. The experiments should be carried out for more than two years in multiple locations.

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APPENDIX 1.

Initial soil chemical properties (phase one)

Site	Depth (cm)	Soil pH H_2O	Soil pH $Cacl_2$	%N	%C	C:N
Kabete	0-15	5.71	4.89	0.27	2.58	9.5:1
	15-30	5.73	4.79	0.27	2.06	7.6:1
Njoro	0-15	6.40	5.45	0.33	2.79	8.5:1
	15-30	6.44	5.40	0.30	2.68	8.9:1

APPENDIX 2.
Weather data at Kabete.

Season I

		Rainfall (mm)	Ave. R.H. (%)	Solar Rad. (MJM^2)	Temperature(^oC) Max	Min	Windrun (Km/day)
1993	October	30.9	62.5	386.2	20.7	14.8	156.1
	November	98.8	70.0	386.3	22.9	14.1	150.4
	December	177.8	72.6	414.6	22.5	13.7	156.4
1994	January	4.9	58.9	497.8	24.9	13.5	157.4
	February	35.7	48.7	437.7	25.9	14.0	129.9

Season II

		Rainfall (mm)	Ave. R.H. (%)	Solar Rad. (MJM^2)	Temperature(^oC) Max	Min	Windrun (Km/day)
1994	March	56.3	62.5	440.1	25.9	14.4	139.5
	April	237.2	70.3	399.8	23.8	14.6	101.6
	May	92.2	75.2	339.9	22.2	13.8	72.3
	June	44.4	73.2	316.2	21.7	11.9	51.0
	July	18.8	75.5	283.6	20.5	11.8	47.7
	August	33.9	74.5	278.2	20.5	12.2	57.3

APPENDIX 3.

Weather data at Njoro.

		Rainfall (mm)	Ave. R.H. (%)	Solar Rad. (MJM^2)	Temperature(oC) Max	Min	Windrun (Km/day)
				Season I			
1993	November	82.8	57.0	491.7	23.1	10.0	134.4
	December	55.8	61.0	531.8	23.1	9.8	139.2
1994	January	3.0	45.0	612.9	25.7	9.0	175.2
	February	20.8	40.0	601.3	26.1	9.6	182.4
	March	70.6	49.0	579.9	26.2	10.6	158.4
				Season II			
1994	April	139.4	62.0	535.3	24.5	11.2	127.2
	May	123.9	70.0	565.3	22.5	10.7	117.6
	June	95.7	78.0	510.4	21.6	10.2	108.0
	July	140.2	78.0	507.0	21.1	9.5	103.2
	August	100.5	72.0	489.1	21.0	9.2	105.6
	September	41.9	61.0	632.9	23.7	8.5	132.0
	October	56.9	56.0	529.9	23.5	12.1	124.8