STUDIES ON GREEN MANURE APPLICATION AND INTERCROPPING IN *Coffea arabica* L. PRODUCTION

by
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DECLARATION BY CANDIDATE

The work reported in this thesis is based on my original work and ideas. It has not been presented for a degree in any other University.

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CONTENTS

LIST OF TABLES

CHAPTER FOUR

CHAPTER FIVE

LIST OF FIGURES

STUDIES ON GREEN MANURE APPLICATION AND INTERCROPPING IN COFFEE (*Coffea arabica* L.)

ABSTRACT

Three experiments were conducted between May 1991 and December 1993 at Coffee Research Station Ruiru, Kenya, to study the effect of green manure application and intercropping on soil chemical properties, coffee plant growth, bean yield and quality.

The first experiment was to study the effect of applying as mulch various leguminous green manures plants to coffee (*Coffea arabica* Cv. `Ruiru 11') at field establishment phase. The leguminous green manures tested were from *Leucaena leucocephala*, *Sesbania sesban*, *Calliandra calothyrus*, *Medicago sativa*, *Desmodium intortum* and *Cajanus cajan*.

Application of the various green manures except that from Desmodium did not significantly affect the coffee growth. The application however, significantly reduced primary extension and leaf area of coffee plants. Application of the various green manures significantly depressed the coffee yields.

It was concluded that application of green manures to coffee plants could only be beneficial during the first year after coffee establishment but the green manures may not be able to supply adequate plant nutrients. They however improved the soil physical characteristics.

The second experiment was to study the effect of intercropping coffee plants, during the establishment phase, with the following fruits: pawpaws (*Carica papaya*), passion fruit (*Passiflora edulis*), apples (*Malus

pumila), oranges (*Citrus sinesis*), bananas (*Musa sapentium*), guava (*Psidium guajava*), avocadoes (*Persea americana*), loquats (*Eriobotrya japonica*) and macadamia (*Macadamia ternifolia*). Banana and guava intercrops significantly depressed coffee plant height, plant stem diameter and yield components (number of primaries and nodes per primary). However, the depression did not affect the clean coffee yields. The other fruit tree intercrops did not significantly affect coffee tree growth or clean coffee yields or the bean quality.

The third experiment was to study the effects of intercropping mature arabica coffee CV SL 28 during the change of cycle phase, with beans (*Phaseolus vulgaris*), cowpea (*Vigna unguiculata*), Irish potatoes (*Solanum tuberosum*), tomatoes (*Lycopersicon esculentum*), sweet potatoes (*Ipomea batatas*) and garden peas (*Pisum sativum*). The results showed that the food intercrops did not significantly affect coffee tree growth and coffee bean yield and quality. Yields of the intercrops were also not affected by coffee plants during the first year after change of cycle. However, during the second year, the yields were reduced due to the heavy canopy especially under high density. Although there was a yield advantage during the two years of change of cycle, it was uneconomical to intercrop during the second year.

The various fruit and food crops evaluated are suitable intercrops in coffee. Intercropping food crops during change of cycle phase should be limited to the first year only.

CHAPTER 1
GENERAL INTRODUCTION

Coffee, which was introduced into Kenya by French Missionaries in 1898 has become an important cash crop in the Kenyan economy. Upto 1989, it was contributing an average of about 30% of the total domestic foreign exchange earnings. In addition to foreign exchange earnings, it is estimated that within the 70% of the national workforce employed by agriculture, 30% is employed by the coffee industry.

Coffee production in Kenya has been increasing steadily since its introduction in 1898. The total annual production by 1988 was more than 130,000 tonnes of clean coffee, and it had been projected to double by the year 2000 (Anon, 1986). The hectarage under coffee has similarly increased over the years (Anon, 1989). However after the collapse of International Coffee Agreement (ICA) in 1989, the coffee prices became depressed and more stochastic (Karanja, 1992). The national coffee output dropped from over 100,000 tonnes of clean coffee in 1989/90 to 87,000 tonnes in 1990/91. The coffee productivity also dropped from 751 kg/ha of clean coffee to 500 kg/ha over the same period (Anon, 1992).

It is the Kenya Government's main objective to increase both the coffee production and productivity with a view of increasing the farm incomes. The increased output would be expected to be realised through intensified production in the existing coffee hectarage. This would entail that, the coffee farmers would have to adopt proven modern technologies of coffee management practices. The recommended methods of coffee production involve greater and timely usage of fertilizer and pesticides

(Anon, 1989). While ensuring high coffee yields and quality, these methods also result in relatively high production costs. The price of Kenya coffee fluctuates according to the international market and bears no relationship to the production cost. The cost of agrochemicals and labour which constitute about 24.3 and 46.7% of the current cost of coffee production, respectively, have been increasing by about 10% annually in the past several years (Anon, 1989). This implies that farmers profitability has continually been eroded over these years.

Karanja (1992) reported that there is a positive relationship between total input expenditures and coffee yield and that manure, fertilizers and farm labour are the most crucial inputs. However, coffee farmers, particularly the small scale farmers either do not use the manure and fertilizers or use them at sub-optimal levels (Karanja, 1992). The prices of farm inputs have also been increasing very rapidly, over the past few years, and consequently the use of fertilizers and other agro-inputs have decreased drastically (Anon, 1991). Despite this decline in the use of chemicals, a lot of money in foreign currency is being spent on the importation of agrochemicals, with fertilizers alone accounting for more than Ksh. 2 billion per year (Anon, 1991). To continue producing coffee at this escalating input prices and declining coffee prices will not be economical. This makes coffee farmers not only unable to increase coffee production but also unable to sustain the current levels of coffee production and quality. There is, therefore, need to look at alternatives that can lower production costs without lowering the coffee quality. This will lead to development of sustainable coffee production systems that will also encourage farmers not to neglect their coffee.

In an attempt to make the coffee farming remain viable under declining coffee prices, an *adhoc* Committee of Coffee Research Advisory Committee of Coffee Research Foundation set up in 1989, recommended that areas that would lower production costs while maintaining the current level of production and quality be looked into (Anon, 1989). Some of these were the use of organic manures and other organic wastes, practising suitable intercropping systems in coffee and the growing of disease resistant cultivars like Ruiru 11.

The advantages of using organic manures and wastes in coffee growing are well documented (Oruko, 1976; Michori, 1981; Njoroge, 1985 a; Njoroge *et al*, 1990). They include increase in organic matter of the soil, improvements of soil structure and provision of plant nutrients. Various forms of organic manures like cattle manure and methane gas plant residues have been used in coffee (Njoroge, 1985 a). Others like green manuring with leguminous tree mulch have been used extensively in annual crops (Kang and Duguma, 1984). The benefits of green manuring with leguminous tree mulch include slow conversion of unavailable plant nutrients to more readily available forms, maintenance of soil organic matter content which indirectly affects soil structure, water holding capacity and infiltration, microbial activity and soil porosity (Asenga, 1991). Leguminous plants are preferred as a source of green manure because some of them have the ability to fix nitrogen and release it to the soil (Agboola and Fayemi, 1972; Palm, 1988; Hichel and Barnes, 1984). These plants can be annual crops (Ojomo, 1981) or perennial trees (Willson and Kang, 1981; Kang *et al*, 1985; Venkateswarlu *et al*, 1990). Use of these green manures would assist coffee farmers in reducing production costs.

The other practice that might lead to reduction of production costs and encourage farmers not to neglect coffee is intercropping. Intercropping is the growing of two or more crops in distinct row arrangement and simultaneously on the same piece of land (Andrews and Kassam, 1976). The advantages of intercropping are well documented (Aiyer, 1949; Andrews, 1972; Osiru and Willey, 1972; Charreau, 1977; Fisher, 1976). They include better utilization of land, light, water and nutrients (Charreau, 1977). The advantages obtained are both due to temporal (Rao and Willey, 1980) and spatial (Natarajan and Willey, 1980) complementarities. A lot of work has been done on intercropping with annual crops (Osiru and Willey, 1972; Rao and Willey, 1980; Fisher, 1976 and 1977). However, very few intercropping experiments have been carried out with coffee (Willson, 1985a).

In Kenya, coffee is mainly grown as an monocrop, and intercropping is not officially allowed. It is assumed that intercropping coffee with other crops may lower the renown quality. However, the small scale farmers have always intercropped their coffee with various food, fruit and tuber crops (Mukunya and Keya, 1985; Whittaker, 1986; Njoroge and Kimemia, 1993). Since coffee occupies some of the most high potential land, intercropping food and fruit crops with coffee would assist in increasing food production.

The objectives of the study were therefore to show the effects of:

1. Applying leguminous green manures to Arabica coffee plants on coffee plant growth and bean yield and quality during the establishment phase.

2. Intercropping perennial fruit crops with coffee plants during the establishment phase on coffee plant growth and bean yield and quality.
3. Intercropping annual food crops with coffee plants during change of cycle stage on coffee plant growth and bean yield and quality.

CHAPTER 2
LITERATURE REVIEW

2.1 Coffee Botany

Most of the coffee grown in Kenya is Arabica coffee, (*Coffea arabica* L.) belonging to the genus *Coffea* from the family Rubiaceae (Muller, 1966). Arabica coffee represents about 90% of the world's coffee farming and trade (Purseglove, 1968). *Coffea arabica* is a perennial woody shrub growing up to 10 m when mature (Purseglove, 1968). It has a dimorphic growth characteristic consisting of a central vertical (orthotropic) stem with lateral (plagiotropic) branches arising from the main stem in pairs opposite each other (Purseglove, 1968). The primary branches give rise to paired secondaries which branch to form tertiaries and finally quaternary branches. Suckers which are actually orthotropic shoots develop from the main stem especially when the latter is cut back.

The root system consists of a central tap root growing to a depth of 30 - 45 cm at plant maturity (Robinson, 1964). The axial roots grow vertically downwards to a depth of 2.3 m originating from the forking of the tap root.

Many lateral roots, 1 - 2 m long in a horizontal plane, form the surface plate in the first foot of soil. Below there are the lower laterals which ratify evenly and more deeply in the soil. Feeder roots are more numerous just under the soil surface (Willson, 1985 b). In moist, cool soils, the surface mat is better developed; while lower laterals predominate in drier, warmer soils.

The leaves are borne in opposite pairs, and are bronze tipped while young and dark green when mature. They are elliptical in shape with an acuminate tip. Their size vary depending on variety, location and season but range between 15 - 30 cm long and 5 - 15 cm wide (Purseglove, 1968).

Flowers are borne on all lateral branches and occasionally on the main vertical stem. The number of inflorescence varies from 2 - 6 per leaf auxiliary bud or 4 - 12 per node. Each inflorescence consists of about 1 - 5 flowers. Buds remain dormant until stimulated by rain or irrigation and the open to white fragrant flowers. It takes 6 - 8 months from flowering to fruit ripening. The fruit (cherry or berry) is a drupe consisting of two seeds and sometimes one (peaberry) due to failure of fertilization of one ovule or subsequent abortion (Purseglove, 1968).

The seedlings take about 12 months from seed germination to reach a sizeable size for planting and the plants take about 12 - 18 months to flower. The first good crop is expected in about 24 months after planting. The cherries are large spherical to slightly elliptical in shape. They have red to deep red pericarp when ripe.

2.1.1 Characteristics of Ruiru 11

In 1985 a new Arabica coffee hybrid was introduced to the coffee growers in Kenya. This cultivar Ruiru 11 is a hybrid representing a composite population of hybrids fairly heterogenous genetically but phenotypically having a high degree of uniformity (Anon, 1990). The cultivar is resistant to coffee berry disease caused by *Colletotrichum kahawae* and coffee leaf rust caused by *Hemileia vastatrix* (B.et Br) (van Vossen, 1981). It has a compact growth characteristic with thick strong laterals. The tree exhibits profuse vegetative growth. The internodes on both main stem and laterals are very short giving the typical compact growth habit. The tree often comes into first flowering within 12 - 18 months after field establishment (Nyoro, 1988; Njoroge, *et al.*, 1993). The cultivar produces beans of the same size, shape and density to the current popular varieties SL 28, 34 and K7 (Njoroge, 1991). The liquor quality attributes are similar to that of traditional cultivars (Owuor, 1988).

2.2 Coffee Plant Characters Affecting Yield

The coffee bean yields are mainly determined by the coffee shoot growth and components of yield like bearing primaries and nodes (Cannell, 1985). The growth rate of both orthotropic and plagiotropic branches can be used to assess the potential coffee production (Reffye, 1981). The growth indicators used to estimate yield are tree height, stem thickness, extension growth of primary branches, bearing primaries, bearing nodes and leaf expansion (Cannell, 1985).

Bean yield per tree has been described as the number of fruits per tree times weight of beans per fruit, where fruits per tree equals the number of fruiting nodes per tree times the number of fruits per node (Cannell, 1985).

The yield per tree is highly dependent on the number of potential flowering nodes produced in the previous year (Gebre-Egziabher, 1978). The number of bearing nodes per tree is therefore the most important variable component of yield and it is the component mostly influenced by cultural practices like fertilization, irrigation and mulching (Cannell, 1985).

The number of fruits per node is an important yield component and under favourable conditions about 12 - 20 fruits per node can be set

(Cannell, 1985). A total of 20 cm^2 leaf area are needed per fruit (Cannell, 1985) and the coffee tree bears only two leaves per node (30 cm^2). Although some fruits do fall off, there can be overbearing leading to `die back' of primary shoots. Shade suppresses floral initiation and this assists in reducing overbearing (Cannell, 1972; Kimemia and Njoroge, 1988).

Developing fruits draw assimilates from all except terminal leaves of the same branch. A heavy crop therefore greatly reduces the growth of vegetative parts through depletion of stored carbohydrate reserves in the wood, restriction of assimilate supply to roots and inhibition of outgrowth of lateral branch buds (Cannell, 1985).

The size of coffee beans is overwhelmingly determined by the amount of rainfall available during the fruit expansion stage (Cannell, 1972). Bean size is not much affected by yield level, or cultural treatments except irrigation (Cannell, 1985; Njoroge and Mwakha, 1985 a).

2.3 Coffee Management

2.3.1 Environmental requirements

Coffee in Kenya is grown at altitudes between 1400 to 2100 m above sea level, where maximum temperatures do not exceed 32°C or minimum temperatures fall below 7°C (Mwangi, 1983). The rainfall should not be less than 1000 mm annually and should be well distributed. Coffee also requires soils that are fairly fertile, free draining to a depth of 1.5 m and slightly acidic (pH 4.4 - 5.4 ($CaCl_2$ method)). These soils are found in areas occupying the broad gentle slopes of Mt. Kenya in the east of the Rift Valley, the slopes of Mt. Elgon on the Ugandan border, in the Rift Valley and some parts of Taita hills.

In Kenya, the widely grown cultivars are French Mission and K7 for the low altitude areas, SL 28 for the medium to low altitude dry areas and SL 34 for the high altitude areas with good rainfall (Mwangi, 1983). The new disease resistant Arabica hybrid cv Ruiru 11 is recommended to be grown in all the coffee growing areas.

2.3.2 Establishment

Coffee seedlings are raised in nurseries as either bareroot or in polybags for about 16 - 18 months (Mwangi, 1983; Willson, 1985 a). Those raised in polybags are preferred because the root system is not disturbed during transportation and transplanting ensuring a better field establishment. The land for planting must be prepared well in advance. All stumps, couch grass and other difficult weeds are dug out. Where the land in sloppy, effective soil conservation measures should be carried out (Mwangi, 1983). Planting holes are dug at least three months before planting to allow weathering. The hole size in Kenya for both the traditional cultivars and Ruiru 11 is 60 x 60 x 60 cm (Mwangi, 1983; Njoroge *et al.*, 1990). The holes are then refilled one month before planting, with top soil mixed with 13 kg of well rotted cattle manure or any other organic manure, and 100 g of double superphosphate (46% $P_2 0_5$) (Mwangi, 1983). Seedlings are planted after the onset of the rains when the planting hole has been wetted to a depth of 50 cm. Application of mulch along the planted row or around the seedlings helps to preserve moisture and suppress growth of weeds (Mwangi, 1983).

2.3.3 Coffee spacing

The first Arabica coffee planters in Kenya adopted from India a relatively close spacing of 1.83 x 1.83 m (2,985 trees per hectare) (Haarer, 1962). However, with introduction of mechanised operations in the coffee estates, wider spacings were adopted in order to accommodate the entire width of the tractor. Thus, the square spacings of 3.05 x 3.05 m, 2.74 m x 2.74 m became traditional practice (Wallis, 1965).

Huxley (1970) and Mitchell (1976), reported that coffee yield per hectare could be significantly increased by planting at higher plant densities. Fisher and Browning (1979) reported that closer spacings increased coffee yields but with increased pest and disease problems. Accordingly, the current standard recommendations for planting arabica coffee in Kenya are square plantings at 2.74 x 2.74 m (1330 trees per hectare), 2.74 x 1.37 m (2660 trees per hectare) and at 1.37 x 1.37 m (5320 trees per hectare) (Mwangi, 1983). For the compact cultivars like Caturra and Ruiru 11, the spacings adopted are 2 x 2 m (2500 trees/ha) and 2 x 1.5 m (3333 trees/ha) for the high rainfall areas or where there is irrigation (Njoroge, 1991).

2.3.4 Weed control

The weeds species in Kenya coffee have been classified into annuals and broad-leaved (Anon, 1993). Weeds have been shown to reduce coffee yields by over 50% as well of the coffee quality (Njoroge and Kimemia, 1990) as compared to clean weeding. Due to this reduction of yield by weeds, various weed control methods are used. The most common are cultural (using forked hoes, slashing, mulching, intercropping and high density plantings) chemical (herbicides) and integrated method that is combining both cultural and chemical weed control (Anon, 1993). Although clean weeding in coffee has substantial yield advantage (Njoroge and Kimemia, 1990), it is not ideal where soil erosion is likely to occur. Slashing and use of herbicides are a better alternative under such conditions.

Herbicides which are classified into foliar and soil, contact and systemic have been used extensively in coffee (Njoroge, 1994; Njoroge and Kimemia; 1990, 1992 a and b). However, use of one type of herbicides leads to development of tolerance some weeds. Njoroge (1989) found out continuous use of gramoxone has led to tolerance of black jack (*Bidens pilosa*).

The procedure of herbicide application in coffee is to spray the herbicide in the two metre interrow for traditional cultivars and one metre path for Ruiru 11 (Mwangi, 1983; Njoroge, 1991). Kamau (1979) showed that the use of herbicides in weeding coffee is comparatively cheaper than hand-weeding, but profitability is influenced by changes in coffee prices. Njoroge and Kimemia (1990) found out that the use of a soil, acting herbicide, followed by spot application of a contact herbicide was more economical in high rainfall areas than use contact herbicides alone or clean weeding.

Njoroge (1990), Kimemia and Njoroge (1991) and Njoroge and Kimemia (1992a), showed that the use of low rates and volumes of recommended herbicides can be used to effectively control annual weeds in coffee. This has become possible through the development of low volume nozzles like Lumark I.O N. For better control of annual weeds, with low rates, it has been recommended to control them at the 1 - 3 leaf stage (Anon, 1993). The low rates and volume used would be a saving to the farmer and an improvement on environmental safety (Kimemia and Njoroge, 1991).

2.3.5 Coffee maintenance

Coffee pruning involves thinning out of unwanted branches and removal of old stems (Anon, 1967). The main reasons for pruning coffee trees are to maintain a suitable crop/leaf ratio, control cropping level, maintain a high proportion of large size beans, open the trees centres to light facilitate disease and pest control as well as harvesting (Fernie, 1970; Willson, 1985a). There are two periods of pruning, namely, the formative and the main cropping periods. Although Wellman (1961) gives ten different systems of pruning coffee, there are basically only two training systems. These are distinguished by the tree framework which carries the bearing branches and the method of renewing or replacing those bearing branches (Wrigley, 1988). These systems are single stem where the tree has one stem, and multiple stem where the tree has a number of stems which are cut when they become too tall and replaced by new stems (Wrigley, 1988). The stems may be capped or not capped. There are many variations of these two systems, adaptations that have resulted from spacing, the presence or absence of shade, cultivation methods, need to spray, growth rate and in some cases intercropping, local economics and the availability and skill of labour.

2.3.6 Fertilizer application

In Kenya, coffee is mainly grown on humic and eutric nitosols commonly referred to as Kikuyu red loam (Siderius and Muchena, 1977; Sombroek *et al.*, 1980). These soils are highly leached and weathered leading to low plant nutrients (Michori, 1981). These soils are particularly very low in nitrogen (Pereira and Jones, 1954) and phosphorus (Keter, 1974; Oruko, 1976).

Nutrients are absorbed from the soil by the coffee root system. A fertile soil with high levels of available nutrient maintains a high growth rate and crop yields. In the absence of fertilizer applications, the nutrient reserves in the soil can be used up. Coffee is a long-lived crop and a significant reduction in the amounts of nutrients available in the soil occurs over time (Willson, 1985b). As a result, fertilizers are added to the soil to improve the soil nutrient status and its ability to support plant growth (Oruko, 1977). The magnitude of yield response to fertilizers depends on the supply and demand balance of the nutrients within the soil-plant system and the environmental factors such as climate, pests and diseases (Oruko, 1977).

Nitrogen is needed for plant growth, and has an influence on flowering and bearing capacity of the plant. It is important for protein formation and is an integral part of chlorophyll (Michori, 1981; Willson, 1985b). It therefore encourages vigorous growth of leaves and new bearing wood leading to increased yields and better quality. It also prevents overbearing due to faulty leaf:crop ratio and subsequent die-back (Pereira and Jones 1954; Malavolta *et al.*, 1958; Montoya *et al.*, 1961).

The amount of nitrogen released from soil organic matter on mineralisation is not adequate to meet coffee needs (Pereira and Jones, 1954). As such coffee has been shown to respond positively to added nitrogenous fertilizers (Michori, 1981; Njoroge, 1985a & 1985b, Njoroge and Mwakha 1985b).

The quantity of the fertilizer applied depends on the amount of crop on the tree, natural nitrogen level of the soil, condition of the tree and the soil moisture status (Mehlich, 1968; Michori, 1981). In order to apply the correct rates and thus avoid toxicity or nutrient imbalances, leaf nitrogen levels are used (Bould and Kimeu, 1971). Arabica coffee in Kenya has responded positively to nitrogen application rates of 50 -100 Kg N/ha/year (Njoroge, 1985b). For the new arabica coffee hybrid cultivar `Ruiru 11' application of 160 Kg N/ha/year significantly improved clean coffee yields (Njoroge, 1992). Nitrogen application was also reported to enhance plant growth characteristics such as height, stem girth, length of primary branches and leaf expansion (Njoroge, 1992). The increase in yield due to nitrogen application leads to a decrease in percentage grade `A' beans unless mulch or irrigation is applied (Mehlich, 1967; Njoroge and Mwakha, 1985b). The proportion of grade `A' sized beans has been shown to be negatively correlated to increased nitrogen rates of application (Njoroge, 1985a). For the best results, nitrogen fertilizers should be applied during the rains as this is the time when the nitrate values in the soil rapidly falls very low due to leaching while the growth surge is likely to be at its maximum (Oruko, 1977; Michori, 1981). This is explained by the fact that coffee tree has rapid vegetative development during the rain period and two coffee crops would be developing at the same time (Huxley and

Cannel, 1968). Nitrogen is therefore needed at this time for its influence on chlorophyll and protein formation (Willson, 1985b).

Investigations in Kenya have shown that split applications of nitrogen gives better results than single dose applications (Njoroge, 1985b). Njoroge (1985b) showed that for coffee growing areas West of the Rift Valley, the annual nitrogen fertilizer requirement should be split 4 to 6 equal applications in April, May, July, October and November. For those areas East of the Rift Valley, it should be split 3 to 4 applications in April, May and November. Various straight nitrogenous fertilizers are recommended for use in Kenya coffee. The type of fertilizer and rate of application are determined by the soil pH and the expected crop on the trees (Anon, 1987). Where the pH is low (<5.4) Calcium Ammonium Nitrate (26% N) is used. In coffee areas where the pH is high Ammonium Sulphate Nitrate (26 % N), Sulphate Ammonium (21 % N) and Urea (46 % N) are used (Anon, 1987). To maintain the soil pH desirable for coffee growth and production CAN is alternated with ASN annually.

Phosphorus is essential for root development, growth and the colour of the coffee beans and their quality (Anon, 1987). An adequate supply of phosphorus also favours flower initiation, good pollination and fruit formation, bringing out early cherry ripening (Willson, 1985b). The amount of phosphorous removed by the coffee crop is small (Willson, 1985b) and increase in phosphorous application gives positive yield response (Oruko, 1977). Coffee growing soils in Kenya are low in available phosphorous (Keter, 1974). Most of the available phosphorous is therefore derived from decaying organic matter (Oruko, 1977). Phosphorous status of the soil may be increased by direct application of inorganic phosphatic fertilizers, application of organic manures and mulch or foliar feed with phosphatic nutrient solution (Oruko, 1976). The use of organic matter would be more advantageous because besides the release of phosphorus on mineralisation, the organic matter also releases organic acids which being negatively charged, compete with phosphorous for the same positive sites on the soil surface and thus reduce phosphorous fixation (Oruko, 1976). The common types of phosphatic fertilizers recommended for application in Kenya coffee are Single Super Phosphate 18 - 22% P_2O_5, Diammonium Phosphate (18% N , 46% P_2O_5), Double Super Phosphate and Triple Super Phosphate (46% P_2O_5) (Anon, 1987). Phosphatic fertilizers should be incorporated in the top soil to allow maximum absorption by the coffee roots (Anon, 1987).

Potassium promotes the assimilation of carbon dioxide and translocation of photosynthates (Wilson, 1985b). As a fruit crop, coffee has a high demand of potassium especially when the berries are developing and ripening, during which time leaf potassium content may decrease considerably (Oruko, 1977; Anon, 1987). This may lead to leaf fall and stoppage of vegetative growth culminating in die-back (Willson, 1985b). Most of the coffee soils in Kenya are well supplied with potassium (Pereira and Jones, 1954). Regular mulching with napier grass mulch adds potassium to the soil. In fact in Kenya negative yield responses to potassium on coffee has been reported (Njoroge and Mwakha, 1986) unless combined with N and P (Njoroge and Mwakha, 1986). Continuous coffee production over many years may ultimately exhaust soil potassium reserves leading to potassium deficiency in plants (Njoroge, 1992).

However potassium is usually replenished where compound NPK fertilizers are used.

2.4 Use of Organic Manures in Coffee

The use of organic manures in coffee as sources of plant nutrients is an old practice in Kenya. Organic manures when applied in the field act as sources of plant nutrients through the process of decomposition, hydrolysis and mineralisation. The amount of nutrients released from these materials depend on nature and origin of the material, rate of decomposition and the prevailing environmental conditions. For example cattle manure and coffee pulp are rich in potassium while sisal waste is rich in calcium and guano is rich in phosphorous (Michori, 1981). Mehlich (1965) analyzed different types of manures and found them to vary considerably in nutrient composition. Owing to these differences, the type of manure applied to coffee should depend largely on the soil nutrient status to avoid inducing imbalances of nutrients in the soil.

2.4.1 Organic manures

Organic waste materials are usually digested in silos for the production of methane gas. There remains a sludge or compost that can be used as an organic fertilizer (Hutchinson, 1965; Kabaara, 1969). Hutchinson (1965), found out that the use methane gas residue increased coffee yields and led to production of large, shiny leaves of very deep green colour which seemed to stay longer on the tree. The application of methane gas sludge also resulted in an increase of soil pH (19%), soil potassium (105%) and soil phosphorous (438%). This effect of the sludge was slightly reduced by incorporation of NPK fertilizers. Njoroge (1985 a), reported that in Kenya compost, sludge and cattle manure gave positive yield responses only when in combination with inorganic fertilizers. The organic manures had no significant effect on coffee quality in terms of grade `A' sized beans (Njoroge, 1985 a).

The use of cattle manure in Kenya has been reported to lead to small increases in coffee yield and quality but only on very poor soils (Mitchell, 1970). Long term usage of cattle manure substantially increased the soil levels of potassium, calcium, magnesium and phosphorous while coffee leaf calcium and magnesium were not affected (Mehlich, 1965). In an another study, Kabaara, (1970) found out that cattle manure increased the soil pH, nitrogen, phosphorous and potassium but had no effect on coffee leaf nitrogen, phosphorous or sulphur while leaf potassium was increased and leaf calcium decreased. The high increase in leaf potassium resulted in Ca + Mg/K imbalance. The high levels of soil potassium may have a depressing effect on calcium and especially magnesium assimilation and thus lead to the decline in yields. The manure also tended to have adverse effect on raw colour of the coffee bean and its liquor quality (Mitchell, 1970). This has attributed to an increase in potassium content and/ or a decrease in magnesium content.

Mulches applied to the coffee plantations do release plant nutrients on decomposition (Mehlich, 1965; Jones *et al*., 1961). By raising the level of nutrient supply, mulch application improves soil fertility and thus crop yield (Oruko, 1977). The use of napier grass mulch leads to higher yields and an increase in grade `A' sized beans (Robinson, 1961). Leaves of coffee mulched with napier grass, contained significantly more phosphorous, sodium, potassium and significantly less calcium and magnesium than un mulched coffee (Robinson, 1961). Continuous use of napier grass mulch, particularly during the dry years, improved the size of the raw coffee bean (Kamau, 1976).

2.4.2 Leguminous plants green manures

Nitrogen fertilizers rank first among the external inputs to maximise output in agriculture but also the most expensive (Hichel and Barnes, 1984). Chemical fertilizers in the past have been considered the cheapest source of supplying nutrients to crops (Beri *et al*, 1989). However the frequent increases in the price of fertilizers, have made it increasingly important to pay more attention to the use of organic source of plant nutrients (Beri *et al*, 1989; Anon, 1991). This can be done by either inclusion of leguminous species in hedgerow intercropping or by rotation in production systems (Kang and Duguma, 1984). This has led to increased interest in utilization of woody leguminous species as sources of green manure (Brewbaker, *et al*., 1982; Dommergues, 1982; Kang *et al*., 1985; NAS, 1979; Rachie, 1983; Roskoski *et al*., 1982; Nair, 1984).

Rachie (1983) indicated that proper inclusion of woody species in cropping systems can offer many advantages at little or no expense. Judicious use of woody legumes for example can aid in recycling of plant nutrients and water from the deep soil layers, provide mulch and green manure that will contribute biologically fixed nitrogen to the companion crop (Rachie, 1983). Partial shading will help in weed suppression and provide favourable conditions for activities of micro/macro organisms and in addition, also aid in soil conservation, provide browse, human food, staking material and firewood (Douglas, 1972; Bishop, 1978; Wilson and Akapa, 1981; Rachie, 1983; Prussner, 1983; Kang *et al.*, 1984).

The majority of tropical legumes are woody perennial many of which are nitrogen fixing (Brewbaker, *et al.*, 1982). However, a great deal of variability exist in the potential of woody leguminous species to fix nitrogen (Roskoski *et al*, 1982). *Leucaena leucocephala* had been observed to fix 500 - 600 Kg N/ha/yr (Guevarra *et al.*, 1978) and pigeon pea (*Cajanus cajan*), 168 - 208 Kg N/ha/yr (Nutman, 1976). Loppings of woody legumes alley cropping also produce high nitrogen yield. *Leucaena leucocephala* and *Gliricidia sepium* yielded 233 and 140 Kg N/ha/yr when cropped in association with food crops on sandy loams of Southern Nigeria (Kang and Duguma, 1984). In India a two year old stand leucaena was found to produce 1.2 tons/ha dry matter which added 30 kg N/ha to the soil annually. A similar stand of *Sesbania sesban* was noted to fix 300 kg N/ha/year (Venikateswarlu *et al*, 1990).

Results of intercropping studies of food crops with woody leguminous species have shown high compatibility of certain species such as *Leucaena leucocephala* with food crops (Kang *et al.*, 1984). Kang *et al.*, (1985) also showed that leucaena extracts moisture from deep soil layers than maize (*Zea mays*). Leucaena hedgerows were observed to withstand repeated prunings and still coppice well. It thus appears that woody legumes grown in alley cropping has distinct advantage over herbaceous legumes as hedgerows remain productive for a longer period (Kang and Duguma, 1984).

Leguminous tree leaves have been found to increase dry matter yields of maize plants in Nigeria (Ezenwa and Alasiri, 1991). Hussain *et al.*,

(1988) found out that the leaves of *Leucaena leucocephala* proved better than urea in increasing the yield and nutrient uptake in sorghum and that the leaves of *Sesbania sesban* were as good as urea when used as mulch.

In Nigeria, leucaena trees were able to fix upto 100 Kg N/ha in 6 months (Mulongoy and Sanginga, 1990). The prunings when applied to an intercropped maize as mulch furnished 159.2 Kg N/ha with an effective supply to maize ranging between 4.4 - 23.8 Kg N/ha. The maize yields increased by 104% (Mulongoy and Sanginga, 1990).

Alferez (1980) found out that in Philippines, maize plants fertilized with herbage from intercropped leucaena produced as much grain as pure stand maize fertilized with 60-30-0 Kg/ha NPK. Prussner (1983) quoted results from Philippines showing that green manuring value of leucaena for maize and rice equals to an application of 90-40-40 and 80-30-30 Kg/ha of NPK respectively. Bottenberg (1981) reported an increase of rice by 89.3% with application of 8 tons of leucaena leaves, which is equivalent to applying 69 Kg N/ha.

Kang *et al*,. (1981) also observed that addition of 10 tons of leucaena prunings incorporated at planting increased maize grain yields by 146% in Nigeria, which was equivalent to application of 100 Kg N/ha of nitrogen fertilizer. When applied to dry beans, leucaena leaves as green manure was observed to have the same effect as chemical fertilizer in increasing bean yields (Chagas *et al*., 1983).

Vioayakumar (1986) found that in Sri Lanka the yields of prunings of leucaena grown under coconut (*Cocos nucifera*) shade could completely replace the requirements of green manure and mulching material for the coconut gardens. The leucaena prunings yielded over 200 Kg N/ha/year.

In Tamil Nadu, India, Vijaraghavan and Ramachandran (1989) in a field experiment to study the ability of green manure crops to grow and establish in coconut basin, found out that incorporation of *Desmodium tortuosum* added 250 Kg N/ha/year. The incorporation of desmodium and sunhemp significantly increased the nut yields.

Venikateswarlu *et al.*, (1990) reported that nitrogen fixation *in situ* and leaf fall are the two important processes that nitrogen fixing trees contribute to soil fertility. Venkateswarlu *et al.*, (1990) argued that the improvement of soil fertility is likely to result through biomass recycling rather than *in situ* nitrogen fixation, and transfer of nitrogen into soils or associated crop.

The return of nitrogen and organic matter from the legume covers to soil and the reduction of leaching losses of nitrogen in rubber and oil palm plantations inevitably led to a better growth of the trees, earlier commencement of harvesting and increased palm oil nut yields (Peoples and Craswell, 1992). Long term trials in rubber have shown that rubber trees would require at least 900 kg N fertilizer/ha to achieve similar rubber yields to those trees under leguminous cover (Peoples and Craswel, 1992).

Guevarra (1976) observed that the direct benefit from nitrogen added from leguminous tree prunings to the immediate maize crop is about 36%. He attributed this low efficiency to delayed release, possible nitrogen volatilisation and poor timing of pruning. Despite the low efficiency of the prunings, it still contributes a significant portion of the crop nitrogen requirement.

From the above discussion it is clear that leguminous tree mulch can be used successfully as green manure in annual food crop production.

However not much work has been done with perennial tree crops, but where green manures has been used with crops like coconut the results have been encouraging. It may therefore be assumed that green manure from leguminous tree crops may be used in coffee to supply most of the coffee tree nutrient requirements. The leguminous crops can be grown either as an intercrop with coffee or at the coffee plantation edges and the mulch transported to the coffee. It is expected that, this will completely replace application of inorganic fertilizers or will supplement to a great magnitude the current recommended fertilizer requirements for coffee. This cropping system should be of great assistance to the smallscale coffee growers in reducing the costs of coffee production.

2.4.3 Decomposition of leguminous green manures

For the nutrients in the green manure to become available the plant material must decompose first. The rate of decomposition depends on soil moisture (Myers, *et al*., 1982) and temperature (Payne and Gregory, 1988), age and size of the plant material (Foth and Ellis, 1988) and nitrogen content of the material (Alexander, 1977). In some legumes lignin and polyphenols contents are considered to be primary indicators of potential mineralization rates (Fox *et al*., 1991; Palm and Sanchez, 1991). While the low C:N ratio and lignin content of a plant like leucaena leaves might lead to faster rates of decomposition their high polypenol content might cause slower release of nitrogen (Oglesby and Fawnes 1992).

For the proper rotting of the green manures, it is necessary that the green material should be succulent and there should be adequate moisture in the soil. The plants at flowering contain the greatest bulk of succulent organic matter with low carbon:nitrogen ratio (Chela and Gill, 1979). With advancing age, the percentage of carbon in plants increases and that of nitrogen decreases. Leucaena leaves were found to decompose much faster than maize stover in Nigeria (Wilson *et al.*, 1986). Buried in the soil fresh and dried leucaena leaves had faster decomposition rates than surface application (Kang and Duguma, 1984; Wilson, *et al.*, 1986). The lower efficiency of broadcast applied prunings is partially attributed to volatilization loss during decomposition (Kang *et al.*, 1981). Loss of leaflets through erosion is also a contributing factor of the low efficiency of surface applied mulch (Alferez, 1980). Therefore, the manurial effects of leucaena prunings are better when buried than when applied as surface mulch (Kang *et al.*, 1981). However, incorporation of green manures in coffee will interfere with the surface feeder roots and reduce the yields. Therefore, despite the relatively lower efficiency of surface application of mulch, this would be preferred. Nyamai (1990b) found out that leucaena decomposed much faster than *Cassia siamea* and thus would be suitable to be applied even at vegetative stage of crop growth while cassia mulch would be applied earlier on to maximize the nitrogen released.

Leucaena was observed to release more than 55% of the initial nitrogen in 52 days during the decomposition (Xu *et al.*, 1993). In another trial, Mulongoy (1983) reported that 50% of nitrogen was released within 4 weeks of decomposition of leucaena leaves and twigs. Studies of residue decomposition in alley cropping systems suggest that 50% of the added legume nitrogen may be released within 1-9 weeks depending on the initial nitrogen content (Wilson *et al.*, 1986). Oglesby and Fawnes (1992) observed that neither the initial N percentage nor the lignin:N ratio of seven tropical woody legumes was strongly correlated with N mineralization.

In a trial in India Upadhay (1993) observed that plant species having higher lignin and lignin:nitrogen ratio decomposed slowly, while those having higher water soluble compounds, base contents and acid soluble cell wall components decomposed faster. Lignin controlled effectively the rate of decay of litter especially in the later phase of decomposition.

2.5 Intercropping in Coffee

2.5.1 Resource use under intercropping

In an intercropping system there is both inter and intra-crop competition during all or part of the crop growth. Crop intensification is both in time and space dimensions (Andrews and Kassam, 1976; Willey, 1979a). It is widely practised in most parts of the world and has been known to be a common and dominant feature in the tropics (Dalrymple, 1971; Anon, 1985).

The advantages of intercropping include better use of environmental resources namely: light, water and mineral nutrients (Rao and Willey, 1980; Reddy and Willey, 1981; Steiner, 1982; Njoroge, 1992). Other advantages attributed to intercropping include better protection of soil against erosion (Kampen, 1979), disease control (Mukiibi, 1980) and reduction in weed infestation (Mugabe *et al.*, 1980; Shetty *et al.*, 1977). These benefits do not automatically occur in all intercropping situations but they may certainly be observed for some mixtures of crops in a given climatic and soil environment. Intercropping has also some disadvantages, for example yields do decrease because of adverse competition effects and allelopathic effects (allelopathy is any direct or indirect harmful effect that one plant has on another) that may reduce yields (Rice, 1974). Intercropping also limits the use of machinery for intercultural operations, particularly where the component crops have different requirements for fertilizer, herbicides and pesticides.

The main expectation from an intercropping system in a perennial plantation, is that the overall return from a unit piece of land is increased without affecting either the current or the long-term productivity of the main crop (Willey, 1979b; Liyanage, *et al.*, 1984). Therefore, intercropping in perennial crops should be a means of increasing the total productivity of lands that are committed to the base crop for many years (Liyanage, *et al.*, 1984). The returns from the additional crops should justify the adoption of the intercropping practise and should contribute to the long-term productivity of the system.

It has been emphasized that one of the main reasons for yield advantages under intercropping is that crops grown in combination may be able to make better overall use of resources than when grown separately (Willey and Osiru, 1972; Rao and Willey, 1978). This synergism can occur when the crops have differences in resource use. The biggest complementary effects and thus the biggest yield advantages seem to occur when the component crops have different growing periods and therefore make their major demands on resources at different times (Rao and Willey, 1978). This situation is usually termed as temporal complementarity (Andrews, 1972; Baker and Yusuf, 1976; Krantz *et al.*, 1976; Osiru and Willey, 1972; Willey and Osiru, 1972).

Although a yield increase must presumably depend on better use of all resources, it has been observed that better use of light is probably a major factor when temporal complementarity occurs (Baker and Yusuf, 1976; Lakhani, 1976). Light as a growth factor differs from others in that it cannot be stored (Baker and Yusuf, 1976). However, in intercropping system, the available light is more efficiently used, as the optimal leaf area index (LAI) is more quickly obtained (Beets, 1978). Successful intercropping system aim at reducing the competition for light without reducing light interception. Various possibilities exist such as relay intercropping, planting the dominant crop in double or wide rows, and the growing of shade tolerant plants and multi-storey cropping system. The slow initial development for a plant like coffee makes it possible to intercrop with annual crops in the early stages of coffee establishment (Njoroge, 1992). Light interception by the coffee plants during the early growth stages and at conversion stages is low and therefore allows cultivation of short duration intercrops. This system makes very efficient spatial use of light, as the coffee and the low growing annuals form different canopy layers. In such a system, the total optimum leaf area index is much higher than in sole crop and the light use efficiency is also higher (Nair, 1979; Steiner, 1982).

There is also evidence that intercropping can result in a greater uptake of nutrients (Sharma *et al.*, 1979). This may result from increased rooting depths or from temporal differences in nutrient requirements. Increase in uptake of the main nutrients by intercrop more than sole crops have been reported for nitrogen (Liboon and Harwood, 1975; De, 1980) and for potassium (Hall, 1974). Other workers have reported better utilization of all the main nutrients including calcium and magnesium (Natarajan and Willey, 1980; Reddy and Willey, 1981).

When the intercropping situation includes a leguminous crop, the nitrogen uptake of the other non-leguminous component may be improved (Sarat and Rajat, 1975; Ahmed and Gunasena, 1979; Searle *et al.*, 1981). The benefit is likely to depend on the relative growth patterns. Shorter season legumes under long season non-leguminous crops may be beneficial. This is because legumes do excrete nitrogen (Agboola and Fayemi, 1972) which may be utilized by the long season non-leguminous intercrop (Sharma, 1979) either by current transfer or residual effects.

The water use efficiency in intercrops has been reported to be higher than in sole crops (Steiner, 1982). Baker and Norman (1975) suggested that better water use was probably a common cause of yield advantage in semi-arid tropical areas, because it is the most limiting resource. However, Natarajan and Willey (1980) indicated that total water use was little affected by the cropping system. Thus the yield advantages of the intercropping system is not achieved at the expense of greater overall demand on soil moisture. A possible reason for the increased water use efficiency with intercropping is the wind break effect when low growing plants are interplanted with tall plants (Steiner, 1982). This leads to an increase in humidity and a reduction in transpiration. Such crop associations allow a better net assimilation rate of each plant at a constant temperature per unit of consumed water (Baldy, 1963). The windbreak effect can be achieved even with only a small percentage (<5%) of tall plants (Hagen and Skidmore, 1974).

Intercropping might give better control over weeds, pests and diseases. Evidence of better weed control is reasonably clear where intercropping provides a more competitive effect against weeds either in time or space, than does sole cropping (Harwood and Bantilan 1974; Shetty 1997; Shetty and Rao, 1977).

The pest and disease problem is much more complex. Better pest control under intercropping systems have been reported (Baker and Norman, 1975; Crookston and Kent, 1976; IRRI, 1975; Raheja, 1977; Trenbath, 1975) but examples of poorer control have also been reported (Osiru, 1974). The reduced pest abundance under intercropping systems can be attributed to a high level of interaction between the pest and its natural enemies in a more favourable microclimate environment (Fabres, 1990).

2.5.2 Yield advantages under intercropping

Several different concepts have been developed to assess yield advantage of intercropping systems. Examples include use of relative coefficient (de Wit 1960), competition index (Donald, 1963), relative yield total (de Wit and Van den Bergh, 1965), relative replacement rate (Bergh, 1968); competitive ratio (CR) (Willey and Rao, 1980) crop performance ratio (Nyamai, 1990a) and land equivalent ratio (LER) (Mead and Willey, 1980). The use of LER has become common practice in intercropping studies because it is a relatively simple concept (Willey and Osiru, 1972; IRRI, 1975). It may be defined as the relative land area under sole crops that is required to produce the yields achieved by intercropping (Willey, 1977). However, Huxley and Maingu (1978) pointed out that the intercrop and sole crop have to be at their optimum populations and the same level of management. Although based on land areas, LER also reflects relative yields, i.e. the LER can be taken as a measure of relative yield advantage (ICRISAT, 1978). A ratio of more than one signifies a yield advantage while a ratio of less than one is a yield disadvantage. There are some problems associated with use of LER. The first problem is that LER is defined in terms of ratios of yields from crop mixtures to sole crop yields, and that large values of LER arise not only when the intercrop yields are large but also when the sole crop yields are small (Mead and Riley, 1981). The second problem is that the use of LER to measure the yield advantage available to the farmer rests on the implicit assumption that the yield proportions obtained from a mixture are exactly those required by the farmer (Mead and Stern, 1979; Mead and Willey, 1980).

When discussing yield advantages the impression may be given that only advantages of intercropping are higher yields or higher net incomes. A part from this, a major advantage of intercropping is yield stability (Steiner, 1982). There are several reasons why intercrops give more stable yields than sole crops. One basic principle of intercropping is compensation. When one component crop suffers from drought, pests or diseases or does not develop properly, the loss of this crop is compensated at least partially by the other component crop(s) since there is now less competition for resources (Steiner, 1982). Yield stability is also increased by reduction of pests (Norton, 1975; Taylor, 1977) and diseases (Bourdon, 1978) in intercrops below the level of epidemics or outbreaks. Intercropping in coffee would be attractive in that during periods of low coffee prices, like what happened after the collapse of the International

Coffee Agreement in 1989, the coffee farmers would be have another source of income. It would also discourage farmers from neglecting or uprooting their coffee during periods of low prices.

2.5.3 Intercropping coffee with annual crops

Coffee has been a monoculture crop and very little research on intercropping in coffee has been carried out (Willson, 1985 a). This does not mean that farmers have not been intercropping coffee with other crops. In Kenya, small scale farmers have been noted to intercrop their coffee with a wide range food crops (Mukunya and Keya, 1975; Whittaker, 1986). Several food crops and trees have been observed to be intercropped with coffee. Such food crops include annual and perennial crops such as dry beans (*Phaseolus vulgaris)*, maize, Irish potatoes *(Solanum tuberosum)*, sweet potatoes *(Ipomea batatus)*, tomatoes *(Lycopersicon esculentum)*, cassava *(Manihot esculenta)*, yams *(Discoera* spp), sorghum *(Sorghum bicolor)*, finger millet *(Eleusine corocana)* and pyrethrum *(Chrysanthemum cinerariaefolium)*.

In a trial with young coffee, intercropped dry beans, garden peas *(Pisum sativum)*, green grams *(Vigna mungo)*, cowpeas *(Vigna unguiculata*) and chick peas *(Cicer arietinum)* significantly depressed the coffee yields by 31, 29, 39, 50 and 30% respectively (Njoroge and Mwakha, 1994). However, all the food crops alone had a positive net economic benefit and all except green grams compensated for the reduced coffee yields. In another trial with young arabica coffee Cv. Ruiru 11, it was found that only maize significantly affected coffee growth, although all the crops depressed the first clean coffee yield (Njoroge *et al.*, 1993). In the same trial, the intercrops did not significantly reduce the coffee quality in terms of grade `A' beans and the organoleptic characteristics. Therefore, dry beans and Irish potatoes could be considered for intercropping with young coffee during the first two years after establishment.

Mwakha (1980a) observed that it is possible to obtain four consecutive dry bean crops from stumped high density coffee without affecting the subsequent coffee yields. In further trials, Mwakha (1980b) recommended that during the first 18 months after block stumping of high density coffee, 2 - 4 dry bean rows per 2 m coffee inter-row may be successfully grown with the application of 80 Kg N/ha per season in high rainfall areas. The growth and yield of beans intercropped too close to the coffee trees were adversely affected (Mwakha, 1987).

Intercropping both young and mature pruned coffee with cotton *(Gossypium hirsutum)*, rice *(Oryza sativa)*, bean, maize and soyabeans *(Glycine max)* in Brazil showed that intercrops removed large quantities of soil nutrients but did not affect the coffee plant growth (Chaves and Guerreiro, 1989). However, the taller crops were noted to affect development and yield of coffee in the same study. Earlier trials had indicated that intercropping bearing coffee with beans, millet, rice and cotton reduced coffee yields with millet having the most adverse effect and the beans the least (Mendes, 1950). Intercropping coffee with maize, beans or rice is traditional during the first three years of coffee establishment in Brazil (Wrigley, 1988).

In Uganda, bananas (*Musa* species) are grown together with robusta coffee (Oduol and Aluma, 1990). The yields of robusta coffee was observed to be adversely affected by intercropping coffee with sweet potatoes (Oduol and Aluma, 1990). Coffee is also found mixed with shade tolerant crops such as taro (*Xanthosoma saqittifolia*), yams (*Dioscorea* spp) and beans in the Kilimanjaro area of Tanzania (Fernandes *et al.*, 1984).

In eastern Ethiopia, coffee has been found grown under shade of several trees and always intercropped with grain, fruit, vegetable, stimulant, oilseed and spice crops (Teketay and Tegineh, 1991). N'Goran and Snoeck (1987) recommended intercropping of upland rice, maize, yam and groundnut (*Arachis hypogaea*) with coffee in Cote d'Ivore. However, maize was observed to depress the first crop of coffee. Nayar (1976) observed that intercropping coffee with ginger *(Zingiber officinale)* and yam in young robusta coffee is not only a source of higher return per unit area per unit time but also provides food and employment opportunity. In general, annual crops can be grown successfully with trees during the early stages of tree growth when canopy has not fully developed (Blencowe, 1969; Von Hesmeer, 1970; Harwood and Price, 1976) and at the change of cycle period (Mwakha, 1987). However, yield depression of the annual crops occurs from the second or third year of tree planting due to shading effects (Maghembe and Redhead, 1982; Parmesh, 1987). The choice of the intercrop would therefore be its economic value over a relatively few years of the intercropping. Though intercropping newly established coffee with food crops have proved possible, there is also need to investigate the possibility of intercropping at the change of cycle period when there is a lot of open space and coffee canopy not yet fully developed.

2.5.4 Intercropping coffee with perennial crops

In Kenya, coffee has been observed to be intercropped with fruit trees such as Macadamia *(Macadamia temifolia)*, citrus *(Citrus* species), bananas *(Musa* species) and mangoes *(Mangifera indica)* (Njoroge and Kimemia, 1993). Several trees have also been grown in coffee mainly as shade trees or for wind break as *Cordia* species, *Grevillea robusta* and *Albizzia* species among others (Njoroge and Kimemia, 1993). Clean coffee yields had been observed not to be affected by intercropping with macadamia as both trees requires similar environmental conditions as coffee (Njoroge and Mwakha).

In Papua, New Guinea, farmers have been reported to have interplanted Arabica coffee with food crops in the early stages of coffee plant growth and then with bananas (*Musa* spp) and *Casuariana oligodon* at later stages of coffee growth (Bourke, 1985). In the same area robusta coffee which is grown in the lowlands has been intercropped with food crops, bananas and leucaena trees (Allen, 1985).

In the moist forest areas of Andes mountains, in Venezuela, Arabica coffee is intercropped with diverse mixture of fruit species such as oranges, bananas, avocadoes *(Persea americana)* and timber trees (Escalante, 1985). However both Arabica and robusta coffee seedling growth was found to be reduced by interplanting with bananas (Mitchell, 1965).

In Colombia bananas are always intercropped with coffee (Dario, 1986). Awatramani (1977) reported that in India coffee is usually intercropped with cocoa *(Theobroma cacao)*and pepper *(Capsicum* spp).

It therefore possible to intercrop coffee with both annual and perennial crops. Despite these work reported on intercropping coffee with perennial crops, there is no clear information on the effect of these intercrops influence coffee growth, yield and coffee cup quality. This information would be useful in guiding farmers on which crops to intercrop with coffee, when and how to intercrop and also the expected effect on coffee. It was therefore the aim of this study to investigate the effect of intercropping coffee on coffee yield, size of coffee beans and overall cup quality. Kenya markets its coffee on quality basis and therefore the liquor quality is of paramount importance while screening possible intercrops in coffee.

CHAPTER 3

EFFECTS OF GREEN MANURE APPLICATION ON GROWTH, YIELD AND QUALITY OF *Coffea arabica* HYBRID CV. "RUIRU 11" DURING FIELD ESTABLISHMENT PHASE

3.1 Introduction

Organic and green manures have been used successfully as sources of plant nutrients in food crop production. They could be used to replace or substitute to some extent the inorganic fertilizer requirements for coffee production, especially in nitrogen deficient coffee soils in Kenya (Michori, 1981). As the manures are available locally, they can be used to reduce the costs of production. This could be of particular importance to the Kenyan coffee farmer especially with the now increasing input prices (Anon, 1991).

Nitrogen is an important crop nutrient required for coffee plant growth and has influence on flowering and bearing capacity of the plant (Willson, 1985b). It is however one of the most expensive plant nutrient (Hichel and Barnes, 1984). Due to the high costs of commercial inorganic nitrogen fertilizers, coffee farmers are not able to apply the recommended rates (Karanja, 1992.) It is therefore necessary to look into alternate sources of nitrogen if high yield and quality of Kenyan coffee is to be maintained.

One alternative is the intercropping of nitrogen fixing trees belonging to the *Leguminosae, Casuarina* and *Alnus* (Nyamai, 1990 a) and the use of their foliage as sources of green manure (Kang *et al.*, 1985).

Roskoski (1982) found that when *Inga jinicuil* is planted as shade trees in a coffee plantation it added over 40 Kg N/ha/year which was 53% of the average amount of nitrogen applied annually. The N fixation by non-crop legumes can therefore be an important nitrogen source for the coffee plants (Roskoski, 1982). This fixed nitrogen supplements the amount released through organic matter mineralization and may provide up to 100 kg N/ha/year (Bornemisza, 1982).

The amount of nitrogen added by green manures to a given soil depends on the rate of decomposition and quality of the green manure material (Sanchez, *et al.*, 1989). It is, therefore, important to identify green manure plants with fast growth rates, decomposition and mineralization.

It was against this background that this study was set up to investigate whether the use of green manures from leguminous plants can provide adequate nutrition for growth and productivity of newly established Arabica coffee trees.

3.2 Materials and Methods

3.2.1 Site

The trial was carried out at Coffee Research Station, Ruiru between May 1991 and December 1993. The site is located at 1^0 06'S, 36^0 45'E, and 1620 m above sea level. The rainfall is bimodally distributed between the long rains (April to July) and short rains (October to December). During the study period weather data were recorded at meteorological station at Coffee Research Station. The annual rainfall received was 866, 1171 and 816 mm in 1991, 1992 and 1993, respectively. Only in 1992 was the rainfall received higher than the longterm average. The maximum temperatures were 23.8, 25.8 and 25.2°C while the mean minimum temperatures were 11.8, 12.8 and 12.5°C in 1991, 1992 and 1993 respectively. The weather pattern during the trial period is shown in Appendix 1. The soils at the station are humic nitosols with a deep profile with reddish brown to dusky brown clays (Jaetzold and Schimdt, 1983). The soil had a bulk density of 1.13 g/cm^3, pH of 5.3, Hp of 0.1 m.e %, 0.33% N, 2.65% C, 72 ppm P, 1.9 m.e% K, 4.3 m.e% Mg, 4.7 m.e% Ca, C:N ratio of 8.03 and a Ca + Mg/K ratio of 5.7.

3.2.2 Treatments

Arabica coffee hybrid `Ruiru 11' was used as the test variety. Six leguminous plants leucaena (*Leucaena leucocephala)*, sesbania *(Sesbania sesban)*, calliandra *(Calliandra calothyrsus)*, desmodium *(Desmodium intortum)* lucerne *(Medicago sativum)* and pigeonpea *(Cajanus cajan)*, were evaluated as sources of green manure to be applied to coffee plants during the establishment phase. The green manure application was compared with the application of 10 tons/ha cattle manure, 100 kg N/ha (Calcium ammonium nitrate - 26% N) and napier grass mulch. The treatments are shown in Appendix 2.

The leguminous plants were intercropped with coffee and the branches lopped and applied as mulch around the coffee plants. Leucaena, sesbania and calliandra plants were also grown on pure stands at the edges of the coffee plots and their branches lopped and used as mulch. Leucaena, sesbania and calliandra were transplanted when six month old. They were planted using the same procedure used for planting coffee seedlings. Desmodium, lucerne and pigeonpea were planted between coffee rows at different plant densities as shown in Table 3.1. At six months old, the plants were cut and the foliage used as mulch around the coffee plants.

Two control plots were maintained. One where the coffee plants were top dressed with 100 Kg N/ha/year split in April, May and November (Mwangi, 1983), and the other control plot was unfertilized.

3.2.3 Experimental design

The 13 treatments were laid out in a completely randomised block design, with three replications. Each experimental plot was 48 m^2 and consisted of 20 coffee plants (4 rows of 5 trees each). The six central coffee plants were the effective plants for growth and yield data collection. The field lay out is shown in Appendix 2.

3.2.4 Cultural practices

The coffee plants were planted in May 1991 at a spacing of 2 x 2 m. Each plant received 13 kg of well rotted cattle manure in the planting hole. The chemical composition of the cattle manure used is shown in Appendix 3. No inorganic fertilizers or pesticides were applied. The coffee plants were raised on single stem pruning method. Weed control was done by hand when necessary.

Green manure application commenced in December 1991, six months after coffee establishment and continued at three month intervals until December 1993. The green manure was spread in an area of 15 cm from the base of the coffee plant to the drip line.

Table 3.1: Planting methodology for green manure plants

Plant	Spacing (cm)	No of rows per coffee interrow	Distance from coffee tree (cm)
Leucaena	200 x 50	1	100
Sesbania	200 x 50	1	100
Calliandra	200 x 50	1	100
Desmodium	30 x 10	4	55
Lucerne	Rows at 30cm apart	4	55
Pigeonpea	50 x 30	2	75

Note: The purestand spacings of leucaena, sesbania and calliandra were similar to those used in the intercrop

Starting in March 1992 and continued until September 1993, cattle manure was applied twice a year in March and September at the rate of 10 tonnes per hectare per annum (4 kg/tree/ year). Napier grass mulch was applied along the coffee plants as proposed by Mwangi (1983). In April and May the fertilizer was applied in form of calcium ammonium nitrate (26% N) and in November in form of 20:10:10 NPK fertilizer.

3.2.5 Data collection

3.2.5.1 Dry matter and potential nutrient production from green manure plants: At the time of sourcing green manures from each of the various plants, all cut foliage was weighed and total fresh weight recorded. One kilogram of the fresh foliage was weighed and oven-dried at 80^0 C for 36 hours to constant weight. Dry matter percentage was then calculated. This percentage was used to estimate the total dry matter applied per plot. One hundred grams of each of the dried green manures were taken and analyzed for nutrient composition as described for coffee leaves (Bould and Kimeu, 1971). The annual potential nutrient yield was a product of the total annual dry matter applied and the nutrient concentration in the green manures.

3.2.5.2 Rate of green manure decomposition: The green manures were decomposed in the field for fifteen weeks starting from 17 June 1992 till 23 September 1992. Standard litter bags made of exuded polyvinyl with a 7 mm mesh were used to determine the rate of green manure decomposition as described by Anderson and Ingram (1989) and Asenga (1991). The bags were made to retain a shape of a shallow box-like container of approximately 30 cm long, 30 cm wide and 2.5 cm deep. Fresh green manure weighing 100 g was put evenly inside a bag and sealed with a nylon string. At the same time 100 g of fresh green manure were oven dried to constant weight to determine the initial dry matter. Six bags of each of the various green manures replicated three times, were kept on the soil surface in the coffee interrow. Weeds growing through the bags were clipped back and the bags were therefore not interfered with. A bag from each replicate of each green manure was removed from the plots after 1, 3, 6, 9, 12 and 15 weeks. During the removing the litter bags were wrapped with polythene sheeting to reduce loss of decayed material while transporting them to the laboratory. Excess soil adhering to the bags was removed manually. The decomposing material was removed from the bag and dried at 80°C to constant weight. The resulting weight was expressed as a percentage of the original dry weight. This gave the percentages of undecomposed material of each green manure which were then plotted against time. The time taken for 50% the material to decompose (t_{50}) was determined.

3.2.5.3 Determination of available nitrogen in decomposing green manure: Each of the green manure was incubated as described by Oglesby and Fawnes (1992). Fresh soil was sieved through 10 mm sieve and 50g placed in a polyethylene bag . Fresh green manure was added to the soil at a rate of 3 mg per gram of dry soil and mixed thoroughly. The bags were incubated at 26° C for 1, 2, 3, 4, 8 and 12 weeks. A control bag containing soil alone was also incubated. At each week, four replicate bags of each green manure and four bags of soil alone were sampled and analyzed for ammonium and nitrate concentration as described by Anderson and Ingram (1989).

Ammonium and nitrate ions in the soil were extracted with 2 M potassium chloride. Four samples of 50g of soil were weighed into a 500 ml wide mouthed-plastic bottle. Two hundred mls of 2 M KCl were added and the samples shaken for one hour in a mechanical shaker. The mixture was then filtered using a Whitman filter paper No. 42 into 150 ml plastic sample bottles. Fifty ml of the filtrate was pipetted into a 250 ml two neck distillation flask. Two hundred mg of oven dried MgO was added into the flask through the side arm of the distillation flask and the sample solution steam distilled. The liberated ammonia was collected in a graduated 150 ml conical flask containing a mixed indicator of bromocresol green and methyl red. The amount of distillate collected in each distillation was about 50 mls. The distillate was titrated against 0.01N H_2SO_4 using a microburette to quantify the ammonium nitrogen. The colour change was green to purple.

The nitrate nitrogen was determined in the same filtrate by reduction of nitrate to ammonium with 0.2g of Devardas alloy, and the liberated ammonia collected in 10 mls of boric acid containing indicator. This was then titrated against 0.01N H_2SO_4.

Duplicate blanks of the extracting solution (2m KCl) were treated in the same way like soil sample filtrate and their average titrate values subtracted from the titration values of each soil sample. The amount of exchangeable NH_4^+-N or NO_3-N for each sample was calculated using the following equation:

$$\text{N mg in sample} = \frac{\text{Mls } 0.01\text{N } H_2SO_4 \times 0.01 \times 14.01}{P}$$

where P = fraction of the volume of soil extract used for steam distillation.

0.01 = the normality of sulphuric acid

14.01 = The equivalent weight of nitrogen in g

The percent of green manure nitrogen mineralized was calculated as described by Anderson and Ingram (1989) using the following equation:

$$\text{Percent N mineralized} = \frac{N_{green} - N_{soil}}{N_{initial}} \times 100$$

Where

N_{green} = total available N extracted from the decomposing green manure crop

N_{soil} = total available N extracted from the soil alone

$N_{initial}$ = Initial amount of nitrogen added by the green manure crops to each bag

3.2.5.4 Determination of soil bulk density: The soil bulk density was determined as described by Anderson and Ingram (1989). This was done before planting the coffee plants in March 1991 and two and a half years later in September 1993. 1-2 cm depth of surface soil was removed from a spot between the coffee trees along the row. A core ring with a diameter and length of 5 cm was used. The core ring was weighed before sampling. The ring was driven to the ground using a core sampler. The soil around the ring was excavated and the soil beneath the tube cut. Excess soil from both ends of the tube was trimmed. The soil in the core ring was dried at 105° C for 24 hours and then reweighed. The soil bulk density was calculated by dividing the weight of the dry soil with the volume of the core ring.

3.2.5.5 Soil chemical analysis: Top and sub-soil samples were taken from each plot in March 1991 and September 1993. Three samples were taken randomly from each plot around the coffee trees drip line, thoroughly mixed and a sample taken for analysis. The top soil sample was taken from the top 0-15 cm while the sub-soil one was taken from 15-50 cm depth. The sampling was done using a soil auger. After sampling the soil was oven dried at 105 °C, ground using a pestle and mortar and then sieved using 850 micrometer mesh.

Soil reaction (pH) was determined by calcium chloride method at a ratio of 1:2.5 soil : $CaCl_2.2H_20$ solution (Ingram and Anderson, 1989). Ten grams of dry soil samples were weighed into 50 ml plastic bottles and 25 mls of working 0.01 M $CaCl_2.2H_20$ solution added. The mixture was mixed thoroughly and the undissolved particles allowed to settle for one hour. The Ph was measured using a pH meter model PW9418 Phillips. A buffer solution pH 4.0 and 7.0 were used for calibrations.

The soil exchangeable acidity (Hp) was determined by Barium Chloride method (Anderson and Ingram, 1989). Sintered glass funnels of 50 mls were covered on the surface with Whatman No.1 filter paper. Five grams of dry soil was put in and another filter paper placed on it. Fifty millilitres of 0.6 N $Bacl_2.2H_20$ solution was added and the filtrate was collected into 100 mls flat bottomed flask. A drop of phenolphthalein indicator was added into each filtrate using an eyedropper. The filtrate was titrated with 0.05 M NaOH. The volume of NaOH required to change the solution to pink was proportional to the exchangeable acidity (Hp m.e.%).

Potassium (K), sodium (Na), calcium (Ca), magnesium (Mg) and manganese (Mn) were determined by flame emission photometry on the Pye Unicam atomic absorption spectrophotometer model SP9 at wavelengths of 766.5, 589.0, 422.7, 285.2 and 279.5 nm, respectively. Five grams of oven dry soil were put into 50 mls plastic bottles and 25 mls of working extracting double acid solution (0.1 N HCl and 0.025N H_2S0_4) added (Mehlich *et al.*, 1962). The mixture was shaken on the mechanical shaker for 30 minutes. Whatman No.42 filter paper was placed on a glass bottle, one scoop of phosphate free charcoal added and the mixture filtered. Two mls of each extract was put into polythene specimen bottles and 18 mls of distilled water added.

Soil nitrogen was determined using the Kjeldahl method (Black, 1965; Hesse, 1971). Half gram of fine air dried soil was transferred into a digestion tube calibrated to 50 ml. Half gram of a selenium - mixture (selenium + $CuS0_4$ + Na_2S0_4), which is a catalyst, was added and mixed. A few drops of water to moisten the soil and 10 ml of H_2S0_4 (95 - 97%) were added and mixed thoroughly. The water stimulates the decomposition of the soil particles and the mixing with sulphuric acid. The digestion tube was heated in a block digester at about 350°C in fume cupboard until it was pale green and thereafter heated gently for about 30 minutes. It was then removed from the block digester and allowed to cool. About 40 ml of water was added little at a time with frequent swirling, and the mixture allowed to cool.

The soil organic carbon was determined using the method described by Walkley and Black method (Walkley, 1947). Five grams of dry soil were ground to a fineness of less than 0.5 mm with a pestle and mortal and using a 0.5 mm sieve. Half gram were weighed accurately and transferred to a 500 ml wide mouthed conical flask. Ten mls of 1.0 N potassium dichromate were added and the flask swirled gently to disperse the soil in the solution. In a fume cupboard, 15 ml of conc H_2SO_4 was added. The flask was swirled gently at first until the soil and the reagents were mixed then more vigorously for about one minute. The mixture was allowed to stand for exactly 30 minutes. 150 ml of dilute water was added and allowed to cool. Then 5 ml of 85% phosphoric acid was added and finally 10 drops of diphenylemine indicator added. The solution was titrated with 1.0 N ferrous ammonium sulphate. Two blank determinations on potassium dichromate titrated against ferrous ammonium sulphate were carried out in the same way. The amount of ferrous ammonium sulphate needed to reach the end point in each case was recorded.

The percent carbon was calculated as follows:

$$\%C = \frac{3\,(B-S)}{B \times W}$$

where:	B =	ml Ferrous ammonium sulphate used for the blank
	S =	ml Ferrous ammonium sulphate used for the sample
	W =	Weight of soil in g
	3 =	Corresponding weight of C to 1 ml I.0 N Ferrous ammonium sulphate

From march 1992 the soil moisture was determined gravimetrically twice in a year in March and September at depths of 0 -15 cm and 15 - 50 cm for top and sub soils, respectively. The samples were weighed and oven-dried at 105^{0}C for 24 hours to constant weight. The difference in weight was the moisture content in the soil (Landon, 1991).

3.2.5.6 Coffee leaf analysis: The coffee leaf analysis was carried out after two years of green manure application in September 1993. The fourth leaf per branch from the top middle canopy primary branches were sampled from the six effective coffee trees in each plot (Bould and Kimeu 1971). An average of 100 leaves were sampled per plot to make one sample. The leaves were washed with deionised water, dried then ground. The leaf nutrient concentrations were determined as described by Bould (1974).

The ground leaf sample was dried in the oven at 100 - 105°C for one hour and then cooled in a desiccator. About 100 mg of the dry material was placed into excel tubes. Two mls of sulphuric- selenium mixture were added and heated in aluminium blocks for three hours until digestion was complete. The digest was cooled and diluted to 15 mls with water. Two mls of 10% sodium acetate solution were added and made into volume of 20 mls with distilled water. Samples were then filtered with Whatman filter paper No.1 into polythene specimen tubes.

Leaf N and P were determined simultaneously with Auto-Analyser 1. Nitrogen was determined by the alkaline sodium phenate-sodium hypochlorite reaction method at 37°C filtered at 625 nm. Phosphorus was determined by the molybdovanadate reaction method at 37°C and filtered at 420 nm. Potassium was determined by flame emission spectroscopy using the same digest solution as N and P, with Atomic Absorption spectrophotometer model SP9 Pye Unicam at a wavelength of 766.5 nm.

Leaf Cu, Fe, Zn, Mn were determined by absorption spectroscopy using Atomic Absorption spectrophotometer model Sp9 Pye Unicam at wavelengths of 324.8, 248.3, 213.9 and 279.5 nm, respectively (Bould, 1974). One gram of leaf material was dried at 100-105°C for one hour and cooled in a desiccator was weighed and put into 50 ml wide mouth pyrex conical flasks. They were then ashed overnight at 450°C. Two mls of 3:1 HNO_3: $HClO_4$ were added to the ash and refluxing funnels put on the mouth of the conical flask and heated to dryness on hot plate (medium gauge). Refluxing funnels were removed and 10 ml of 0.5 N HCl and one ml of freshly prepared 0.5% $NaNO_2$ added. The refluxing funnels were replaced and the sample boiled for 5-10 minutes. The heat was reduced to minimise the excessive spurring of the samples. The contents of the conical flasks were transferred into excelo tube and left to stand overnight for the silica to settle and then made to volume of 20 mls. Samples were filtered through

Whatman filter paper No.40 into polythene specimen tubes. The filtrates were then analyzed for Cu, Fe, Zn and Mn as described above.

3.2.5.7 Coffee plant growth and yield components: Coffee plant growth commenced after six moths after coffee establishment and before the green manure application commenced. height was recorded as the length (cm) from the base to the tip of the plant. Six plants were measured after every three months starting from January 1992 to December 1993. The average height of the six plants per measuring date was recorded. The difference in height between two consecutive recording dates was the actual increase in plant height.

Stem thickness was taken as the diameter (cm) of the stem. The diameter was measured using a pair of callipers at about 15 cm from ground level. An average diameter of the six trees as for height. Stem diameter was measured at the same time as height measurements. The difference in stem diameter between two consecutive recording dates was the actual increase in stem diameter.

For leaf area measurements one leaf per tree on the fourth primary from the top of the tree was used. The area of each leaf was estimated by multiplying the length, width at the broadest portion and a factor of 0.88 (Walyaro, 1983). The average leaf area cm^2 was recorded. The leaf area was measured on monthly basis on the same leaf for three months after which a new leaf was selected. The difference in leaf area between two consecutive recording dates was the actual increase in leaf area.

The coffee primary growth was taken as the average increase in length of six primaries per plot. The primaries had initially been tagged at three nodes from the tip. The primaries had been selected from the middle canopy of the plants. Their primary length were measured at the same time with plant height. The difference in primary length between two consecutive recording dates was the actual increase in primary length.

Total number of nodes per primary was obtained as the average number of nodes per primary used for primary growth measurements. The counting of nodes was done over the same period as that for primary growth. At the same time the number of primaries which were bearing (with berries, flowers or flower buds) were recorded. The number of bearing nodes (nodes with berries, flowers or flower buds) on the tagged bearing primaries was also recorded.

3.2.5.8 Leaf water potential: This was measured with a PMS Instruments Company pressure chamber, Model 600. The leaf water potential was measured in March and August every year. It was measured at about midday 12.00 - 13.00 hours which is the hottest period of the day. This was done by sampling the fourth leaf from a primary branch apex at the middle of the canopy. The fourth leaf is the most physiologically active leaf on a coffee plant (Kumar and Tieszen, 1976). The cut leaf was placed in the chamber with the cut surface exposed. Pressure was slowly applied to the sample using nitrogen gas. The cut surface was observed to determine when the leaf water was forced back to it and seen indicating the water potential (Scholander *et al.*, 1965). The pressure applied at this point was recorded in bars.

3.2.5.9 Clean coffee bean yield and quality: Coffee cherries were harvested from the six effective trees per plot between July and December 1993 and yields recorded. Only red ripe cherries were picked. The cherries were then processed to parchment and later hulled to clean coffee. The loss from parchment to clean coffee was approximately 20% by weight. At the time of harvesting 10% sample from each plot was taken for quality analysis. This involved bean size and coffee liquor characteristics.

A bean grader was used to determine the various fractions of bean sizes in each sample as described by Mwangi (1983). The bean fractions were expressed in terms of percentage by weight. The percent grade `A' sized beans which included all coffee of commercial grades AA, AB, E plus part of PB and TT was recorded as density grading was not done. The grade `A' sized beans are the larger coffee beans retained by a No 17 screen with holes of size 6.75 mm in diameter.

3.2.5.10 Liquor quality attributes: The assessment of liquor quality was organoleptic and was based on a number of attributes as described by Devonshire (1956). The liquoring reports of the Mild Coffee Trade Association (M.C.T.A), Kenya, who assessed the quality of the material in this study, included the following attributes:

(i) Quality of raw beans, that is, size and colour with scores of 0-7 where:-

0 Fine

1 Good to fine

2 Good

3 Fair to Good

4 Fair Average Quality

5 Poor to Fair

6 Poor

7 Very poor

(ii) Quality of roast beans as the general appearance and centre cut of roast coffee bean on a scale of 0-5 where:-

0 Fine

1 Good to fine

2 Fair to Good

3 Fair Average Quality

4 Poor to Fair

5 Poor

(iii) Liquor quality. This was assessed according to acidity, body and flavour. The acidity on a scale of 0-4 where:-

0 Pointed

1 Medium

2 Light Medium

3 Light

4 Lacking

The body was also on a scale of 0-4 where:-

0 Full

1 Medium

2 Light Medium

3 Light

4 Lacking

and the flavour of the brewed coffee was assessed on a scale of 0-6 where:-

0 Fine
1 Good to fine
2 Good
3 Fair to Good
4 Fair Average Quality
5 Poor to Fair
6 Poor

(iv) Overall standards. This was the overall evaluation of liquor quality on the basis of the above (1-3) attributes on a scale of 0-7 where:-

0 Fine
1 Good to fine
2 Good
3 Fair to Good
4 Fair Average Quality
5 Poor to Fair
6 Poor
7 Very poor

3.2.6 Data analysis

The data recorded were subjected to analysis of variance as described by Gomez and Gomez (1984) using MSTAT package (Smail, *et al.*, 1984). The ANOVA tables are shown in Appendix 5.1 - 5.16.

3.3 Results

3.3.1 Dry matter and potential nutrient yields from green manure plants

3.3.1.1 Dry matter production: During the first year, green manure plants produced between 4919 and 18042 kg/ha/year of dry matter (Table 3.2). Desmodium, calliandra and sesbania produced significantly more dry matter than pigeon pea. In second year, plants produced between 315? and 10468 kg/ha/year of dry matter (Table 3.3). Desmodium and pigeonpea produced significantly more dry matter than sesbania.

3.3.2.2 Potential nutrient yields: The nutrient composition of the leguminous green manures which were applied to coffee are shown in Appendices 4a and 4b.

In the first year, sesbania green manure had significantly higher nitrogen content than luceme and pigeon pea green manures (Table 3.2) while during the second year, calliandra and desmodium green manures had significantly more nitrogen than leucaena, sesbania, luceme and pigeonpea green manures (Table 3.3). Pigeon pea green manure yielded significantly lower potassium than the other green manures (Table 3.2). Desmodium green manure, yielded significantly more potassium than the other green manures in the second year (Table 3.3).

Table 3.2: Dry matter and potential nutrient yield from green manure plants in 1992

Crop	Yield in Kg $ha^{-1}yr^{-1}$					
	DM*	N	P	K	Ca	Mg
Leucaena	8083 ab	445 bc	20 b	343 a	145 b	43 ab
Sesbania	11446 a	780 a	36 a	382 a	219 a	49 a
Calliandra	8944 a	570 ab	24 ab	263 a	176 ab	35 ab
Desmodium	18042 a	595 ab	18 b	278 a	155 b	18 c
Lucerne	9002 ab	319 c	24 ab	368 a	122 b	31 bc
Pigeonpea	4919 b	262 c	18 b	131 b	58 c	19 c
SED (10 df)		98.2	5.6	50.8	24.6	6.5
C.V %		24.2	29.3	21.5	20.7	24.0

Means followed by the same letter down the column were not significantly different according to Tukey's Honestly Significant Test, 5% level.

*DM - Dry matter

P - Phosphorous

N - Nitrogen content

K - Potassium

Ca - Calcium

Mg - Magnesium

Table 3.3: Dry matter and potential nutrient yield from green manure plants in 1993

Crop	Yield in Kg $ha^{-1}yr^{-1}$					
	DM*	N	P	K	Ca	Mg
Leucaena	5419 de	243 bc	18 a	130 b	33 cd	13 de
Sesbania	3153 f	127 ef	9 b	77 c	24 d	7 ef
Calliandra	7835 bc	310 a	23 a	134 b	41 c	16 cd
Desmodium	10468 a	295 ab	22 a	247 a	90 a	23 b
Lucerne	4695 ef	168 de	10 b	132 b	58 b	12 cde
Pigeonpea	9043 ab	232 bcd	19 a	158 b	59 b	53 a
SED (10 df)	867	29.4	2.7	20.4	7.9	2.8
C.V %	18.4	18.9	23.5	19.8	20.8	20.1

Means followed by the same letter in each column were not significantly different according to Tukey's Honestly Significant Test, 5% level.

*DM - Dry matter

P - Phosphorous

N - Nitrogen content

K - Potassium

Ca - Calcium

Mg - Magnesium

Sesbania green manure yielded significantly more phosphorus than did those of leucaena, desmodium and pigeonpea during the first year of (Table 3.2). However, in the second year, sesbania and lucerne green manures produced significantly less phosphorus than did the other green manure plants (Table 3.3). In the first year, Sesbania green manure yielded significantly more calcium than all other green manures (Table 3.2), while desmodium green manure yielded significantly higher amount of calcium than the rest (Table 3.3). During the first year, sesbania green manure yielded significantly higher amount of magnesium than the rest (Table 3.2). In the following year, pigeonpea green manure significantly yielded more magnesium than the rest (Table 3.3).

3.3.2 Green manure decomposition

All the green manures had an exponential decay pattern (Fig 3.1). Calliandra green manure had a faster rate of decomposition (t_{50}) of 17 days, followed by that of leucaena (17 days) and sesbania (21 days) (Fig 3.1). Pigeon pea green manure had a very slow rate of decomposition with a t_{50} of 60 days. The decomposition pattern of green manure from desmodium and pigeon pea showed total immobilization between the first and third weeks (Fig 3.1).

3.3.3 Nitrogen mineralization rates

The amount of nitrogen mineralized differed significantly between the applied green manures. One week after incubation, green manure from leucaena and calliandra released significantly more nitrogen than the others (Table 3.4). By the fourth week of incubation, green manures from

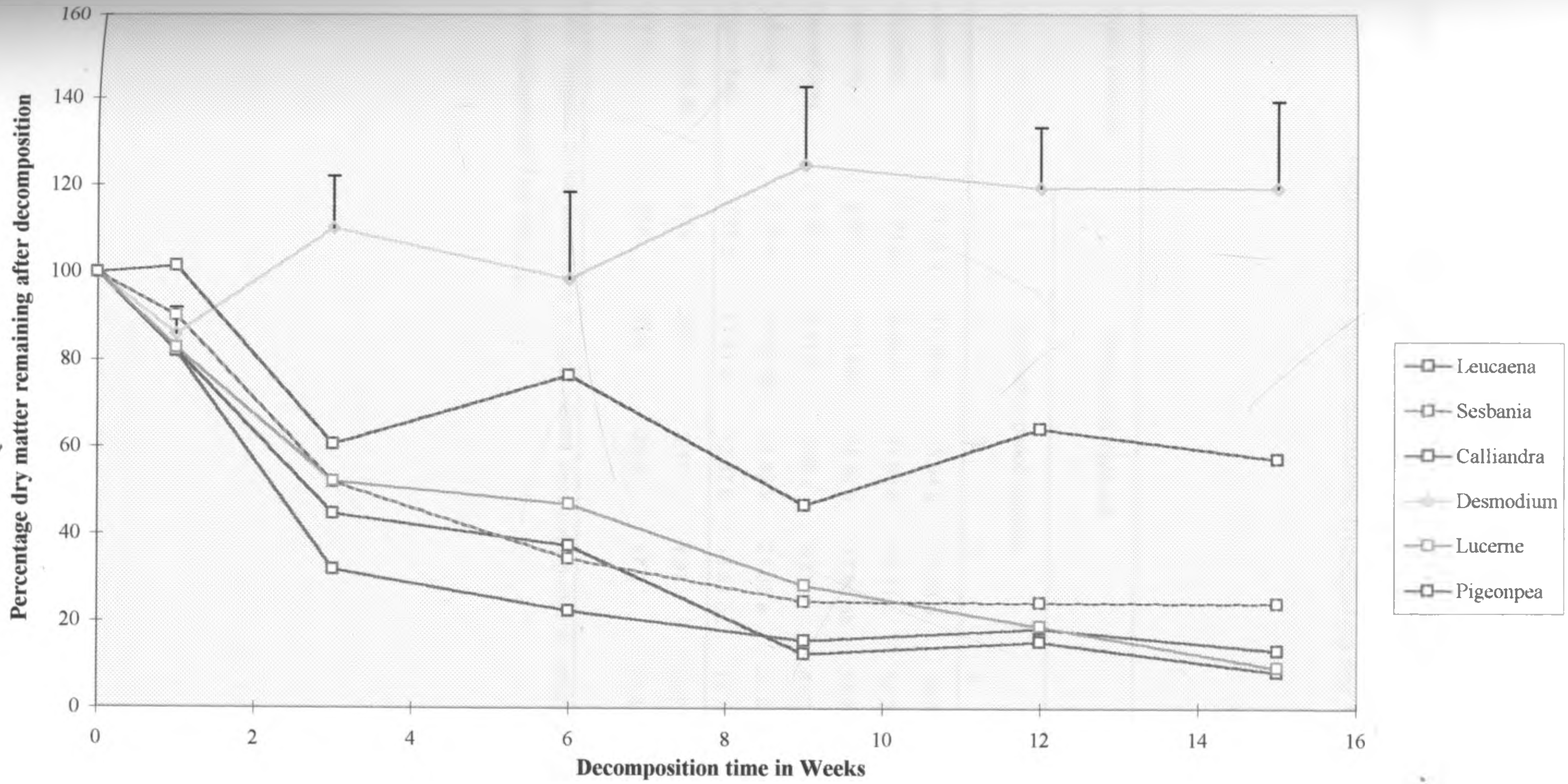

Fig 3.1: Percentage dry matter remaining after field decomposition of the green manure plants for 15 weeks

Table 3.4: Amount of available nitrogen released by decomposing leguminous green manures incubated for 12 weeks

Green manure	Nitrogen in mg/g soil					
	Incubation period (weeks)					
	1	2	3	4	8	12
Leucena	11.31 a	17.39 a	18.94 a	21.08 a	19.33 ab	26.90 a
Sesbania	3.74 bc	9.95 c	11.83 b	13.41 c	12.26 c	13.90 b
Calliandra	9.37 a	11.14 bc	14.32 b	17.96 ab	14.74 bc	16.64 b
Desmodium	1.97 c	4.31 d	5.98 c	8.85 d	4.62 d	8.59 c
Lucerne	5.09 b	15.92 ab	21.46 a	21.33 a	22.94 a	24.45 a
Pigeon pea	0.99 c	11.41 bc	13.37 b	14.61 bc	15.76	16 49 b
S.E.D (15 df)	1.29	2.21	2.11	1.97	2.47	1.69
C.V %	33.6	26.8	20.8	17.2	23.4	13.4

Means followed by the same letter in each column were not significantly different according to Tukey's Honestly Significant Test, 5% level.

leucaena, calliandra and lucerne had released significantly more nitrogen than those from sesbania, pigeon and desmodium did (Fig 3.2). By twelve weeks of incubation, leucaena and lucerne green manures had released significantly more nitrogen than all the rest. Green manure from desmodium was observed to release very little nitrogen throughout the incubation period (Fig 3.2).

The cumulative percent N mineralized after 12 weeks of incubation ranged from 25% for desmodium green manure to 85% for leucaena green manure (Fig 3.2). The patterns of the N release differed among the green manures. All the green manures except those from desmodium had an exponential release for the first four weeks. Pigeonpea and lucerne green manures appeared to show net nitrogen immobilization within the first week of incubation. Leucaena and calliandra green manures showed some immobilization between the sixth and eighth weeks of incubation. On average, all green manures had relatively little change between the fourth and twelfth weeks of incubation (Fig 3.2), although leucaena green manure showed an increase in N mineralization between the eighth and twelfth weeks of incubation.

3.3.4 Effect of green manure application on soil properties

3.3.4.1 Soil bulk density: After two years of continuous application of leucaena, sesbania and calliandra green manures resulted in significantly lowering the top soil bulk density more than applying cattle manure or napier grass (Table 3.5). The application of nitrogen fertilizer, napier grass and desmodium significantly increased the subsoil bulk density more than applying the other green manures (Table 3.5).

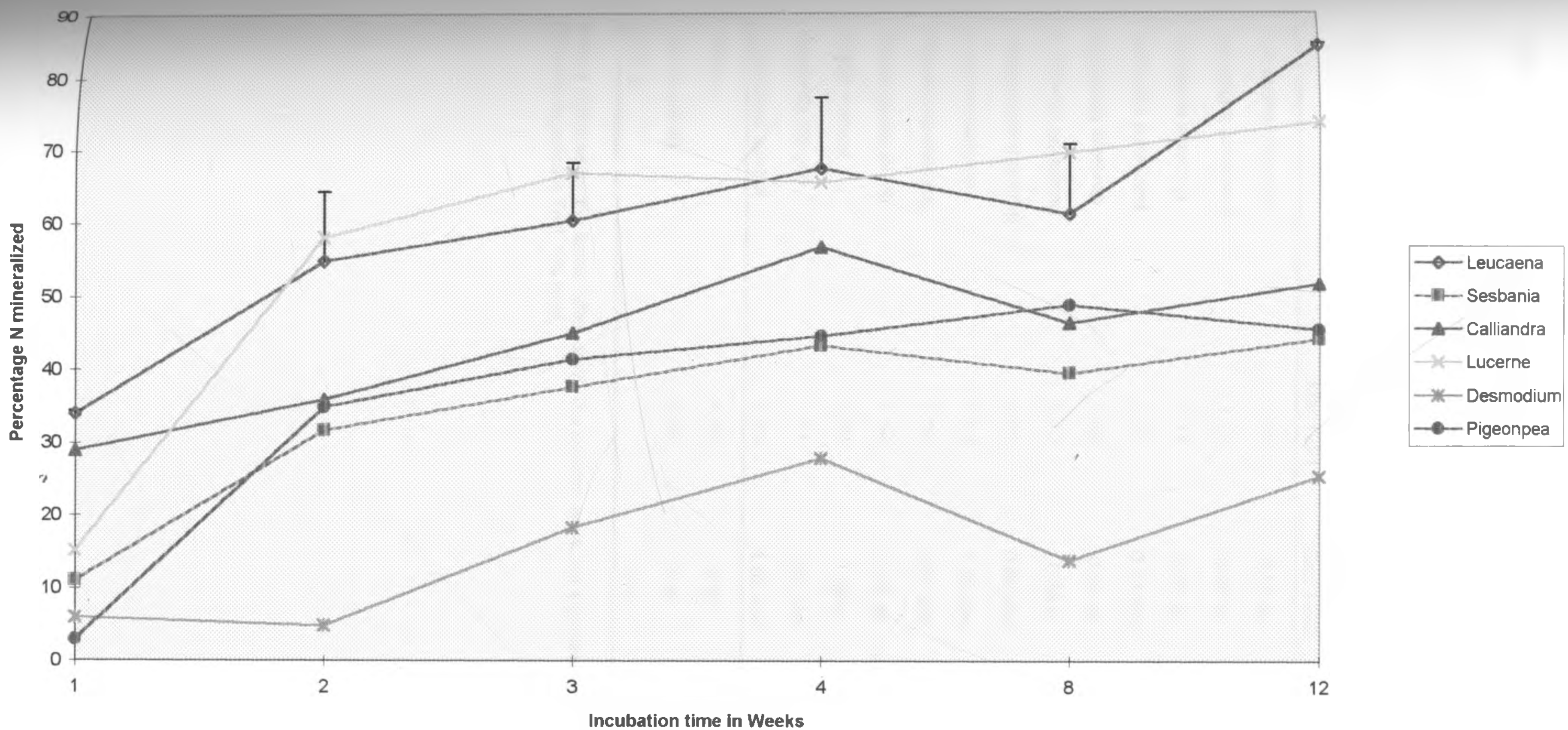

Fig 3.2: Percentage amount of nitrogen mineralized by green manure plants after incubating them at 26°C for 12 weeks

Table 3.5: **Effect of leguminous green manure application to young coffee plants on intra-row top and subsoils bulk density (g/cm^3) sampled in March 1991 and September 1993**

Source of green manure	Bulk density (g/cm^3)			
	Topsoil		Subsoil	
	Mar 1991	Sep 1993	Mar 1991	Sep 1993
Leucaena intercrop	1.14	0.90 bc	1.22	0.93 d
Leucaena purestand	1.12	0.90 bc	1.23	0.91 d
Sesbania intercrop	1.14	0.91 bc	1.22	1.01 bcd
Sesbania purestand	1.17	0.94 abc	1.17	0.97 d
Calliandra intercrop	1.08	0.92 bc	1.21	0.99 cd
Calliandra purestand	1.12	0.88 c	1.11	0.96 d
Desmodium intercrop	1.11	0.94 abc	1.24	1.10 ab
Lucerne intercrop	1.13	1.00 abc	1.15	0.98 d
Pigeonpea intercrop	1.16	0 94 abc	1.16	1.01 bcd
Napier grass mulch	1.14	1.05 ab	1.18	1.16 a
Cattle manure	1.16	1.09 a	1.23	0.94 d
Inorganic nitogen	1.11	1.02 abc	1.24	1.15 a
Unfertilized control	1.13	1.02 abc	1.19	1.08 abc
Mean	1.13	0.96	1.20	1.01
S.E.D (24 df)	0 06	0.07	0.27	0.04
C V %		8.5		5.00

Means followed by the same letter down the column were not significantly different according to Tukey's Honestly Significant Test, 5% level.

Table 3.6: **Effect of leguminous green manure application to young coffee plants on intra-row top soil Hp, N, K and Ca + Mg/K ratio, sampled in September 1993**

Source of green manure	Hp m.e %	N %	K m.e %	Ca+mg/K
Leucaena intercrop	0.09 b	0.20 ab	1.35 b	5.78 ab
Leucaena purestand	0.11 ab	0.21 ab	0.91 b	7.33 ab
Sesbania intercrop	0.11 ab	0.20 ab	1 28 b	5.56 b
Sesbania purestand	0.18 ab	0.25 a	1.15 b	6.02 ab
Calliandra intercrop	0.12 ab	0.22 ab	1.40 b	5.95 ab
Calliandra purestand	0.15 ab	0.21 ab	0.9 b	7.26 ab
Desmodium intercrop	0.08 b	0.24 ab	1.23 b	6.54 ab
Lucerne intercrop	0.13 ab	0.23 ab	1.24 b	5.84 ab
Pigeonpea intercrop	0.23 a	0.20 ab	1.25 b	5.51 b
Napier grass mulch	0.13 ab	0.23 ab	2.01 a	3.65 c
Cattle manure	0.13 ab	0.19 b	1.03 b	6.77 ab
Inorganic nitrogenr	0.13 ab	0.19 b	0.94 b	7.56 a
Unfertilized control	0.10 b	0.21 ab	1.23 b	6.06 ab
Mean	0.13	0.22	1.23	6.14
S.E.D (24 df)	0.05	0.02	0.22	0.80
C.V %	44.0	12.4	22.4	16.0

Means followed by the same letter down the column were not significantly different according to Tukey's Honestly Significant Test, 5% level.

Note: Initial soil analysis

Hp	0.1 m.e%
N	0.33%
K	1.90 m.e%
Ca + Mg/K ratio	5.7

3.3.4.2 Soil Acidity (pH): Application of green manures and nitrogen fertilizer did not significantly affect the pH of top soil. However, the pH of the subsoil of plots where napier grass had been applied was significantly higher than those soils top dressed with nitrogen (Table 3.7).

3.3.4.3 Exchangeable acidity (Hp): Continuous application of pigeonpea green manures resulted in significantly higher topsoil exchangeable acidity than applying the other green manures (Table 3.6). Subsoil exchangeable acidity was not affected by application of the green manures (Table 3.7).

The soil exchangeable acidity increased over the two year period (Table 3.8). The largest increase occurred in the coffee plots applied with pigeonpea green manure. Over the two year period there was no change in the exchangeable acidity in the unfertilized plot.

3.3.4.4 Effect of green manures on soil nutrients: After two years of green manure application there was a significantly higher nitrogen concentration in the top soil in plots applied with sesbania green manure than those plots where cattle manure or nitrogen fertilizer had been applied (Table 3.6). There was however, a decline in both the top and sub soil nitrogen levels over the two year period (Table 3.8). The levels of organic carbon of topsoil was not significantly affected by the application of green manures. It averaged 3.2%, however, there was significantly higher organic carbon in the subsoil of plots applied with napier grass than those fertilized with cattle manure (Table 3.7).

Table 3.7: **Effect of leguminous green manure application to young coffee plants on intra-row sub soil pH, Hp, C, N, K, Mn and Ca + Mg/K ratio sampled in September 1993**

Source of green manure	pH	Hp m.e %	C %	N %	K m.e %	Mn m.e %	Ca+Mg/ K
Leucaena intercrop	5.10 ab	0.13 ab	2.9 ab	0.19 ab	1.41 ab	1.44 ab	5.39 ab
Leucaena purestand	4.90 ab	0.16 ab	2.7 ab	0.21 ab	0.94 b	1.44 ab	6.69 a
Sesbania intercrop	5.03 ab	0.19 ab	2.8 ab	0.18 ab	1.34 ab	1.41 ab	5.44 ab
Sesbania purestand	4.93 b	0.21 ab	2.9 ab	0.19 ab	1.10 b	1.39 ab	6.06 ab
Calliandra intercrop	5.03 ab	0.25 ab	2.4 ab	0.16 b	1.25 ab	1.14 b	5.91 ab
Calliandra purestand	4.80 b	0.27 a	2.4 ab	0.20 ab	0.94 b	1.29 ab	6.52 a
Desmodium intercrop	5.20 ab	0.09 b	2.9 ab	0.19 ab	1.38 ab	1.38 ab	5.27 ab
Lucerne intercrop	5.00 ab	0.18 ab	2.5 ab	0.21 ab	1.10 b	1.24 ab	6.71 a
Pigeonpea intercrop	4.90 b	0.27 ab	2.6 ab	0.22 ab	1.31 ab	1.28 ab	5.18 ab
Napier grass mulch	5.47 a	0.11 b	3.0 a	0.23 ab	1.78 a	1.59 a	3.93 b
Cattle manure	4.93 b	0.11 b	2.2 b	0.16 b	0.94 b	1.31 ab	6.99 a
Inorganic nitrogen	4.93 b	0.16 ab	2.3 ab	0.18 ab	0.89 b	1.23 ab	7.14 a
Unfertilized control	5.00 ab	0.15 ab	2.3 ab	0.19 ab	1.13 b	1.28 ab	6.13 a
Mean	5.02	0.17	2.6	0.19	1.19	1.33	5.95
S.E.D (24 df)	0.22	0.07	0.3	0.02	0.23	0.18	0.91
C.V %	5.4	47.9	15.1	15.0	24.1	16.8	18.8

Means followed by the same letter down the column were not significantly different according to Tukey's Honestly Significant test, 5% level.

Note: Initial soil analysis

pH	5.3
Hp	0.1 m e%
N	0.33%
C	1.91
K	1.70 m e%
Mn	1.30 m e%
Ca + Mg/K ratio	5.5

Table 3.8: Effects of leguminous green manure application to young coffee plants on percentage intra-row soil chemical changes (March 1991 to September 1993)

Source of green manure	Bulk density	pH	Hp	C	N	K	Ca	Mg	P	Ca+ Mg/K
Leucaena intercrop	-11.5	-3.2	-10	24.5	-39.4	-29.0	1.5	-30	-5.5	1.4
Leucaena purestand	-10.6	-6.2	50	9.4	-36.4	-52.1	-11.3	-42.8	-11.5	28.6
Sesbania intercrop	-5.3	-2.5	10	28.3	-39.4	-27.4	-3.6	-30.2	-0.4	-2.5
Sesbania purestand	-10.6	-7.0	80	20.8	-24.2	-39.5	-12.8	-39.1	-11.5	5.6
Calliandra intercrop	-8.0	-0.6	60	20.8	-33.3	-26.3	9.1	-28.4	2.3	4.4
Calliandra purestand	-5.3	-8.1	50	17.0	-36.4	-52.6	-17.0	-40.7	-12.4	27.4
Desmodium intercrop	-14.2	-1.9	-20	17.0	-27.3	-35.3	-1.5	-32.6	-9.7	14.7
Lucerne intercrop	-12.4	-6.2	3.0	32.1	-30.3	-34.7	-15	-41.2	-10.1	2.5
Pigeonpea intercrop	-13.3	-5.7	130	17.0	-39.3	-34.2	-14.3	-38.6	-8.7	-3.3
Napier grass mulch	-7.1	-1.9	30	28.3	-30.3	5.8	-10.6	-31.2	-5.5	-36.0
Cattle manure	-4.4	-2.5	30	9.4	-42.4	-45.8	-9.1	-37.6	-8.7	18.8
Inorganic nitrogen	-8.8	-5.1	30	9.4	-42.4	-50.5	-9.1	-36.5	-10.8	32.6
Unfertilized control	-9.7	-1.9	0	13.2	-36.4	-35.3	-13.4	-38.8	-12.4	6.3
Mean	-8.2	4.6	41.9	19.0	-35.2	-37.4	-7.5	-37.4	-7.9	10.5
SED	±3.6	2.6	1.2			14.7	7.2	±5.6	4.7	16.7

The levels of carbon in the soil declined over the two year trial period (Table 3.8).

The top and sub soil-K content in plots applied with napier grass was significantly higher than in those plots applied with green manures and nitrogen (Tables 3.6 and 3.7). Except in plots where coffee was mulched with napier grass, the soil-K declined over the two year (Table 3.8). However, continuous application of napier grass raised the soil-K level over the same period.

Application of the green manures and nitrogen did not significantly affect both the top and subsoil Ca levels. The Ca level was noted to decline over the two year period except in those plots where coffee plants were applied with leucaena and calliandra green manure from intercrops (Table 3.8). The soil Mg was not significantly affected by the application of green manures to young coffee plants. However, the Mg level declined by over 37% over the two year period (Table 3.8).

Top dressing coffee plants with nitrogen fertilizer resulted in significantly higher Ca + Mg : K ratio in the top soil than applying napier grass, pigeonpea and sesbania green manures (Table 3.6). Similarly, in the subsoil, the Ca + Mg:K ratio was significantly lower in plots mulched with napier grass than in those plots where coffee plants were top dressed with nitrogen (Table 3.7).

During the two year study period the Ca + Mg:K ratio increased in most of the coffee plots except where sesbania and pigeonpea and napier grass mulches were used. The ratio increased by 10.5% (Table 3.8).

3.3.4.5 Soil moisture: During the trial period application of green manures and nitrogen fertilizer did not significantly affect the soil moisture which ranged between 14.4 - 22.1% (Table 3.9).

3.3.5 Leaf tissue nutrient concentration

Application of napier grass as mulch to coffee plants resulted in significantly lower leaf N concentration than in the leaves of coffee plants top dressed with nitrogen fertilizer (Table 3.10). The coffee leaf boron concentration was significantly higher in the leaves of those coffee plants applied with leucaena green manure from intercrop than in those coffee plants top dressed with nitrogen fertilizer (Table 3.10). During the same period application of pigeonpea green manures to young coffee plants resulted in significantly higher leaf manganese concentration than in those plants in the unfertilized control (Table 3.10).

3.3.6 Effect of green manure application on coffee plant growth

3.3.6.1 Plant height: During the first year, application of green manures had significantly less effect on increase in plant height than top dressing with nitrogen fertilizer (Table 3.11). Intercropping leucaena, sesbania and calliandra with coffee did not affect the coffee plant height. During the second year, application of desmodium green manure had significantly reduced the increase in plant height compared to top dressing with nitrogen (Table 3.11). Application of the other green manures did not significantly affect the increase in coffee plant height.

Table 3.9: Effects of leguminous green manure application to young coffee plants on subsoil water holding capacity (1991-93)

Sources of green manure	Soil moisture % December 1991	August 1992	March 1993
Leucaena intercrop	19.7 ab	21.6 abc	14.0 ab
Leucaena purestand	17.5 ab	20.1 ab	10.9 b
Sesbania intercrop	17.8 ab	19.1 ab	17.2 a
Sesbania purestand	18.1 ab	24.3 a	16.6 a
Calliandra intercrop	17.6 ab	22.3 ab	13.2 ab
Calliandra purestand	18.8 ab	23.4 ab	14.0 ab
Desmodium intercrop	17.0 ab	26.3 a	16.3 ab
Lucerne intercrop	16.5 b	16.3 b	13.8 ab
Pigeonpea intercrop	19.1 ab	25.1 a	13.9 ab
Napier grass mulch	20.9 a	22.7 ab	15.1 ab
Cattle manure	17.4 ab	22.7 ab	13.2 ab
Inorganic nitrogen	16.7 ab	22.6 ab	13.9 ab
Unfertilized control	18.5 ab	21.0 ab	15.7 ab
Mean	17.6	22.1	14.4
S.E.D (24 df)	1.7	3.3	2.2
C.V %	19.8	18.2	19.3

Means followed by the same letter down the column were not significantly different according to Tukey's Honestly Significant test, 5% level

Table 3.10: Effects of leguminous green manure application to young coffee plants on coffee leaf nutrient concentration sampled in September 1993

Source of green manure	N %	Mn ppm	Bo ppm
Leucaena intercrop	2.86 abc	177 b	74 a
Leucaena purestand	2.88 abc	289 ab	56 bc
Sesbania intercrop	2.89 abc	217 b	60 abc
Sesbania purestand	2.89 abc	263 b	46 c
Calliandra intercrop	2.94 abc	269 ab	69 ab
Calliandra purestand	3.00 abc	190 b	60 abc
Desmodium intercrop	2.94 abc	209 b	59 abc
Lucerne intercrop	3.12 a	232 b	56 abc
Pigeonpea intercrop	2.80 b	375 a	56 abc
Napier grass mulch	2.74 c	285 b	61 abc
Cattle manure	2.93 abc	215 b	49 c
Inorganic nitrogen	3.05 ab	256 ab	55 bc
Unfertilized control	2 87 abc	223 b	62 abc
Mean	2.91	246	59
S.E.D (24 df)	0.11	59.0	7.15
C.V %	4.7	30.3	14.9

Means followed by the same letter down the column were not significantly different according to Tukey's Honestly Significant test, 5% level.

Table 3.11: Effects of leguminous green manure application to young coffee plants on actual increase of coffee tree height (Jan 1992 - Dec 1993)

	Increase in height (cm)	
Sources of green manure	Jan - Dec 92	Jan - Dec 93
Leucaena intercrop	39.7 ab	45.5 ab
Leucaena purestand	34.9 ab	50.8 a
Sesbania intercrop	34.8 ab	42.5 ab
Sesbania purestand	36.8 ab	42.3 ab
Calliandra intercrop	52.4 a	44.3 ab
Calliandra purestand	40.3 ab	51.7 a
Desmodium intercrop	29.7 b	29.2 b
Lucerne intercrop	30.8 b	43.3 ab
Pigeonpea intercrop	33.2 b	45.2 ab
Napier grass mulch	36.5 ab	53.2 a
Cattle manure	33.6 ab	43.2 ab
Inorganic nitrogen	44.4 a	50.4 a
Unfertilized control	44.0 a	42.8 ab
Mean	37.8	44.9
S.E.D (24 df)	6.6	5.7
C.V %	28.5	20.8

Means followed by the same letter down the column were not significantly different according to Tukey's Honestly Significant test, 5% level.

3.3.6.2 Stem diameter: During the first year applying green manures increased stem diameters less than top dressing with nitrogen (Table 3.12). However, in the second year, application of green manure from calliandra intercrop resulted in significantly higher increase in stem diameter than top dressing with nitrogen fertilizer (Table 3.12).

3.3.6.3 The length of coffee primary branches: During the first year application of green manures from desmodium, sesbania and lucerne significantly reduced the increase in the length of primary branches than the top dressing with nitrogen fertilizer (Table 3.13). During the second year, application of green manures from sesbania, desmodium and pigeonpea significantly reduced the increase in the length compared the unfertilized coffee plants (Table 3.13). Application of the other green manures did not significantly affect the increase in the length.

3.3.6.4 Leaf area: Between May and July 1992, during the first year of green manure application, leaves of coffee plants top dressed with nitrogen fertilizer had significantly higher increase in leaf area than those from plants applied with leucaena, sesbania, calliandra, desmodium and lucerne green manure from intercrop (Table 3.14). Between October and December 1992, leaves of coffee plants top dressed with nitrogen fertilizer had significantly higher leaf area than those applied with sesbania and desmodium green manures (Table 3.14).

Table 3.12: Effects of leguminous green manure application to young coffee plants on actual increase in coffee stem diameter (Jan 1992 - Dec 1993)

Sources of green manure	Increase in stem diameter	
	Jan - Dec 92	Jan - Dec 93
Leucaena intercrop	1.25 a	1.32 a
Leucaena purestand	1.19 a	1.49 a
Sesbania intercrop	1.19 a	1.42 a
Sesbania purestand	1.39 a	1.24 a
Calliandra intercrop	1.04 a	1.67 a
Calliandra purestand	1.39 a	1.36 a
Desmodium intercrop	0.75 b	1.51 a
Lucerne intercrop	0.83 b	1.41 a
Pigeonpea intercrop	0.95 b	1.36 a
Napier grass mulch	1.15 a	1.96 a
Cattle manure	1.31 a	1.19 a
Inorganic nitrogen	1.53 a	1.47 a
Unfertilized control	1.48 a	1.40 a
Mean	1.18	1.45
S.E.D (24 df)	0.20	0.13
C.V %	27.4	14 2

Means followed by the same letter down the column were not significantly different according to Tukey's Honestly Significant Difference Test, 5% level.

Table 3.13: Effects of leguminous green manure application to young coffee plants on actual increase in coffee tree primary branch length (Jan 1992 - Dec 1993)

	Primary extension (cm)	
Sources of green manure	Jan - Dec 92	Jan - Dec 93
Leucaena intercrop	39.3 abc	40.8 ab
Leucaena purestand	40.8 abc	38.1 abc
Sesbania intercrop	29.3 cd	34.2 abc
Sesbania purestand	42.8 a	29.6 c
Calliandra intercrop	35.7 a-d	33.1 abc
Calliandra purestand	45.2 a	37.9 abc
Desmodium intercrop	25.5 d	30.5 bc
Lucerne intercrop	29.7 bcd	32.7 abc
Pigeonpea intercrop	34.7 a-d	28.6 c
Napier grass mulch	37.7 a-d	37.8 abc
Cattle manure	44.3 a	32.4 abc
Inorganic nitrogen	46.7 a	34.6 abc
Unfertilized control	44.9 a	42.8 a
Mean	38.2	34.8
S.E.D (24 df)	5.8	2.3
C.V %	18.6	16.0

Means followed by the same letter down the column were not significantly different according to Tukey's Honestly Significant test, 5% level.

Table 3.14: Effects of leguminous green manure application to young coffee plants on actual increase in area of coffee leaf (cm^2), 1992

Sources of green manure	May - July 92	Oct - Dec 92
Leucaena intercrop	27.4 abc	30.5 a-d
Leucaena purestand	14.3 c	30.4 a-d
Sesbania intercrop	12.8 c	17.3 d
Sesbania purestand	25.4 abc	38.4 a-d
Calliandra intercrop	13.9 c	32.9 a-d
Calliandra purestand	37.2 a	41.4 abc
Desmodium intercrop	17.1 bc	20.7 cd
Lucerne intercrop	16.7 bc	24.0 bcd
Pigeonpea intercrop	23.8 abc	39.6 abc
Napier grass mulch	30.7 ab	53.7 a
Cattle manure	25.8 abc	50.3 a
Inorganic nitrogen	38.7 a	47.0 ab
Unfertilized control	27.6 abc	44.4 ab
Mean	24.0	36.2
S.E.D (24 df)	6.9	10.1
C.V %	35.1	34.2

Means followed by the same letter down the column were not significantly different according to Tukey's Honestly Significant test, 5% level.

Between March and May 1993, during the second year of application, leaves of coffee plants top dressed with nitrogen had significantly more leaf area than those of coffee plants applied with desmodium green manure (Table 3.15). Between June and November 1993 period, application of green manures and nitrogen fertilizer did not significantly affect the increase in leaf area (Table 3.15).

3.3.7 Effect of green manure application on coffee leaf water potential

In the first year of growth, the leaves of coffee plants applied with calliandra green manure from intercrop resulted in significantly higher leaf water potential than in those plants top dressed with nitrogen fertilizer (Table 3.18).

Intercropping green manure plants with coffee plants did not significantly affect water status of coffee leaf (Table 3.16). Application of the green manures and nitrogen fertilizer did not affect the leaf water potential during subsequent growth periods.

3.3.8 Effect of green manure application on the yield components coffee plant

3.3.8.1 Total number of primaries: In the first year, application of green manures from desmodium, luceme and pigeonpea significantly decreased the number of primaries per coffee plant than top dressing with nitrogen fertilizer (Table 3.17). In the following year, application of desmodium green manure to coffee plants significantly decreased the number of primaries per coffee plant (Table 3.18).

Table 3.15: Effects of leguminous green manure application to young coffee plants on actual increase in area of coffee leaf (cm^2) (1993)

Sources of green manure	Mar - May 93	Jun - Aug 93	Sept - Nov 93
Leucaena intercrop	33.4 bcd	36.3 c	10.9 ab
Leucaena purestand	34.1 bcd	48.2 abc	6.0 b
Sesbania intercrop	29.4 cd	43.1 abc	16.8 a
Sesbania purestand	39.5 ab	44.2 abc	13.4 ab
Calliandra intercrop	34.6 bcd	40.2 abc	11.0 ab
Calliandra purestand	31.3 bcd	50.0 abc	16.4 a
Desmodium intercrop	26.8 d	39.0 bc	9.9 ab
Lucerne intercrop	29.6 cd	42.4 abc	12.0 ab
Pigeonpea intercrop	36.8 abc	36.3 c	10.4 ab
Napier grass mulch	34.1 bcd	52.9 ab	11.1 ab
Cattle manure	45.3 a	48.9 abc	13.0 ab
Inorganic nitrogen	38.7 abc	53.8 a	19.6 a
Unfertilized control	38.63 abc	48.2 abc	9.7 ab
Mean	34.8	44.9	12.8
S.E.D (24 df)	3.9	5.6	4.3
C.V %	13.9	16.3	42.3

Means followed by the same letter down the column were not significantly different according to Tukey's Honestly Significant test, 5% level.

Table 3.16 Effects of leguminous green manure application to young coffee plants on coffee leaf water potential at midday (1992)

	Coffee leaf water potential (-bars)	
Sources of green manure	March 1992	August 1992
Leucaena intercrop	-14.7 ab	-15.2 ab
Leucaena purestand	-12.5 ab	-15.3 ab
Sesbania intercrop	-15.6 a	-13.7 b
Sesbania purestand	-14.5 ab	-15.5 ab
Calliandra intercrop	-11.5 b	-18.3 a
Calliandra purestand	-13.5 ab	-14.7 b
Desmodium intercrop	-13.0 ab	-16.7 ab
Lucerne intercrop	-14.9 ab	-15.9 ab
Pigeonpea intercrop	-14.2 ab	-14.8 b
Napier grass mulch	-14.2 ab	-13.8 b
Cattle manure	-14.3 ab	-16.7 ab
Inorganic nitrogen	-15.2 a	-14.1 b
Unfertilized control	-14.0 a	-16.7 ab
Mean	-14.0	-15.5
S.E.D (24 df)	1 4	1.25
C.V %	12.4	10.4

Means followed by the same letter down the column were not significantly different according to Tukey's Honestly Significant test, 5% level.

Table 3.17: Effects of leguminous green manure application to young coffee plants on total primaries, nodes and nodes and number of bearing nodes (Jan -Dec 1992)

Treatments	Total primaries	Bearing primaries	Total nodes per primary	Bearing nodes per primary
Leucaena intercrop	19 abc	3 cde	14 abc	0 d
Leucaena purestand	19 abc	4 cde	10 c	3 a-d
Sesbania intercrop	18 abc	1 e	10 c	2 a-d
Sesbania purestand	20 ab	16 a	15 ab	7 abc
Calliandra intercrop	20 ab	4 cde	13 abc	0 d
Calliandra purestand	19 abc	7 b-e	15 ab	5 a-d
Desmodium intercrop	13 c	0 e	10 c	0 d
Lucerne intercrop	15 bc	2 de	12 abc	1 cd
Pigeonpea intercrop	16 bc	0 e	13 abc	1 cd
Napier grass mulch	18 abc	11 abc	12 abc	7 ab
Cattle manure	18 abc	8 bcd	16 a	4 a-d
Inorganic nitrogen	22 a	12 ab	15 ab	8 a
Unfertilized control	21 ab	3 de	15 ab	2 bcd
Mean	18	5	13	3
S.E.D (24 df)	2.5	3.1	2.1	2.3
C.V %	16.5	70.5	19.7	92.5

Means followed by the same letter down the column were not significantly different according to Tukey's Honestly Significant test, 5% level.

Table 3.18: Effects of leguminous green manure application to young coffee plants on total and bearing primaries branches (1993)

Source of green manure	Total primaries	Bearing primaries
Leucaena intercrop	44 a	34 ab
Leucaena purestand	42 a	34 ab
Sesbania intercrop	38 ab	32 ab
Sesbania purestand	52 a	25 b
Calliandra intercrop	44 a	28 ab
Calliandra purestand	46 a	32 ab
Desmodium intercrop	26 b	32 ab
Lucerne intercrop	42 a	31 ab
Pigeonpea intercrop	40 a	34 ab
Napier grass mulch	54 a	28 ab
Cattle manure	48 a	20 b
Inorganic nitrogen	46 a	29 b
Unfertilized control	46 a	39 a
Mean	44	30
S.E.D (24 df)	3.5	5.6
C.V %	19.7	44

Means followed by the same letter down the column were not significantly different according to Tukey's Honestly Significant test, 5% level.

3.3.8.2 Bearing primaries: In the first year, application of the green manures except that from sesbania from purestand decreased significantly the number of bearing primaries per coffee plant than top dressing with nitrogen fertilizer (Table 3.17). In the second year, application of green manures and nitrogen fertilizer did not significantly affect the number of bearing primaries per coffee plant (Table 3.18).

3.3.8.3 Total number of nodes per primary: In the first year, application of green manures from leucaena from purestand and sesbania and desmodium from intercrop reduced significantly the number of nodes per primary than the application of nitrogen fertilizer (Table 3.17). Application of green manures and nitrogen fertilizer did not significantly affect the number of nodes per primary during the second year.

3.3.8.3 Bearing nodes per primary: During the first year, application of green manures from leucaena, calliandra, desmodium lucerne and pigeonpea from intercrop significantly reduced the number of bearing nodes per primary (Table 3.17). The application of green manures to coffee plants did not affect significantly the number of bearing nodes during the second year of manure application (Tabble 3.18).

3.3.9 Effect of green manures on yields of clean coffee beans

Application of green manures from leucaena, sesbania, desmodium and pigeonpea intercrops significantly decreased yields of clean coffee for the first coffee crop after establishment than top dressing the coffee plants with

Table 3.19: The effect of leguminous green manure application to young coffee plants on the first yield of clean coffee and percent grade 'A' beans (1993)

Source of green manure	Clean coffee yield kg/ha	Percent grade 'A' beans	Percent yield depression
Leucaena intercrop	100 d	33.3 bcd	80.0
Leucaena purestand	297 a-d	46.3 a-d	46.6
Sesbania intercrop	156 cd	33.3 bcd	68.8
Sesbania purestand	217 bcd	72.2 abc	56.6
Calliandra intercrop	305 a-d	65.1 abcd	39.0
Calliandra purestand	305 a-d	67.6 abc	39.0
Desmodium intercrop	63 d	25.0 cd	87.4
Lucerne intercrop	190 bcd	44.4 a-d	62.0
Pigeonpea intercrop	63 d	16.7 d	87.4
Napier grass mulch	583 a	78.3 ab	(16.6)
Cattle manure	308 a-d	85.5 a	38.8
Inorganic nitrogen	500 ab	80.8 ab	0
Unfertilized control	453 abc	49.1 a-d	9.4
Mean	272	53.7	
SED (24 df)	142	20.8	
C.V. %	64.1	47.5	

Means followed by the same letter down the column were not significantly different according to Tukey's Honestly Significant test, 5% level.

nitrogen fertilizer (Table 3.19). Application of the other green manures did not significantly reduce the yields clean coffee.

3.3.10 Effect of green manures on coffee bean size and liquor attributes

Application of green manure from desmodium and pigeon pea decreased significantly the grade A sized beans than top dressing with nitrogen fertilizer (Table 3.19). The application of green manures and nitrogen fertilizer to coffee did not significantly affect the raw and roast bean quality or the liquor acidity, body and flavour.

3.4 Discussion

3.4.1 Green manure decomposition and N mineralization

The amount of available nitrogen released by the green manures is determined by the rate of N-mineralization. In the current study most of the green manures had relatively high rates of decomposition. *Desmodium intortum*, though it had a high nitrogen yield, exhibited very low decomposition and N-mineralization rates, releasing only 25% of the initial nitrogen after 11 weeks of decomposition. Hence, the high inherent nitrogen in the manure may not be all available to coffee in the short run. On the other hand, leucaena and lucerne green manures had slightly lower nitrogen yield but better N-mineralization rates. The green manures from leucaena, calliandra and lucerne released 50% of their initial nitrogen concentration within four weeks of decomposition. This concurred with the findings of Mulongoy (1983) who reported that more than 50% of initial nitrogen in leucaena was released in 4 weeks of decomposition. In this study the green manures potential nitrogen yield ranged from 262 - 780 kg/ha/year. If 50% of this potential nitrogen is mineralized and released to the soil, the available nitrogen would then range from 130 - 390 kg N /ha/year. The above model assumes ideal conditions for decomposition and mineralization which may not exist in the field. Still, some of the nitrogen mineralized would be lost through leaching and volatilization. Therefore the amount of nitrogen available to coffee will be less than the total amount mineralized. Coffee requires between 100 -160 kg N/ha/year (Mwangi, 1983; Njoroge, 1991). From the observed results in this study the coffee nitrogen requirements may be met by the green manures except that from desmodium green manure.

The peak nitrogen demand occurs after the onset of the rains and for the best results nitrogenous fertilizers should be applied during the rains (Oruko, 1977; Michori, 1981). This is the period that the coffee fruits are in the rapid expansion stage (Willson, 1985b). The photosynthetic rates at this time should be at the peak and nitrogen is essential for photosynthesis (Willson, 1985b). It is therefore important to time the application of the green manure such that maximum nitrogen release corresponds with the peak nitrogen demand. The application of the green manure during the rainy season would be ideal for quicker decomposition. This is because for proper decomposition of the green manures there should be adequate moisture in the soil (Chela and Gill, 1979). The green manures releasing 50% of the available nitrogen in 4 weeks would therefore be applied at the beginning of rainy seasons. This would correspond with April and May/June split applications of nitrogen (Njoroge, 1985a). The other application would be done in October to coincide with the November nitrogen application. It therefore means that the green manure plants may be harvested 3 - 4 times a year to provide green manure.

3.4.2 Soil and leaf nutrient concentrations

The use of green manures in coffee resulted in a significant reduction in soil bulk density. The reduction in bulk density may be attributed to the addition of organic matter by the green manures as was indicated by the increase in soil organic carbon. Addition of organic materials to soils has been observed to lead to a decrease in soil bulk density (MacRae and Mehuys, 1985; Boparai *et al.*, 1992). Due to this effect, Yadvinder *et al.*, (1991), reported that the soil physical parameters most likely to be affected by green manuring are aggregate stability and bulk density. The results from this study confirmed that use of green manures resulted in lowering the soil bulk density.

Application of green manures to coffee plants was observed to lead to a significant increase in soil acidity. This acidification effect could be attributed to the addition of nitrogen rich green manures. Suarez and Panchan, (1976) and Szott *et al.*, (1991) observed that the application of nitrogen rich organic materials and green manures to rice fields tended to increase soil acidity. They attributed this acidification to the release of organic acids and ammonia by the decomposing green manures.

Although it is often assumed that green manures do increase soil nutrients, (Nyamai, 1990a; Sanchez *et al.*, 1989) this was found not to be the case in this study. The soil nutrients were observed to have declined with time. This concurs with the findings of Szott *et al.*, (1991) who reported a similar decline in plant nutrients after using green manures in rice and indicated that the decline could have been probably due to the fact that the nutrients applied are retained in organic and inorganic forms not detectable by the analysis methods used, or they are removed rapidly by the crop. All these factors could have attributed to the observed decline in soil nutrients.

3.4.3 Plant growth

Most of the green manures applied to young coffee plants did not affect coffee plant growth. However, intercropping coffee plants with desmodium plants as sources of green manure adversely affected the height, stem diameter and length of the primary branches of coffee plants. Desmodium being a creeping plant had a choking effect on the young coffee plants. Even though the desmodium plants were trimmed regularly the plant tended to grow more vigorously around the coffee plant probably due to the effect of cattle manure used in planting coffee. This interfered with the coffee plant growth. Similar effects were observed when young coffee plants were intercropped with sweet potatoes in Kenya (Njoroge and Kimemia, 1995).

Application of cattle manure and napier grass to coffee plants significantly increased the coffee leaf expansion. This could be attributed to high level of soil potassium observed in coffee plots applied with these manures. Use of potassium rich organic materials was reported to lead to the production of large and shiny leaves in coffee (Hutchnison, 1965). Leaves are the main photosynthic sites and yields are directly related to the leaf area (Salisbury and Ross, 1986). In this study coffee plants that were applied with napier grass had bigger leaves and significantly higher yields of clean coffee than those that had been applied with green manures.

3.4.4 Clean coffee yield, size of coffee beans and liquor attributes

Application of green manures to coffee plants significantly depressed yields of clean coffee. This could be attributed to a number of factors. Firstly, intercropping coffee plants with some of the green manure crops like desmodium, lucerne and sesbania significantly reduced coffee growth (height, primary length) and yield components (bearing primaries and nodes). The yields of coffee bean are mainly determined by plant growth and components of yield like primary branches and bearing nodes (Cannell, 1985). The growth of both the vertical and horizontal brar :he determine the amount of productive wood and hence the coffee bean ielc (Reffye, 1981). Any factor that affects the growth of the plant consequently affects the yields of coffee beans. The adverse effect of the green manure crops on coffee plant growth could therefore have affected the yields of clean coffee.

Secondly, the amount of nutrients released by the green manures may not have been adequate for both coffee and the green manure plants leading to competition. Yadvinder *et al.*, 1991 found out that the amount of nutrients released by decomposing lucaena plants was not adequate to support both the green manure and wetland rice. Despite the continuous application of the green manures, the soil nutrient levels were observed to decline with time. This indicates that the application of the green manures was not replacing all the nutrients removed from the soil by the coffee plants.

Thirdly, the use of green manures resulted in increase in soil acidification. Low soil pH affects the nutrient uptake, particulary nitrogen leading to low yields (Willson, 1985 b). To overcome this problem liming is recommended.

The beneficial effects of low soil bulk density (easier root penetration, better water infiltration and more production of root hairs) (Willson, 1985 a) were probably nullified by the decline in soil nutrients and soil acidification.

Application of most the green manures did not affect adversely the grade a sized beans. However, application of desmodium and pigeonpea green manures significantly reduced the percent of grade `A' sized beans. There was also a tendency to have more grade `A' sized beans where coffee plants were applied with leucaena and sesbania green manure from purestand. Coffee beans from coffee plants applied with nitrogen fertilizer and cattle manure tends to have a higher percentage of grade A sized beans (Njoroge, 1985 a). Large beans in Kenya have been reported to contribute to high coffee quality (Kamau, 1976). Application of green manures and nitrogen did not affect the raw, roast and liquor quality. The overall assessment of beans raw, roast, acidity, body and flavour indicated that the beans were of Fair Average Quality (FAQ), light, light medium and FAQ. These observations concurred with the findings of Gathaara and Kiara (1990) who observed that fertilizers do not influence the organoleptic characteristics of coffee beans.

3.5 Conclusions

Results from the green manure application experiment showed that it is possible to meet nutrition requirements of young newly established coffee through the application of the green manures from the various sources except that from desmodium. Application of green manure from desmodium significantly reduced the coffee plant height, plant diameter, number of primaries and nodes. Furthermore, the green manure from this plant had very low rates of decomposition and nitrogen mineralization. It was, therefore, found not to be a suitable source of green manure for young coffee plants.

Continuous application of the green manures to coffee plants resulted in a significant decline in soil plant nutrients and an increase in soil acidity. This had adverse effect on the young coffee plants nutrition and hence the first crop yield of clean coffee. The use of the green manures was found to reduce significantly the yield of clean coffee. They can be therefore be recommended to be used in young coffee where the nutrient requirement is not very high. However, their use improved the soil structure through an increase in the soil carbon and a reduction in soil bulk density. The use of the green manures can therefore be recommended for soil structure improvement purposes only. More work on substitution of inorganic fertilizers with green manures is suggested.

CHAPTER 4

THE INFLUENCE OF INTERCROPPING *Coffea arabica L* WITH PERENNIAL FRUIT TREES ON YOUNG COFFEE PLANT GROWTH, CLEAN COFFEE YIELD AND QUALITY

4.1 Introduction

In Kenya, coffee farmers, especially the small scale ones have for the past years intercropped their coffee with various food and fruit crops and timber trees despite an official government ban under the Coffee Act of 1979. The main fruit trees intercropped with coffee include macadamia *(Macadamia* spp)., citrus *(Citrus* spp)., bananas *(Musa* spp)., mangoes *(Mangifera indica)* and papaws *(Carica papaya)* (Mukunya and Keya, 1975; Whittaker, 1986). Coffee has been intercropped with bananas in Papua New Guinea and Uganda (Bourke, 1985; Oduol and Aluma, 1990), with oranges and avocadoes in the Andes mountains (Escalante, 1985).

The main expectations from such intercropping systems is that the overall return from a unit of land is increased without adversely affecting the current or the long-term productivity of the coffee crop (Liyanage, *et al.*, 1984). Intercropping coffee with other perennial crops would increase light use efficiency due to the combined canopy (Natarajan and Willey, 1980) and utilization of light at different layers (Steiner, 1982). There would also be better water use efficiency mainly by utilizing water at different depths in the soil as some of the component crops may be deeper rooted than coffee. There is also likely to be better utilization of nutrients as there is evidence of increased uptake of the main nutrients by intercrops more than the sole crops (Liboon and Harwood, 1975; De, 1980; Reddy and Willey, 1981).

Most research in intercropping systems in coffee have been focused on annual crops (Mwakha, 1987; Njoroge and Kimemia, 1993). There is, therefore, need to study the effect of perennial tree crops on coffee with a view of formulating a field management package for use by the small scale farmers. This study was focused on the effects of fruit trees intercropped with coffee during the first production cycle after field establishment.

4.2 Materials and Methods

4.2.1 Site

The trial was conducted at Coffee Research Station, Ruiru, from May 1991 to December 1993. The site description and land preparation procedures were as described in Chapter 3. The weather data during the trial period are as described in Chapter 3. The soil at the beginning of the trial had a pH of 4.9, 73 ppm P, 1.38 m.e % K, 3.75 m.e % Ca, 2.37 m.e% Mg and a Ca + Mg/K ratio of 5.66.

4.2.2 Treatments

Arabica coffee cultivars Ruiru 11 and SL 28 were used in the study. Both the coffee and fruit trees were planted in May 1989. Nine fruit crops: bananas (*Musa sapientum)*, papaws *(Carica papaya)*, Guava *(Psidium* *guajava)*, loquats *(Eriobotrya japonica)*, avocadoes *(Persea americana)*, oranges *(Citrus sinesis)*, passion fruit *(Passiflora edulis)*, macadamia *(Macadamia ternifolia)* and apples *(Malus pumila)* were intercropped with newly established coffee. The treatments and planting methodology of fruit trees are shown in Table 4.1 and Appendix 6.

4.2.3 Experimental design

Treatments were laid out in a split plot design with three replicates. The coffee cultivars formed the main plots while the fruit tree treatments were the subplots. The subplot consisted of four rows of either eight Ruiru 11 plants (84 m^2) or four rows of six SL 28 trees (112 m^2). Six central coffee plants in each plot were selected for growth and yield data. The field layout is shown in Appendix 6.

4.2.4 Cultural practices

Ruiru 11 coffee variety was planted at a spacing of 2 m x 2 m, while `SL 28' was at a spacing of 2.74 x 2.74 m. Coffee and fruit trees were planted in holes of 60 x 60 x 60 cm. The soil was mixed with 13 kg of cattle manure and 100g P_2O_5 per hole. Coffee trees were fertilized with 50kg N/ha/year during the first year and 100 kg N/ha/year in subsequent years. The application was in three splits a year in April, May and November. Both coffee varieties were raised on one head and free growth pruning system. In this system there was minimal handling with only the primary branches touching the ground, unnecessary branches and suckers removed four times in a year (February, May, August and December). The cultivar `SL

Table 4.1: Planting methodology of fruit trees during the study

Crop	Variety	Spacing (m)	
		SL 28	Ruiru 11
1. Pawpaws	Kiru	3 x 3	2 x 2
2. Passion fruit	purple	3 x 3	2 x 2
3. Apples	Winter Banana	3 x 3	2 x 2
4. Oranges	Washington Navel	4 x 4	6 x 6
5. Bananas	Lectern	4 x 4	6 x 6
6. Guava	Red Flesh	4 x 4	6 x 6
7. Avocadoes	Fuerte	4 x 4	6 x 6
8. Loquats	local	4 x 4	6 x 6
9 Macadamia	KRG-1	4 x 4	6 x 6

28' was protected against coffee berry disease caused by *Colletotrichum kahawae* (Waller and Bridge), and coffee leaf rust caused by *Hemileia vastatrix* (Berk et Br.), with fungicidal sprays (tank mixtures of 5.5 kg/ha of copper + 2.2 kg/ha of daconil in a 1000 litres of water) in February, March, April, May, June, July, October and November. Ruiru 11 being resistant to those two diseases was not sprayed.

Fruit trees were planted in the coffee interrows at the centre of four coffee trees . They were planted at their purestand recommended spacings Anon (1981) as shown in Table 4.1. After one year, the fruit trees were pruned to remove interlocking branches and excessive wood twice in a year as recommended by Anon (1981). The lower branches were also pruned off. Fruit trees were protected against diseases and pests as per recommendations of Ministry of Agriculture (Anon, 1981 and Anon, 1984). The main diseases were powdery mildew (*Oidium caricae)* and *(Podosphaera leucotricha)* in pawpaws and apples respectively which were controlled by application of fungicidal sprays. The main pests were green (*Coccus viridis)* and brown *(Coccus hesperidium)* scales, citrus aphids *(Toxoptera citricidus)* and *(Toxoptera aurantii)* in citrus, fruit fly in guavas, and Kenya mealybug *(Planococcus kenyae)* in passion fruit. These pests were controlled by application of Ethion 20% at the rate of 1000 ml per 20 l of water when necessary.

4.2.5 Data collection

4.2.5.1 Soil and leaf nutrient analysis: The analysis method of soil and leaf nutrients were as described in Chapter 3. Soil samples were taken in the space between the coffee and fruit trees. Leaf sampling was done the selected central coffee plants as described in Chapter 3.

4.2.5.2 Soil Water holding capacity: Soil samples were taken from the space between the fruit trees and coffee plants. Soil moisture determination was done as described in Chapter 3.

4.2.5.3 Coffee growth parameters: The methodology and calculation of coffee growth parameters were as described in Chapter 3. Six central coffee plants were used per plot.

4.2.5.4 Leaf water potential: This was measured as described in Chapter 3. Six leaves from the central trees which had been selected for growth recording per plot were used. The leaves were sampled from the middle canopy. The leaf water potential was determined at midday (12.00 - 13.00 hours East African time) during the dry months.

4.2.5.5 Amount of light on top of coffee canopy: This was measured using a Decagon Sunfleck Ceptometer model SF-80 from Delta-T United Kingdom. Only the photosynthetically active radiation (PAR), 400 - 700nm was measured. The recordings was done once in a month at midday. The percentage amount of light reaching the coffee was calculated from the following equation:

$(I_i / I_o)100$ where

I_i = Amount of light recorded on top of coffee canopy

I_o = Amount of light (PAR) measured in the open

4.2.5.6 Yields components of Coffee: These were the number of bearing primaries per plant and number of bearing nodes per primary. These were recorded as described in Chapter 3.

4.2.5.7 Yields and quality of Coffee: The yield and quality of coffee was determined as in Chapter 3.

4.2.5.8 Yields of fruits: The fruits were harvested when ripe and the yield recorded. The total fruits harvested in a year were calculated and converted to yield per hectare for three years.

4.2.5.9 Net benefits: The net benefits for both the coffee and food crops were determined as described by Perrin, *et al.*, (1986)

4.2.6 Data analysis

The data collected was subjected to analysis of variance for split plot design (Gomez and Gomez, 1984) using MSTAT computer package (Smail, *et al.*, 1984). The Anova tables are shown in Appendix 7.1 - 7.10.

4.3 Results

4.3.1 Effect of fruit intercrops on coffee plant growth

4.3.1.1 Height, diameter and primary length: Throughout the study period, the intercropping did not significantly affect the actual increase in coffee plant height, stem diameter and primary length.

4.3.1.2 Coffee plant leaf area expansion: During the first year of study intercropping did not significantly affect the actual increase in coffee plant leaf area (Table 4.2). Between June and December 1992, the leaf area of Ruiru 11 coffee plants intercropped with bananas increased significantly more than leaf area of sole coffee plants (Table 4.3). The increase in leaf area was not significantly affected by the intercropping during the other recording dates (Tables 4.3 and 4.4).

4.3.2 Effect of fruit tree intercrops on soil water status

In March 1993, there was significantly more moisture in the top soil of plots where coffee plants were intercropped with bananas and passion fruit than in the sole coffee plots (Table 4.5). In the month of September 1993, there was significantly more soil moisture in the pure stand Ruiru 11 coffee plot than in those plots where Ruiru 11 coffee plants were intercropped with pawpaw, oranges, avocadoes and macadamia (Table 4.5). During the same month plots of sole SL 28 had significantly more subsoil moisture than plots intercropped with pawpaw, passion fruit, apples, guavas, loquats and macadamia (Table 4.5).

Table 4.2: **Effect of fruit tree intercrops on actual increase in coffee plant leaf area (cm^2), (1991)**

	May - July 1991			October - Dec 1991		
Treatment	R11	SL28	Mean	R11	SL28	Mean
Coffee + pawpaw	42.1 ab	53.9 ab	48.0 ab	44.6 a-d	39.9 a-d	42.3 abc
Coffee + passion	40.1 b	44.4 ab	42.2 b	39.8 a-d	33.9 cd	36.9 c
Coffee + apples	66.6 a	57.4 ab	62.0 a	46.6 a-d	32.8 d	39.7 abc
Coffee + oranges	49.2 ab	51.0 ab	50.1 ab	57.1 ab	46.4 a-d	51.8 a
Coffee + bananas	47.0 ab	61.1 ab	54.1 ab	51.3 a-d	51.9 a-d	51.6 ab
Coffee + guavas	48.2 ab	63.2 ab	55.7 ab	47.9 a-d	47.3 a-d	47.6 abc
Coffee + avocadoes	53.5 ab	40.8 b	47.2 ab	59.1 a	40.4 a-d	49.8 abc
Coffee + loquats	58.3 ab	48.2 ab	53.2 ab	39.0 b-d	37.4 cd	38.2 bc
Coffee + macadamia	53.9 ab	45.1 ab	49.5 ab	47.1 a-d	35.7 cd	41.4 abc
Sole coffee	57.3 ab	62.4 ab	59.9 a	53.1 a-d	40.9 a-d	47.0 abc
Mean	51.6 a	52.8 a	52.2	48.6	40.6	44.6
SED Coffee Cultivar		2.98			1.68	
SED Fruit Trees		5.15			4.02	
SED Interaction		7.28			5.69	
CV%		24.3			22.1	

Means followed by the same letter down the column were not significantly different according to Tukey's Honestly Significant Test, 5% level.

Table 4.3: Effect of fruit tree intercrops on actual increase in coffee plant leaf area (cm^2), (1992)

	June - Sept 1992			October - Dec 1992		
Treatment	R11	SL28	Mean	R11	SL28	Mean
Coffee + pawpaw	48.7 ab	35.6 b-f	42.1 ab	18.4 abc	18.1 abc	18.2 ab
Coffee + passion	34.4 b-f	28.1 c-f	31.3 c	22.4 abc	17.1 abc	19.7 ab
Coffee + apples	37.7 b-f	29.1 c-f	33.4 bc	25.9 a	19.9 abc	22.9 ab
Coffee + oranges	38.4 b-d	23.8 f	31.1 c	15.6 abc	19.6 abc	17.6 ab
Coffee + bananas	57.3 a	37.1 b-f	47.2 a	24.1 a	22.9 abc	23.5 a
Coffee + guavas	34.8 b-f	27.9 c-f	31.3 c	23.5 ab	17.2 abc	20.3 ab
Coffee + avocadoes	32.0 c-f	25.7 d-f	28.9 c	25.3 a	16.4 abc	20.9 ab
Coffee + loquats	41.3 bc	30.1 c-f	35.7 bc	17.7 abc	15.0 abc	16.3 ab
Coffee + macadamia	37.2 b-f	39.6 b-d	38.4 a-d	25.4 a	12.4 bc	18.9 ab
Sole coffee	36.9 c-f	35.8 b-f	36.4 bc	26.4 a	16.4 abc	21.4 ab
Mean	39.9 a	31.3 b	35.6	22.9	17.5	20.0
SED Coffee Cultivar		0.60			1.67	
SED Fruit Trees		2.97			2.37	
SED Interaction		4.20			2.35	
C.V. %		20.6			29.7	

Means followed by the same letter down the column were not significantly different according to Tukey's Honestly Significant Test, 5% level.

Table 4.4: Effect of fruit tree intercrops on actual increase in coffee plant leaf area (cm^2), (1993)

	Feb - April 1993			June - August 1993		
Treatment	R11	SL28	Mean	R11	SL28	Mean
Coffee + pawpaw	41.9 ab	37.5 b	39.7 ab	42.8 ab	36.6 a-d	39.1 a
Coffee + passion	33.7 b	33.0 b	33.4 b	37.6 a-d	29.9 a-d	33.8 a
Coffee + apples	30.1 b	36.7 b	33.4 b	32.9 a-d	29.6 a-d	31.3 a
Coffee + oranges	40.8 ab	40.9 ab	40.9 ab	35.9 a-d	28.6 a-d	32.2 a
Coffee + bananas	55.2 a	37.8 b	46.5 a	44.2 a	28.5 a-d	36.4 a
Coffee + guavas	43.7 ab	34.7 b	39.2 ab	44.2 a	23.2 d	33.7 a
Coffee + avocadoes	41.2 ab	39.2 b	40.2 ab	35.6 a-d	25.6 cd	30.6 a
Coffee + loquats	40.3 ab	37.1 b	38.7 ab	41.0 abc	28.2 a-d	34.6 a
Coffee + macadamia	35.4 b	39.8 ab	37.6 ab	38.2 a-d	26.8 b-d	32.5 a
Sole coffee	39.6 ab	42.5 ab	41.1 ab	39.9 abc	28.5 a-d	34.2 a
Mean	40.2 a	37.9 b	39.1	39.2 a	28.6 b	33.9
SED Coffee Cultivar		1.01			1.16	
SED Fruit Trees		3.29			3.37	
SED Interaction		4.65			4.77	
CV %		21.0			24.5	

Means followed by the same letter down the column were not significantly different according to Tukey's Honestly Significant Test, 5% level.

Table 4.5: Effect of fruit tree intercroppped with coffee plants on soil moisture, (1993)

	Soil moisture (%)								
	March 1993			September 1993			December 1993		
Treatment	R11	SL28	Mean	R11	SL28	Mean	R11	SL28	Mean
Coffee + pawpaw	19.8	21.7	20.7 ab	19.2 d	20.2 cd	19.7 e	19.7 abc	19.04 abcd	19.38 ab
Coffee + passion	20.9	21.5	21.2 a	20.2 b-d	20.4 bcd	20.4 b-e	19.5 a-d	20.90 abd	20.22 a
Coffee + apples	19.8	19.7	19.8 ab	21.3 a-d	19.1 d	20.5 b-e	19.9 abc	19.0 a-d	19.4 ab
Coffee + oranges	20.4	19.1	19.7 ab	19.6 d	21.2 a-d	20.4	19.7 abc	19.1 a-d	19.4 ab
Coffee + bananas	21.7	21.6	21.7 a	21.7 a-d	22.1 a-d	21.9	20.5 abc	20.5 abc	20.5 a
Coffee + guavas	20.6	19.8	20.2 ab	20.4 a-d	19.4 d	19.8 c-e	16.1 d	18.5 a-d	17.3 b
Coffee + avocadoes	18.9	20.9	19.9 ab	19.8 d	21.9 a-d	20.8 b-e	20.0 abc	19.9 abc	20.0 a
Coffee + loquats	19.8	19.7	19.8 ab	20.2 a-d	19.6 d	20.2 b-e	18.1 a-d	20.1 abc	19.1 ab
Coffee + macadamia	18.9	20.8	19.9 ab	19.2 d	19.4 d	19.3 e	17.5 bcd	21.4 a	19.5 ab
Sole coffee	18.9	18.9	18.9 b	23.3 ab	23.5 a	23.4 a	20.6 abc	17.3 cd	19.0 ab
Mean	20.0	20.4	20.2	20.7	20.8	20.8	19.1 a	19.6 a	19.4
SED									
Coffee Cultivar		0.4			0.06			1.04	
Fruit trees		0.9			0.62			1.02	
Interactions		1.2			0.87			1.45	
C.V. %		7.5			7.2			9.2	

Means followed by the same letter down the column were not significantly different according to Tukey's *Honestly Significant Test, 5% level.*

4.3.3 Effect fruit tree intercrops on coffee leaf water potential

Throughout the study period the coffee leaf water potential at midday was not significantly affected by the intercrops. The leaf water potential ranged between -16.7 - -29.6 bars.

4.3.4 Light interception by the fruit trees

During the second and third years of study bananas and guavas were intercepting significantly more photosynthetically active radiation than oranges and pawpaws (Table 4.6). There were no significant differences between the other intercropping treatments.

4.3.5 Effect of fruit tree intercrops on soil chemical properties

4.3.5.1 Soil pH: Throughout the study period, both the top and subsoil pH was not significantly affected by the intercrops and averaged 4.4.

4.3.5.2 Exchangeable Acidity (Hp): In December 1991 both the top and subsoil exchangeable acidity was significantly lower in coffee plots intercropped with pawpaw and guava than in the sole coffee plots (Table 4.7 and 4.8).

In September 1993, the top and subsoil of coffee plots intercropped with guava had significantly higher exchangeable acidity (Tables 4.9 and 4.10).

4.3.5.3 Soil nutrients: The soil potassium level in both the top and sub soil was not significantly affected by the intercrops in December 1991.

Table 4.6: Effect of fruit tree intercrops on mean percentage light reaching the top of coffee canopy at midday (January 1992 - November 1993)

Treatment	1992	1993
Coffee + pawpaw	70.2ab	75.0a
Coffee + passion	83.8ab	58.9ab
Coffee + apples	75.7ab	71.3ab
Coffee + oranges	89.5a	80.9a
Coffee + bananas	37.6d	55.0ab
Coffee + guavas	15.9e	14.3c
Coffee + avocadoes	24.2de	38.5bc
Coffee + loquats	33.4de	13.7c
Coffee + macadamia	45.2cd	46.9abc
Mean	41.8	47.4
SED Fruit trees	9.3	11.7
C.V %	23.3	39.7

Means followed by the same letter down the column were not significantly different according to Tukey's Honestly Significant Test, 5% level.

Table 4.7: Effect of fruit tree intercropped with coffee on top soil chemical properties (December 1991)

Treatment	Soil Hp			Na m.e%			Ca m.e%		
	R11	SL28	Mean	R11	SL28	Mean	R11	SL28	Mean
Coffee + pawpaw	0.25 bcd	0.50 a	0.38 a	0.10 abc	0.07 c	0.09 abc	3.8 abc	2.3 c	3.1 b
Coffee + passion	0.15 cd	0.23 bcd	0.19 bc	0.09 abc	0.06 c	0.08 abc	4.7 abc	5.5 abc	5.1 ab
Coffee + apples	0.21 bcd	0.21 bcd	0.21 bc	0.09 abc	0.15 a	0.12 a	5.1 abc	5.5 abc	5.3 ab
Coffee + oranges	0.22 bcd	0.21 bcd	0.22 bc	0.09 abc	0.07 c	0.08 abc	4.3 abc	3.3 bc	3.8 b
Coffee + bananas	0.25 bcd	0.36 abc	0.31 abc	0.09 abc	0.14 ab	0.12 a	5.3 abc	4.4 abc	4.9 ab
Coffee + guava	0.34 a-d	0.33 a-d	0.34 ab	0.08 c	0.07 c	0.07 bc	3.1 bc	2.5 bc	2.8 b
Coffee + avocadoes	0.22 bcd	0.13 d	0.17 c	0.09 abc	0.08 c	0.09 abc	4.6 abc	4.4 abc	4.5 ab
Coffee + loquats	0.22 bcd	0.36 abc	0.29 abc	0.07 c	0.08 c	0.07 c	4.3 abc	4.8 abc	4.6 ab
Coffee + macadamia	0.27 bcd	0.22 bcd	0.25 abc	0.07 c	0.09 abc	0.08 abc	2.7 bc	6.3 ab	4.5 ab
Sole coffee	0.14 cd	0.18 bcd	0.16 c	0.09 abc	0.08 c	0.08 abc	7.2 a	5.7 abc	6.5 a
Mean	0.23 a	0.28 a	0.26	0.08	0.09	0.08	4.4	4.4	4.4
SED Coffee cultivar		0.03			0.01			0.4	
SED Fruit trees		0.05			0.02			0.8	
SED interaction		0.06			0.18			1.1	
C.V %		43.7			43.3			43.6	

Means followed by the same letter down the column were not significantly different according to Tukey's Honestly *Significant Test, 5% level.*

Table 4.7 continued..

Treatment	Mg m.e%			P ppm		
	R11	SL28	Mean	R11	SL28	Mean
Coffee + pawpaw	2.7 ab	2.7 ab	2.7 ab	72 ab	65 b	69 b
Coffee + passion	2.8 ab	3.0 ab	2.9 ab	78 ab	75 ab	77 ab
Coffee + apples	2.8 ab	2.8 ab	2.8 ab	81 ab	78 ab	80 ab
Coffee + oranges	3.0 ab	2.6 ab	2.8 ab	83 ab	73 ab	78 ab
Coffee + bananas	3.4 ab	3.2 ab	3.3 ab	85 ab	73 ab	79 ab
Coffee + guava	2.5 ab	2.7 ab	2.6 b	69 ab	68 ab	69 b
Coffee + avocadoes	3.1 ab	2.8 ab	2.9 ab	70 ab	70 ab	70 b
Coffee + loquats	3.0 ab	3.0 ab	3.0 ab	82 ab	74 ab	78 ab
Coffee + macadamia	2.4 ab	3.8 a	3.1 ab	65 b	87 ab	76 ab
Sole coffee	3.8 a	3.6 ab	3.7 a	96 a	82 ab	89 a
Mean	2.9 a	3.0 a	2.9	77	74	76
SED Coffee cultivar			0.08		4.3	
SED Fruit trees			0.31		6.0	
SED Interaction			0.44		8.1	
C.V %			26.1		18.5	

Means followed by the same letter down the column were not significantly different according to Tukey's Honestly *Significant Test, 5% level.*

Table 4.8: Effect of fruit trees intercropped with coffee plants on sub soil chemical properties (December 1991)

Treatment	Hp m.e%			Na m.e%			Mg m.e%		
	R11	SL28	Mean	R11	SL28	Mean	R11	SL28	Mean
Coffee + pawpaw	0.38 ab	0.33 ab	0.35 a	0.07 ab	0.06 b	0.06	2.4 b	2.8 ab	2.6 ab
Coffee + passion	0.18 ab	0.26 ab	0.22 ab	0.07 ab	0.06 b	0.07	2.6 ab	2.3 b	2.5 ab
Coffee + apples	0.22 ab	0.21 ab	0.22 ab	0.08 ab	0.13 a	0.10	2.6 ab	3.3 ab	3.0 ab
Coffee + oranges	0.23 ab	0.23 ab	0.23 ab	0.07 ab	0.12 ab	0.09	2.9 ab	2.5 ab	2.7 ab
Coffee + bananas	0.28 ab	0.32 ab	0.30 ab	0.08 ab	0.08 ab	0.08	3.0 ab	2.6 ab	2.8 ab
Coffee + guava	0.22 ab	0.35 ab	0.29 ab	0.07 ab	0.08 ab	0.08	2.7 ab	2.4 b	2.5 ab
Coffee + avocadoes	0.37 ab	0.34 ab	0.36 a	0.07 ab	0.06 b	0.08	2.4 ab	2.2 b	2.3 b
Coffee + loquats	0.25 ab	0.25 ab	0.25 ab	0.06 b	0.07 ab	0.06	2.8 ab	3.0 ab	2.9 ab
Coffee + macadamia	0.39 a	0.22 ab	0.30 ab	0.10 ab	0.08 ab	0.09	2.3 b	3.0 ab	2.6 ab
Sole coffee	0.18 ab	0.14 b	0.16 b	0.09 ab	0.11 ab	0.10	3.7 a	2.8 ab	3.3 a
Mean	0.27	0.27	0.27	0.08	0.08	0.08	2.7	2.7	2.7
SED Coffee cultivar			0.02		0.01			0.26	
SED Fruit trees			0.05		0.01			0.19	
SED Interaction			0.07		0.02			0.37	
C.V. %			46.5		47.2			24.0	

Means followed by the same letter down the column were not significantly different according to Tukey's Honestly *Significant Test, 5% level.*

Table 4.8 continued..

Treatment	Mn m.e%			Ca+Mg/K		
	R11	SL28	Mean	R11	SL28	Mean
Coffee + pawpaw	2.0 bc	2.4 abc	2.2 ab	5.1 b	5.5 b	5.3
Coffee + passion	2.1 bc	1.8 bc	1.9 b	4.8 b	5.2 b	5.0
Coffee + apples	2.1 bc	2.1 abc	2.1 ab	6.2 ab	8.0 ab	7.1
Coffee + oranges	2.0 bc	1.7 c	1.9 b	5.5 b	11.4 a	8.5
Coffee + bananas	2.2 abc	2.3 abc	2.2 ab	6.7 ab	5.1 b	5.9
Coffee + guava	2.3 abc	2.9 a	2.6 a	6.1 ab	4.2 b	5.2
Coffee + avocadoes	2.3 abc	2.1 bc	2.2 ab	5.0 b	5.2 b	5.1
Coffee + loquats	2.1 bc	2.2 abc	2.1 ab	5.7 b	7.2 ab	6.5
Coffee + macadamia	2.5 ab	1.9 bc	2.2 ab	4.2 b	6.1 ab	5.2
Sole coffee	2.0 bc	1.7 c	1.9 b	8.2 ab	5.5 b	6.9
Mean	2.2	2.1	2.1	5.9	6.2	6.0
SED Coffee varieties			0.07		0.5	
SED Fruit trees			0.16		0.8	
SED Interaction			0.23		1.2	

Means followed by the same letter down the column were not significantly different accordin to Tukey's Honestly Significant Test, 5% level.

Table 4.9: Effect of fruit trees intercropped with coffee plants on top soil chemical properties (September 1993)

Treatment	Hp m.e%			K m.e%		
	R11	SL28	Mean	R11	SL28	Mean
Coffee + pawpaw	0.39 a	0.35 a	0.35 a	1.10 a	1.24 a	1.17 a
Coffee + passion	0.12 a	0.22 a	0.17 a	2.06 a	1.54 a	1.80 a
Coffee + apples	0.13 a	0.12 a	0.25 a	1.26 a	1.87 a	1.56 a
Coffee + oranges	0.12 a	0.23 a	0.13 a	1.16 a	1.12 a	1.14 a
Coffee + bananas	0.27 a	0.28 a	0.26 a	1.89 a	1.99 a	1.94 a
Coffee + guava	0.41 a	0.57 a	0.51 a	0.97 b	1.04 a	1.00 b
Coffee + avocadoes	0.65 a	0.10 b	0.36 a	1.10 a	1.49 a	1.29 a
Coffee + loquats	0.16 a	0.21 a	0.21 a	1.19 a	1.46 a	1.32 a
Coffee + macadamia	0.28 a	0.42 a	0.32 a	1.38 a	1.39 a	1.39 a
Sole coffee	0.17 a	0.17 a	0.12 a	1.17 a	1.42 a	1.30 a
Mean	0.25	0.27	0.26	1.32	1.42	1.38
SED Coffee cultivar		0.04			0.03	
SED Fruit trees		0.1			0.2	
SED Interactions		0.2			0.2	
C.V %		26.7			27.9	

Means followed by a similar letter within the coffee cultivar and fruit tree interactions and within the overall means were not significantly different according to Tukey's Significant Difference Test, 5% level.

Table 4.9 continued..

Treatment	Ca m.e%			Mn m.e%			P ppm			Ca+Mg/K		
	R11	SL28	Mean	R11	SL28	Mean	R11	SL28	Mean	R11	SL28	Mean
Coffee + pawpaw	3.17 a	3.93 a	3.55 a	0.82 a	0.94 a	0.88 a	49 b	54 a	51 a	4.74 a	5.34 a	5.04 a
Coffee + passion	5.67 a	4.90 a	5.28 a	0.96 a	0.81 a	0.89 a	81 a	59 a	70 a	4.42 a	5.00 a	4.71 a
Coffee + apples	4.43 a	6.13 a	5.28 a	0.93 a	0.95 a	0.94 a	60 a	70 a	65 a	5.47 a	5.47 a	5.47 a
Coffee + oranges	3.77 a	6.10 a	3.93 a	0.86 a	0.68 b	0.77 b	53 a	56 a	55 a	5.58 a	5.85 a	5.72 a
Coffee + bananas	4.27 a	3.63 a	3.95 a	0.95 a	0.73 b	0.84 a	62 a	53 a	57 a	3.97 a	2.87 b	3.42 b
Coffee + guava	3.03 a	2.37 b	2.70 b	0.92 a	0.90 a	0.91 a	52 a	43 b	47 b	5.42 a	4.42 a	4.92 a
Coffee + avocadoes	2.63 b	5.43 a	4.03 a	0.99 a	0.74 b	0.87 a	43 b	63 a	53 a	4.28 a	5.69 a	4.99 a
Coffee + loquats	4.47 a	4.70 a	4.58 a	0.95 a	0.87 a	0.91 a	62 a	61 a	61 a	6.07 a	5.04 a	5.55 a
Coffee + macadamia	4.50 a	3.73 a	4.12 a	1.07 a	0.98 a	1.02 a	63 a	54 a	59 a	5.37 a	4.50 a	4.93 a
Sole coffee	5.10 a	5.43 a	5.27 a	1.18 a	0.90 a	1.04 a	57 a	66 a	61 a	6.73 a	6.33 a	6.53 a
Mean	4.13	4.58	4.28	0.96	0.84	0.5	58	57	58	5.23	5.08	5.1
SED Coffee cultivar			0.2		0.09			0.5			0.2	
SED Fruit trees			0.7		0.07			6.1			0.6	
SED Interactions			1.0		0.09			8.7			0.9	
C.V. %			40.6		17.9			26.0			29.8	

Means followed by a similar letter within the coffee cultivar and fruit tree interactions and within the overall means were not significantly different according to Tukey's Significant Difference Test, 5% level.

Table 4.10 Effect of fruit trees intercropped Arabica coffee plants on sub soil chemical properties (September 1993)

Treatment	pH			Hp m.e%			K m.e%		
	R11	SL28	Mean	R11	SL28	Mean	R11	SL28	Mean
Coffee + pawpaw	5.1 a	5.2 a	5.1 a	0.47 a	0.23 a	0.35 a	0.94 a	1.14 a	1.04 a
Coffee + passion	5.2 a	5.2 a	5.2 a	0.12 a	0.23 a	0.17 a	1.74 a	1.38 a	1.56 a
Coffee + apples	5.3 a	5.0 a	5.2 a	0.11 a	0.40 a	0.25 a	1.10 a	1.15 a	1.12 a
Coffee + oranges	5.0 a	4.9 a	5.0 a	0.13 a	0.13 a	0.13 a	1.15 a	0.98 a	1.06 a
Coffee + bananas	5.2 a	4.9 a	5.1 a	0.07 a	0.44 a	0.26 a	1.08 a	1.29 a	1.18 a
Coffee + guava	4.8 a	4.5 a	4.6 a	0.33 a	0.69 a	0.51 a	0.87 a	0.83 a	0.85 a
Coffee + avocadoes	4.4 a	5.5 a	4.9 a	0.65 a	0.08 a	0.36 a	0.94 a	1.30 a	1.12 a
Coffee + loquats	5.2 a	5.0 a	5.1 a	0.15 a	0.27 a	0.21 a	0.72 a	1.19 a	0.95 a
Coffee + macadamia	5.3 a	5.1 a	5.2 a	0.08 a	0.56 a	0.32 a	1.20 a	1.08 a	1.14 a
Sole coffee	5.2 a	5.4 a	5.3 a	0.14 a	0.10 a	0.12 a	1.00 a	1.37 a	1.18 a
Mean	5.1	5.0	5.1	0.22	0.30	0.26	1.07	1.16	1.13
SED Coffee cultivar			1.7		0.04			0.04	
SED Fruit trees			0.2		0.1			0.10	
SED Interactions			0.3		0.2			0.20	
C.V %			8.8		23			28.0	

Means followed by a similar letter within the coffee cultivar and fruit tree interactions and within the overall means were not significantly different according to Tukey's Significant Difference Test, 5% level.

Table 4.10 continued..

Treatment	P ppm			Ca+Mg/K		
	R11	SL28	Mean	R11	SL28	Mean
Coffee + pawpaw	48 a	57 a	52 a	5.98a	5.35 a	6.17 a
Coffee + passion	66 a	61 a	64 a	4.48 a	5.67 a	5.07 a
Coffee + apples	60 a	53 a	57 a	6.70 a	7.04 a	6.87 a
Coffee + oranges	57 a	58 a	58 a	5.78 a	7.25 a	6.52 a
Coffee + bananas	61 a	48 a	54 a	8.92 a	4.57 a	6.75 a
Coffee + guavas	51 a	41 a	46 a	6.35 a	4.68 a	5.51 a
Coffee + avocadoes	39 a	60 a	50 a	4.06 a	5.77 a	4.92 a
Coffee + loquats	64 a	56 a	60 a	12.10 a	5.43 a	8.77 a
Coffee + macadamia	67 a	49 a	58 a	6.30 a	5.17 a	5.74 a
Sole coffee	58 a	60 a	59 a	7.66 a	5.78 a	6.72 a
Mean	57	54	56	6.85	5.82	6.27
SED Coffee cultivars		2.5			0.3	
SED Fruit trees		5.1			1.0	
SED Interaction		7.2			1.4	
C.V. %		22.3			38.2	

Means followed by a similar letter within the coffee cultivar and fruit tree interactions and within the overall means were not significantly different according to Tukey's Significant Difference Test, 5% level.

However in September 1993, there was significantly more soil potassium in the top soil of plots where coffee plants were intercropped with bananas than in the sole coffee (Table 4.9).

In December 1991, there was significantly less calcium level in the topsoil of guava and macadamia intercrops than in sole coffee (Table 4.9). Two years later, both the top and subsoil calcium content were not significantly affected by the intercrops.

Intercropping Ruiru 11 coffee plants with pawpaws and avocadoes significantly reduced the subsoil magnesium content after two years of intercropping (Table 4.8). Two years later, both the top and subsoil Mg levels were not significantly affected by the intercrops.

The subsoil manganese content was significantly increased by the guava intercrops (Table 4.8), while two years later it was significantly reduced by the orange intercrops (Table 4.9).

In December 1991, the topsoil sodium content was significantly increased by intercropping SL 28 coffee plants with apples and bananas (Table 4.7). Two years later, both the top and subsoil Na content were not affected by the intercrops.

The top and subsoil P content were not significantly affected by the intercrops throughout the study period and ranged between 58 to 76 ppm.

The Ca+Mg/K ratio in both the top and subsoil was not significantly affected by the intercrops during December 1991 period. During this period, the ratio averaged 6 which is within the adequate range for coffee. Two years later, in September 1993, the Ca+Mg/K ratio in the topsoil was significantly reduced by intercropping coffee plants with bananas (Table 4.9). The subsoil ratio was not significantly affected by the intercrops and averaged 6.72.

4.3.6 Effect of fruit tree intercrops on coffee leaf tissue nutrient concentration

4.3.6.1 **Nitrogen**: The coffee leaf-N was not significantly affected by the intercrops and averaged 2.9% (Table 4.11). The leaf-N was adequate for normal coffee growth (2.5-3.0%).

4.3.6.2 **Phosphorous**: The coffee leaf-P was significantly increased by intercropping coffee with bananas and significantly reduced by pawpaw, guava, avocadoes and loquats intercrops (Table 4.11). The levels were however adequate for normal coffee growth (0.15-0.30 %), except in coffee plants intercropped with guavas, avocadoes and loquats.

4.3.6.3 **Potassium**: The coffee leaf K concentration was not significantly affected by the intercrops and the concentration was adequate for normal coffee growth (2.0 - 3.0 m.e %).

4.3.6.4 **Magnesium**: The non intercropped SL 28 had significantly more leaf-Mg than SL 28 trees intercropped with macadamia and Ruiru 11 intercropped with bananas (Table 4.11).

Table 4.11: Effect of fruit trees intercrops on arabica coffee leaf tissue nutrient concentration sampled on September 1993

Treatment	N %			P %			K %			
	R11	SL28	Mean	R11	SL28	Mean	R11	SL28	Mean	R11
Coffee + pawpaw	2.84 ab	2.85 ab	2.84 c	0.14 e	0.15 d	0.14 c	2.26 abc	1.79 d	2.03 ab	241 ab
Coffee + passion	2.81 b	2.81 ab	2.86 bc	0.15 d	0.15 d	0.15 b	2.22 abc	2.15 abc	2.19 ab	198 ab
Coffee + apples	2.92 ab	2.94 ab	2.93 abc	0.14 e	0.15 d	0.15 b	2.33 ab	2.10 a-d	2.21 ab	227 ab
Coffee + oranges	2.90 ab	2.83 b	2.87 abc	0.15 d	0.14 e	0.15 b	2.34 a	2.22 abc	2.28 a	206 ab
Coffee + bananas	2.89 ab	2.96 ab	2.92 abc	0.19 a	0.16 c	0.18 a	2.39 a	2.16 abc	2.28 a	222 ab
Coffee + guava	2.97 ab	3.06 a	3.01 a	0.12 g	0.14 e	0.13 d	2.32 ab	1.96 cd	2.14 ab	285 a
Coffee + avocadoes	2.87 ab	2.82 b	2.84 c	0.13 f	0.15 d	0.14 c	2.18 abc	2.19 abc	2.19 ab	222 ab
Coffee + loquats	2.88 ab	2.93 ab	2.91 abc	0.13 f	0.14 e	0.14 c	2.20 abc	1.98 bcd	2.09 ab	190 b
Coffee + macadamia	2.89 ab	2.94 ab	2.91 abc	0.17 b	0.14 e	0.15 b	2.26 abc	2.20 abc	2.23 ab	213 ab
Sole coffee	2.95 ab	2.95 ab	2.95 abc	0.15 d	0.15 d	0.15 b	2.40 a	2.09 a	2.24 ab	187 b
Mean	2.90	2.93	2.90	0.15	0.15	0.15	2.29 a	2.09	2.2	219
SED Coffee cultivar		0.16			0.03			0.24		
SED Fruit trees		0.06			0.0			0.10		
SED Interactions		0.09			0.0			0.14		
C.V %		3.7			15.0			8.1		

Means followed by the same letter down the column were not significantly different according to Tukey's Honestly *Significant Test, 5% level.*

Table 4.11 continued

Treatment	Ca %			Bo ppm			Cu ppm			Mn ppm		
	R11	SL28	Mean	R11	SL28	Mean	R11	SL28	Mean	R11	SL28	Mean
Coffee + pawpaw	1.22 ab	1.48 ab	1.35 ab	61 ab	65 a	63	129 c-g	202 a-e	165	241 ab	199 ab	220 ab
Coffee + passion	1.61 a	1.35 ab	1.48 a	65 a	59 ab	62	119 e-g	212 abc	166	198 ab	205 ab	202 ab
Coffee + apples	1.34 ab	1.24 ab	1.29 ab	63 a	67 a	65	111 fg	152 b-g	132	227 ab	172 b	199 ab
Coffee + oranges	1.30 ab	1.08 b	1.19 b	61 ab	58 ab	59	91 g	207 a-d	149	206 ab	184 b	195 ab
Coffee + bananas	1.19 ab	1.36 b	1.28 ab	55 ab	67 a	61	135 e-g	238 a	187	222 ab	216 ab	219 ab
Coffee + guava	1.08 b	1.15 b	1.11 b	64 a	57 ab	61	151 b-g	119 a-e	175	285 a	198 ab	241 a
Coffee + avocadoes	1.25 ab	1.19 ab	1.22 ab	63 ab	61 ab	62	170 a-g	137 c-g	154	222 ab	211 ab	216 ab
Coffee + loquats	1.38 ab	1.22 ab	1.30 ab	47 b	64 a	55	99 g	171 a-g	135	190 b	231 ab	210 ab
Coffee + macadamia	1.36 ab	1.16 ab	1.26 ab	61 ab	62 ab	61	125 d-g	192 a-f	159	213 ab	187 b	200 ab
Sole coffee	1.30 ab	1.40 a	1.35 ab	57 ab	55 ab	56	126 d-g	187 a-f	156	187 b	157 b	172 ab
Mean	1.29 a	1.27 a	1.30	60	67	61	122 a	194 a	160	220	200	210
SED Coffee cultivar			0.05		4.3			85.5			24.5	
SED Fruit trees			0.13		4.7			50.6			27.1	
SED Interactions			0.19		6.7			71.5			38.3	
C.V %			18		13.5			27.5			22.3	

Means followed by the same letter down the column were not significantly different according to Tukey's Honestly Significant Test, 5% level.

4.3.6.5 Calcium: The leaf Ca concentration was not significantly affected by the intercrops.

4.3.6.6 Boron: The leaf-Bo concentration was not significantly affected by the intercrops. The leaf nutrient concentration averaged 61 ppm which was within the adequate range for normal coffee growth (40-100 ppm).

4.3.6.7 Copper: The leaf Cu concentration was not significantly affected by the intercrops and averaged 160 ppm. This was in excess of that required for normal coffee growth (20-100 ppm).

4.3.6.8 Manganese: The leaf-Mn concentration was significantly increased by intercropping Ruiru 11 coffee plants with guava (Table 4.12). The leaf-Mn concentration of coffee plants intercropped with pawpaw, passion fruit, bananas, guavas, avocadoes and loquats increased beyond 200 ppm which is the upper limit required for normal coffee growth (50-200 ppm).

4.3.7 Effect of fruit tree intercrops on coffee yield components

4.3.7.1 Total number of primaries and bearing primaries:

Between January and December 1992, the number of primaries and bearing primaries per coffee plant were significantly reduced by intercropping coffee plants with bananas (Table 4.12).

Table 4.12: **Effect of fruit tree intercrops on arabica coffee plant total and bearing primaries (1992)**

	Total primaries Jan - Dec 1992			Bearing primaries Jan - Dec 1992		
Treatment	R11	SL28	Mean	R11	SL28	Mean
Coffee + pawpaw	23 a	23 ab	23 a	24 abc	34 a	29 ab
Coffee + passion	26 a	19 ab	23 a	31 abc	21 bc	26 ab
Coffee + apples	23 a	20 ab	22 a	29 abc	26 abc	28 ab
Coffee + oranges	25 a	13 b	22 a	27 a	24 abc	26 ab
Coffee + bananas	21 ab	13 b	17 b	23 abc	20 c	21 b
Coffee + guavas	25 a	23 a	24 a	34 a	29 abc	32 a
Coffee + avocadoes	24 a	22 ab	23 a	30 abc	29 abc	30 ab
Coffee + loquats	24 a	22 ab	23 a	29 abc	34 a	31 a
Coffee + macadamia	20 ab	21 ab	21 a	29 abc	32 abc	31 a
Sole coffee	25 a	27 ab	26 a	31 abc	27 ab	29 a
SED Coffee Cultivars		1.3			1.6	
SED Fruit trees		1.8			2.6	
SED Interactions		2.6			3.7	
C. V. %		20.1			22.7	

Means followed by the same letter down the column were not significantly different according to Tukey's Honestly Significant Test, 5% level.

4.3.7.2 Nodes per primary branch: Between May and September 1991, the number of nodes per bearing primary were significantly reduced by intercropping coffee plants with guava (Table 4.13). Between January and December 1992, the number of nodes per bearing primary were significantly reduced by intercropping coffee plants with bananas, guava, avocadoes and loquats (Table 4.13).

4.3.7.4 Bearing nodes: The number of bearing nodes per primary were not affected by the intercrops throughout the study period.

4.3.8 Effect of fruit tree intercrops on clean coffee yields

For the first coffee crop, Ruiru 11 clean coffee yields were significantly reduced by intercropping with bananas and guavas fruit trees (Table 4.14). The clean coffee yields of the SL 28 coffee plants were not significantly affected by the intercrops. For the second crop harvested in 1992, the clean coffee yields were not significantly affected by the intercrops. The clean coffee yields averaged 1516 kg/ha for Ruiru 11 plants and 1274 kg/ha for SL 28 plants. In 1993 the clean coffee yields of SL 28 coffee plants were significantly increased by intercropping with macadamia (Table 4.15).

4.3.9 Effect of fruit tree intercrops on coffee bean and liquor attributes

The size of coffee beans in terms of grade A sized beans was not significantly affected by the intercrops throughout the study period. This

Table 4.13: **Effect of fruit tree intercrops on arabica coffee total number of nodes per coffee tree primary branch (May 1991 - December 1992)**

	May- Sep 1991			Jan - Dec 1992		
Treatment	R11	SL28	Mean	R11	SL28	Mean
Coffee + pawpaw	11 a	9 ab	10 ab	3 d-f	4 a-f	9 ab
Coffee + passion	9 ab	8 b	9 bc	4 a-f	3 d-f	4 b
Coffee + apples	10 ab	9 ab	9 bc	5 a-d	5 a-d	5 ab
Coffee + oranges	11 a	9 ab	10 ab	2 f	3 d-f	3 bc
Coffee + bananas	8 b	9 ab	10 ab	6 a	2 f	4 b
Coffee + guavas	6 ab	10 ab	8 c	4 a-f	4 a-f	4 b
Coffee + avocadoes	11 a	8 b	9 bc	5 a-d	4 a-f	4 b
Coffee + loquats	10 ab	10 ab	9 bc	4 a-f	4 a-f	4 b
Coffee + macadamia	11 a	10 ab	10 ab	6 a	5 a-d	6 a
Sole coffee	10 ab	10 ab	10 ab	5 a-d	6 a	6 a
Mean	10	9	10 ab	4	4	4
SED						
Coffee cultivars		0.2			0.5	
Fruit trees		1.0			0.7	
Interactions		1.0			1.2	
C.V. %		12.8			29.5	

Means followed by the same letter down the column were not significantly different according to Tukey's Honestly Significant Test, 5% level.

Table 4.14: **Effect of fruit tree intercrops on yield of clean coffee and fruit yields, (1991)**

Treatment	Clean coffee (Kg ha^{-1}) Ruiru 11	SL 28	Mean	Fruit yields (kg ha^{-1} $year^{-1}$)
Coffee + pawpaw	883 bc	347 de	615 ab	23047
Coffee + passion	1202 ab	314 de	758 ab	0
Coffee + apples	778 bcd	460 cde	619 ab	300
Coffee + oranges	1021 b	408 cde	714 ab	0
Coffee + bananas	477 cde	396 cde	436 b	54154
Coffee + guavas	471 cde	335 de	403 b	1284
Coffee + avocadoes	1204 ab	273 de	739 ab	0
Coffee + loquats	1529 ab	184 e	857 a	50
Coffee + macadamia	736 bcd	414 cde	575 ab	0
Sole coffee	1174 ab	164 e	669 ab	-
Mean	948 a	330 b	639	
S.E.D Coffee Cultivar		39		
S.E.D Fruit trees		111		
S.E.D Interactions		157		
C.V. %		42.2		

Means followed by the same letter down the column were not significantly different according to Tukey's Honestly Significant Test, 5% level.

Table 4.15: **Effect of fruit tree intercrops on yield of clean coffee and fruit yields, (1993)**

	Clean coffee (Kg ha^{-1})			
Treatment	Ruiru 11	SL 28	Mean	Fruit yields (kg ha^{-1} $year^{-1}$)
Coffee + pawpaw	1785 a-e	1388 b-f	1586 ab	25131
Coffee + passion	2230 a	1199 b-f	1715 ab	4749
Coffee + apples	1625 a-f	1643 a-f	1634 ab	348
Coffee + oranges	1941 a-c	1515 a-f	1728 ab	1204
Coffee + bananas	1429 a-f	1141 c-f	1285 bc	21002
Coffee + guavas	1097 def	1404 b-f	1251 bc	12154
Coffee + avocadoes	1408 b-f	1265 b-f	1337 bc	741
Coffee + loquats	1859 a-d	1580 a-f	1719 bc	0
Coffee + macadamia	1978 ab	1920 a-d	1949 a	25
Sole coffee	1570 a-f	952 f	1261 bc	-
Mean	1692 a	1306 b	1499	
S.E.D Coffee Cultivar		77.1		
S.E.D Fruits trees		238		
S.E.D Interactions		336		
C.V. %		27.8		

Means followed by a similar letter within the coffee cultivar and fruit tree interactions and within the overall means were not significantly different according to Tukey's Honestly Significant Test, 5% level.

averaged 60%. Similarly, the coffee bean raw and roast qualities and liquor body, acidity, flavour and overall qualities were not significantly affected by the intercrops. The overall assessment indicated that the coffee bean and liquor quality was "Fair Average Quality".

4.3.10 Net Benefits of the intercropping systems

Intercropping young coffee plants with fruit trees resulted in higher net benefits than unintercropped coffee (Table 4.16). Intercropping oranges, guava, avocadoes, loquats and macadamia with SL 28 coffee plants resulted in negative economic benefits during the first year of study. However, during the other years all the intercrops resulted in higher net benefits than sole coffee (Table 4.16).

4.4 Discussion

Fruit crops intercropped with coffee did not adversely affect the growth of coffee trees in terms of tree height, diameter and primary branch. Intercropping coffee plants with bananas was to result in a significantly higher increase in leaf area. This could be attributed to the observed high level of soil and leaf potassium. Potassium promotes the assimilation of CO_2 and translocation of photosynthates in the plant (Willson, 1985b), which results in better growth. The application of K-rich methane gas plant residues to coffee plants in Kenya was observed to lead into the production of large and shiny leaves (Hutchinson, 1965). This effect of K could explain the observed high increase in leaf area of those coffee plants intercropped with bananas.

Table 4.16 **Net benefits of intercropping arabica coffee with fruit trees coffee with fruit trees (1991 - 1993)**

	Incremental benefit (Ksh)					
	1991		1992		1993	
Treatment	R11	SL28	R11	SL28	R11	SL28
Coffee + pawpaw	71,920	119,320	121,410	231,000	145,55	167,455
Coffee + passion	14,110	26,310	19,240	47,240	160,98 0	119,500
Coffee + apples	-35,342	33,858	-24,700	43,300	17,620	81,220
Coffee + oranges	-26,039	-23,661	-11,660	36,640	55,780	74,980
Coffee + bananas	92,762	185,662	-40,684	21,916	48,906	81,906
Coffee + guava	-69,016	-18,384	-49,232	29,268	- 35,146	57,354
Coffee + avocadoes	3,000	-10,906	10,200	46,600	-2,180	46,120
Coffe + loquats	35,550	20,500	-7,767	20,233	28,900	62,800
Coffee + macadamia	-43,800	-2,500	-26,500	29,900	41,300	97,300
Sole coffee	0	0	0	0	0	0

The soil water status was not affected significantly by the intercropping treatments. Natarajan and Willey (1980) indicated that the total water use was little affected by a cropping system, and thus yield advantages of intercropping are not achieved at the expense of greater overall demand on soil moisture. This might be attributed to the windbreak effect which occurs when low growing plants in this case coffee, are intercropped with tall plants like the fruit trees. This leads to an increase in humidity and a reduction in transpiration (Steiner, 1982). This windbreak effect can be achieved with only a small percentage of tall plants that are at least 20-30 cm above the sheltered crop (Hagen and Skidmore, 1974).

Under intercropping systems, the taller plants are normally dominant, intercepting the greater share of light as observed in this study. Consequently, the shorter plants grow less than the taller ones and often have lower yields (Steiner, 1982). Bananas and guava were observed in this study to grow taller than coffee and intercepting more than 80% of photosynthetically active radiation. The low light intensity reaching the coffee trees could lead to high gibberellic acid production which inhibits flower initiation and development which results in poor yields (Kumar, 1979). Bananas and guava were also providing shade to coffee. Shade trees not only reduce the amount of light reaching the lower crops but also the light quality (Willey, 1975). In a study carried out in India, showed that when light passed through the leaf of an Albizzia tree, about 50% of the infrared light was absorbed, but for the visible light which is photosynthetically active, the figure was as high as 98% (Willey, 1975). Thus, light passing through taller plants is of poor quality resulting in poor yields. Intercropping coffee with bananas and guavas caused an insignificant yield depression compared to the non intercropped coffee.

Intercropping coffee with fruit crops did not affect adversely coffee nutrition as indicated by the soil and coffee-leaf analysis. Recommended fertilization for both coffee and the fruit trees was applied . It, therefore, seems that adequate nutrients were supplied to both crops and consequently no competition occurred. In Brazil, Chaves and Guerreiro (1989), observed that large quantities of nutrients were removed by the intercropped plants, but this did not affect the growth of coffee plants (Chaves and Guerreiro, 1989).

In this study, significantly higher K was observed in the soil and coffee leaves in the plot intercropped with bananas. The banana leaves and pseudo stem after harvesting were used as mulch material. Regular mulching with some dry vegetation such as napier grass has been observed to maintain potassium availability at a high level (Willson, 1985b). The high soil K, increased the K uptake by the coffee plants as depicted in the coffee leaf analysis. The high K level in the plots where coffee was intercropped with bananas resulted in a Ca + Mg:K imbalance, and the ratio was less than adequate for coffee growth and productivity (<5.0). This low Ca + Mg : K ratio did not affect coffee growth nor the clean coffee yields.

It was also observed that the manganese levels in all the coffee leaves was in excess of that required by coffee plant. Manganese uptake by plants is increased by low soil pH (de Geus, 1973). The excess uptake of manganese can be controlled by liming. The soils at the trial site were acidic and this was corrected by an application of dolomitic limestone at the rate of 1000 kg/ha.

In general, the studied fruit crops did not depress significantly the yields of clean coffee compared to the sole crop. In fact, intercropping coffee with most of the fruit crops tended to increase though non significantly, the clean coffee yields. In a trial in Kenya, clean coffee yields were observed not to be affected by intercropping with macadamia (Njoroge and Kimemia, 1993), while intercropping young coffee with food crops resulted in significantly higher clean coffee than the non intercropped coffee (Njoroge and Kimemia, 1995). In the absence of concrete data, this increase in coffee yields is thought to be due to manure and fertilizers applied to the intercrops (Njoroge, 1992).

Bananas were observed to depress yields of clean coffee throughout the trial period. The growth and yield of arabica and robusta coffee has been found to be reduced by intercropping coffee with bananas (Mitchell, 1965). In this study it was observed that the coffee trees intercropped with bananas regardless of coffee cultivar had significantly fewer number of both total and bearing nodes per primary. The coffee bean yields are mainly determined by the coffee shoot growth and components of yield like primary branches (Cannell, 1985). The yield of the coffee tree is also highly dependent on the number of potential flowering nodes (Gebre- egziabher, 1978). Any cultural practice that affects the yield components will also affect the coffee yields. Therefore, the low number of bearing primaries and nodes observed on coffee trees intercropped with bananas and guava contributed significantly to the low yields of clean coffee observed.

In this study, it was observed that the fruit intercrops increased the net monetary benefits. Intercropping coffee with pawpaws and bananas resulted in the highest net benefits over the three year study period. This concurs with the findings of Bheemiah and Shariff (1989) who reported that intercropping coffee with oranges and bananas in India resulted in high and stable incomes.

4.5 Conclusions

Results from this study have indicated that it is possible to intercrop young arabica coffee at establishment phase with the various fruit trees without adversely affecting the coffee yields and quality. Bananas, although they did not depress coffee yield significantly, were found to affect coffee tree growth. To minimise this effect lower plant densities than the ones used in this study are suggested.

The yields of the fruits were very high and this adds a great monetary advantage to the farmer. The inclusion of these trees will encourage the farmers to take care of their coffee trees even in periods of low coffee prices. More research into root interactions between coffee and fruit plants, planting spacings for the fruit trees and general husbandry of the fruit crops is suggested.

CHAPTER 5

THE EFFECT OF INTERCROPPING *Coffea arabica* L, WITH ANNUAL FOOD CROPS DURING THE CHANGE OF CYCLE, ON COFFEE PLANT GROWTH, CLEAN COFFEE YIELD AND BEAN QUALITY

5.1 Introduction

In Kenya, intercropping coffee with beans, maize, potatoes, peas, bananas and various vegetables has been reported in the small scale sector (Mukunya and Keya, 1985). The effect of these crops on coffee growth and yield has only been studied with young newly established coffee (Njoroge *et al.*, 1993; Njoroge and Kimemia, 1995)). Intercropping mature coffee has been studied with beans (Mwakha, 1987).

Mwakha (1980 a) observed that it is possible to obtain 4 consecutive bean crops from stumped high density (5320 trees/ha) coffee without affecting the subsequent coffee yields. In further work, Mwakha (1980 b) recommended that during the first 18 months after block stumping, 2 - 4 dry bean rows per 2 m coffee interrow may be successfully grown with application of 80 Kg N/ha per season.

Mwakha (1987) reported that the only suitable period in the coffee cropping cycle for successful intercropping with beans is during the change of cycle, when the coffee canopy is drastically reduced for about two years, provided adequate fertilization is provided to both crops. In Brazil, intercropping young and mature pruned coffee with rice (*Oryza sativa)*, bean *(Phaseolus vulgaris)*, maize *(Zea mays*) and soyabeans *(Glycine* *max*) did not significantly affect the coffee plant growth (Chaves and Guerreiro, 1989).

With the current trend in coffee world prices and the noticed increase in intercropping coffee with other crops, it is necessary to study the effect of this cropping system on coffee plant growth, coffee bean yield and quality.

This study was therefore set up to study the effects of food intercrops on the growth, yield and quality Arabica coffee cv SL 28 at the change of cycle phase.

5.2 Materials and Methods

5.2.1 Site

The trial was carried out at Coffee Research Station, Ruiru between January 1992 and December 1993. The rainfall was bimodally distributed between the long rains (April to July) and short rains (October and December). The annual rainfall recorded was 866, 1171 and 816 mm in 1991, 1992 and 1993 respectively. Only in 1992 was the rainfall received higher than the long term average. The maximum temperatures were 23.8, 25.8 and 25.2^{0}C while the mean minimum temperatures were 11.8, 12.8 and 12.5^{0}C in 1991, 1992 and 1993 respectively. The soils at the station are humic nitosols with a deep profile with reddish brown to dusky brown clays (Jaetzold and Schimdt, 1983). They are moderate in bases, low in phosphorus and slightly acidic (pH range of 4.0 - 5.4 $CaCl_2$ method) (Siderius and Muchena, 1977).

5.2.2 Treatments

Arabica coffee Cv `SL 28' planted in 1981 was used. The coffee had been planted at three tree densities of 1330 (2.74 x 2.74 m), 2660 (2.74 x 1.37 m) and 5320 (1.37 x 1.37 m) trees/ha. These three densities are normally referred to as conventional, hedgerow and high density spacings, respectively (Mwangi, 1983). The coffee had been raised on multiple stem pruning system. In the conventional, hedgerow and high density spacings the coffee plants were raised on three, two and one stems, respectively. The change of cycle started by removing the primaries in the centre of the canopy, leaving only a few branches at the top. This allowed the coffee trees to bend outwards. In August 1991, two and one stems were removed from the conventional and hedgerow spaced coffee, respectively. For the high-density spaced coffee, the stem was cut back leaving only the lowest pair of primaries (breather). Suckers were then encouraged to grow, and in December 1991, the excess suckers were removed to leave three, two and one young stems per stump for the conventional, hedgerow and high density spacings, respectively. The remaining old stems and stumps were removed in March 1993.

The food crops used as intercrops were Irish potatoes (*Solanum tuberosum)* Cv Annet, tomatoes *(Lycopersicon esculentum)* Cv. Money maker, dry beans *(Phaseolus vulgaris)* Cv. GLP 1004, cowpeas *(Vigna unguiculata)* Cv. K80, garden peas *(Pisum sativum)* Cv. Greenfeast and sweet potatoes *(Ipomea batatas)* Cv. Muibai. A sole plot of coffee and the intercrops were maintained as controls. The food intercrops were planted in both the long rains and short rains each year. They were grown in the 2 m interrow space of coffee plants continuously for a period of two years during change of coffee cycle period. This was from the time the stems were pruned off in January 1992 till the new suckers bore their first main crop in December 1993. A total of four crops were harvested except in the high density planting where only three crops were produced. The planting methodology is shown in Table 5.1.

5.2.3 Experimental design

The 21 treatments were laid in a split plot design with four replicates. The three coffee tree densities were the main plots, while the seven intercropping systems formed the subplots. The subplots size was 45 m^2. The conventional, hedgerow and high density spacing had 12, 20 and 35 coffee trees and the central 2, 6 and 9 trees were used data collection respectively. The field layout of the trial is shown in Appendix 8.

5.2.4 Cultural practices

During the study period the coffee were trained on the multiple stem uncapped system (Mwangi, 1983). The coffee trees were fertilized with 100 kg/ha N per year which was applied in form of calcium ammonium nitrate (CAN - 26% N) in April and May, and in form of NPK (20:10:10) in November. These fertilizer rates were applied on area basis regardless of the coffee tree density and, therefore the amount of fertilizer applied per tree varied. Weeding was done by hand eight times in a year. The coffee trees were sprayed with fungicides against coffee berry disease and leaf rust using a tank mixture of 5.5 kg/ha copper and 2.2 kg/ha Daconil, in February, March, April, May, June, July, October and November in 1992 and 1993.

Table 5.1 Food crop intercrops and their planting methodology in coffee plots (1992 - 1993)

Intercrop	Spacing (cm)	Number of rows per coffee interrow		
		Coffee plant density (trees ha^{-1})		
		1330	2660	5320
Dry beans	25 x 15	6 (74.5)	6 (74.5)	2 (56.0)
Cowpeas	30 x 10	4 (92.0)	4 (92.0)	2 (53.5)
Irish potatoes	75 x 30	3 (62.0)	3 (62.0)	1 (68.5)
Tomatoes	100 x 50	2 (87.0)	2 (87.0)	1 (68.5)
Sweet potatoes	100 x 30	1 (137.0)	1 (137.0)	1 (68.5)
Gardenpeas	30 x 10	4 (92.0)	4 (92.0)	2 (53.5)
Sole coffee		-	-	-

Note
1. The distance (cm) from the coffee tree to the food intercrop row indicated in brackets

2. The purestand food crops were planted in a similar procedure to the intercrops

The Irish potatoes were planted using 500 kg/ha of DAP (18% N and 46% P_2O_5). They were protected against late blight (*Phytophthera infestans)* by using Dithane M45 at the rate of 4 kg/ha applied on weekly intervals. They were harvested after three months.

Tomatoes were planted using 200 kg/ha DAP and later top dressed with 100 kg/ha CAN (26% N) at 25 cm. They were protected from late blight the same way as Irish potatoes. Insect pests, mainly American Bollworm (*Heliothis armigera)* and white fly *(Bemisia tabaci)*, were controlled using Decis at the rate of 10 ml/20 ml of water. The insecticide was mixed with Dithane and two were sprayed simultaneously. The plants were staked and pruned to leave one stem and the laterals pinched out as they grew. Fruits were harvested as they ripened and cumulative yield recorded.

Beans, cowpea and peas were planted using 200 kg/ha DAP. Beans and cowpea were harvested when dry, threshed and the yield per plot recorded, while peas were harvested green continuously for about 2 weeks and cumulative yield recorded.

Sweet potato vines were planted in two rows per coffee interrow for the conventional and hedgerow spacings and one row per inter row in the high density spacings. The vines were planted using cattle manure at the rate of 10 tonnes per hectare. The vines were allowed to creep but trimmed along the coffee row. The tubers were harvested as they matured without destroying the vines and cumulative yield recorded.

Sole food crops were planted in a similar procedure as described above. The plots were of the same size as for intercrops and were adjacent to the coffee plots.

5.2.5 Data collection

5.2.5.1 Soil and coffee leaf analysis: The soil and leaf sampling and analysis were as described in Chapter 3.

5.2.5.2 Soil moisture status: This was done as detailed in Chapter 4. Soil samples were taken in the middle of the coffee interrow after the food crops were harvested.

5.2.5.3 Coffee growth and yield components: These were taken as described in Chapter 3. The parameters were measured on one selected stem.

5.2.5.4 Light transmission and canopy gap fraction: These were measured under the coffee canopy and top of the food crops in the middle coffee interrow per plot as described in Chapter 4.

5.2.5.5 Coffee yield and quality: The yield of clean coffee, proportion of grade `A' sized beans and the coffee liquor quality were determined as described in Chapter 3.

5.2.5.6 Yield of food crops: This was harvested from the whole plot, as each crop matured. The yield was recorded per plot then converted into hectare basis per each year.

5.2.5.7 **Yield advantage**: The yield advantage of intercropping were calculated using Land Equivalent Ratio (LER) as described by Mead and Willey (1980). The LER is calculated from the equation:

$$\text{LER} = \frac{Y_A}{S_A} + \frac{Y_B}{S_B}$$

Where Y_A and Y_B are the individual crop yields when intercropped while S_A and S_B are the yields of the sole crops.

The partial budget analysis for the food intercrops was calculated as described by Perrin et al., (1976)

5.2.5.8 **Data analysis**: The coffee growth and yield parameters were subjected to analysis of variance as described by Gomez and Gomez (1984) for split plot design. The analysis of variance tables are shown in Appendix 9.1-9.5. The Land Equivalent Ratio (LER) as described by Willey (1979a) was calculated for all the intercropping systems in each year.

5.3 Results

5.3.1 Effect of food crop intercrops on stem growth of coffee plants

5.3.1.1 **Tree height, stem diameter and primary length**: Throughout the study period, the food intercrops did not affect significantly the increase in coffee plant height, stem diameter and primary length which averaged 74.9, 1.38 and 14.3 cm respectively.

5.3.2 Effect of food crop intercrops on soil chemical properties

The soil pH, Ca, Mg and the Ca + Mg/K ratio were not significantly affected by the intercropped food crops.

Intercropping coffee with cowpeas resulted in significantly higher exchangeable acidity (Hp) in the top-soil (Table 5.2). Except where cowpeas were intercropped with coffee, the exchangeable acidity remained adequate for normal coffee growth.

5.3.3 Effect of food crop intercrops on soil nutrients in the coffee plots

Both the top and sub-soil K concentration were not significantly affected by the food intercrops (Tables 5.2 and 5.3). The soil potassium content was within the adequate range for normal coffee growth (0.4 -2.0 m.e %). Intercropping coffee with Irish potatoes continuously for two years resulted in significantly higher top and sub-soil P-level than in the sole coffee plot (Tables 5.2 and 5.3).

5.3.4 Effect of the food crop intercrops on coffee yield components

During the trial period intercropping coffee with garden pea resulted in significantly lower increase in number of coffee primary branches than intercropping with Irish potatoes (Table 5.4). Intercropping coffee with cowpeas resulted in significantly less increase in bearing primaries throughout the experimental period (Table 5.5).

The total number of nodes and bearing nodes per primary were not affected significantly by the food intercrops.

Table 5.2 **Effects of food intercrops on top soil Hp and nutrients sampled from the coffee plots in May 1993**

Treatment	Hp m.e %	K m.e %	P ppm
Coffee + beans	0.25 b	1.14 b	147.8 b
Coffee + cowpea	0.53 a	1.18 b	140.1 b
Coffee + Irish potatoes	0.24 b	1.27 ab	226.8 a
Coffee + tomatoes	0.27 b	1.10 b	146.2 b
Coffee + sweet potatoes	0.27 b	1.41 a	151.6 b
Coffee + garden peas	0.32 b	1.29 ab	176.9 b
Sole coffee	0.24 b	1.22 ab	160.7 b
Mean	0.30	1.20	164.6
SED	0.1	0.12	21.4
CV %			

Means followed by a similar letter within the coffee tree densities and food crop interactions and within the overall means were not significantly different according to Tukey's Honestly Significant Test, 5% level.

Table 5.3 **Effects of food intercrops on sub soil nutrients sampled from the coffee plots in May 1993**

Treatment	Hp m.e %	K m.e %	P ppm
Coffee + beans	0.95 b	1.73 ab	106.5 b
Coffee + cowpea	0.91 a	1.73 ab	101.0 b
Coffee + Irish potatoes	1.09 ab	1.82 ab	129.4 a
Coffee + tomatoes	0.96 ab	1.80 ab	100.2 b
Coffee + sweet potatoes	1.23 a	1.95 a	122.8 b
Coffee + garden peas	0.95 b	1.81 ab	114.8 b
Sole coffee	0.94 b	1.79 ab	106.5 b
Mean	1.00	1.8	111
SED	0.13	0.95	78.9
C V %		13	41.4

Means followed by a similar letter within food crops were not significantly different according to Tukey's Honestly Significant Test, 5% level.

Table 5.4 **Effects of food intercrops on actual increase in total number of primaries during coffee change of cycle period (July 1992-March 1993)**

Treatment	Number of primaries			
	Tree density (trees ha^{-1}			
	1330	2660	5320	Mean
Coffee + beans	22.3 a	18.8 a	23.0 a	21.3 ab
Coffee + cowpeas	16.8 a	17.3 a	23.0 a	19.0 ab
Coffee + Irish potatoes	25.3 a	25.3 a	22.8 a	24.4 a
Coffee + tomatoes	21.0 a	23.3 a	21.0 a	21.8 ab
Coffee + sweet potatoes	20.0 a	23.8 a	21.8 a	21.9 ab
Coffee + garden peas	18.3 a	15.0 a	15.8 a	16.3 b
Sole coffee	21.3 a	26.0 a	22.0 a	23.1 a
Mean	20.7 a	21.3 a	21.3 a	21.1
SED Tree density (6 df)		1.4		
SED Food crops (54 df)		1.5		
SED Density x Foodcrop (54 df)		24.7		
C.V. %		13.2		

Means followed by a similar letter within the coffee tree densities and food crop interactions and within the overall means were not significantly different according to Tukey's Significant Difference Test, 5% level.

Table 5.5 **Effects of food intercrops on actual increase in number of bearing primaries during coffee change of cycle period (July 1992-March 1993)**

Number of bearing primaries

Treatment	Tree density (trees ha^{-1}			
	1330	2660	5320	Mean
Coffee + beans	18.5 ab	17.0 ab	23.0 ab	19.5 a
Coffee + cowpeas	15.3 ab	17.0 ab	20.0 ab	17.4 a
Coffee + Irish potatoes	20.3 ab	18.8 ab	22.3 ab	20.4 a
Coffee + tomatoes	21.3 ab	16.5 ab	21.0 ab	19.6 a
Coffee + sweet potatoes	19.3 ab	18.5 ab	19.5 ab	19.1 a
Coffee + garden peas	19.8 ab	14.5 b	21.3 ab	18.5 a
Sole coffee	17.5 ab	21.0 ab	23.3 a	20.6 a
Mean	18.8 a	17.6 a	21.5 a	19.3
SED Tree density (6 df)		1.19		
SED Food crops (54 df)		0.9		
SED Density x Foodcrop (54 df)		1.6		
C.V. %		16.3		

Means followed by a similar letter within the coffee tree densities and food crop interactions and within the overall means were not significantly different according to Tukey's Significant Difference Test, 5% level.

Table 5.6 **Effects of food intercrops on clean coffee bean yields during the second year of change of cycle period (1993)**

Treatment	Clean coffee (Kg ha^{-1}) Coffee tree density (trees ha^{-1}) 1330	2660	5320	Mean	% yield depression
Coffee + beans	764 ef	548 f	2199 ab	1171 a	16.7
Coffee + cowpeas	750 ef	681 ef	1895 a-d	1109 a	21.1
Coffee + Irish potatoes	543 f	764 ef	2093 a-c	1133 a	19.4
Coffee + tomatoes	1119 def	798 ef	1512 b-e	1143 a	18.7
Coffee + sweet potatoes	787 ef	1130 c-f	1463 b-f	1127 a	19.8
Coffee + garden peas	742 ef	1130 c-f	2129 ab	1374 a	2.3
Sole coffee	678 ef	731 ef	2810 a	1406 a	0
Mean	769 b	826 b	2014 a	1203	
SED Tree density		134.7			
SED Food crops		1102.4			
SED Density x Foodcrop		177.4			
CV %		29.5			

Means followed by a similar letter within the coffee tree densities and food crop interactions and within the overall means were not significantly different according to Tukey's Significant Difference Test, 5% level.

5.3.5 Effect of the food intercrops on clean coffee beans yields

During the first year of change of cycle, the food intercrops did not significantly affect the clean coffee yields. The clean coffee yields averaged 620 kg/ha. Coffee trees planted at high density had no yields. During the second year the non intercropped coffee trees planted at high density yielded significantly more clean coffee than the intercropped coffee plants (Table 5.6). The food intercrops reduced coffee yields by between 2.3 - 21.0%.

5.3.6 Effect of the food crop intercrops on coffee bean attributes

During the first year of change of cycle, the cowpea and bean intercrops significantly reduced the percent grade A beans in coffee plants planted at conventional and hedgerow spacing respectively (Table 5.7).

During the second year, garden pea intercrop significantly reduced the percent grade "A" beans of coffee plants planted at hedgerow spacing (Table 5.8).

During the two year of change of cycle phase, the food intercrops did not significantly affect the raw and roast coffee bean quality or the coffee liquor quality. The overall coffee liquor quality was fair average quality.

5.3.7 Effects of coffee tree density on percent light reaching the food intercrops

During the first year after change of cycle, there was significantly more light reaching the food crops intercropped in coffee at high density (Table 5.9).

Table 5.7 **Effects of food intercrops on percent grade A beans during the first year of change of cycle period (1992)**

Clean coffee (kg ha^{-1})

	Coffee tree density (trees ha^{-1})			
	1330	2660	5320	Mean
Coffee + beans	80 3 ab	69 7 a	0 c	50.0 a
Coffee + cowpeas	74.8 ab	80.0 a	0 c	51.6 a
Coffee + Irish potatoes	83 0 ab	81.2 a	0 c	54 7 a
Coffee + tomatoes	86.1 ab	86 2 a	0 c	57.4 a
Coffee + sweet potatoes	83 2 ab	83 7 a	0 c	55 6 a
Coffee + garden peas	79 2 ab	80 4 a	0 c	53.2 a
Sole coffee	86.1 ab	87 9 a	0 c	58 0 a
Mean	81.8 a	81.3a	0 b	54 4
SED Tree density		71.2		
SED Food crops		2 2		
SED Density x Foodcrop		4.61		
C.V %		12.0		

Means followed by a similar letter within the coffee tree densities and food crop interactions and within the overall means were not significantly different according to Tukey's Significant Difference Test, 5% level.

Table 5.8 **Effects of food intercrops on percent grade A beans during first year of change of cycle period (1992)**

% grade 'A' beans

Treatments	Coffee tree density (trees ha^{-1}) 1330	2660	5320	Mean
Coffee + beans	89.8 a	93 0 a	83.6 a	88.8 a
Coffee + cowpeas	81 8 a	93 5 a	77.0 a	84.1 a
Coffee + Irish potatoes	82 1 a	84 3 a	79 8 a	82.1 a
Coffee + tomatoes	86 7 a	89.4 a	84 0 a	86.7 a
Coffee + sweet potatoes	87.9 a	84 8 a	81.4 a	84.7 a
Coffee + garden peas	85 8 a	78 1 a	79.6 a	81.2 a
Sole coffee	87.3 a	91.5 a	75.9 a	84.9 a
Mean	87.8 a	85 9 a	80 2 a	84.6
SED Tree density		2.5		
SED Food crops		3.1		
SED Density x Foodcrop		5.4		
C V %		9 0		

Means followed by a similar letter within the coffee tree densities and food crop interactions and within the overall means were not significantly different according to Tukey's Significant Difference Test, 5% level.

Table 5.9 **Effect of coffee tree density on percentage of PAR reaching the intercropped foodcrops at noon, (June-December 1992)**

Coffee density tree/ha	22/6/92	20/7/92	17/8/92	12/9/92	26/10/92	23/11/92	21/12/92
1330	76.2 a	87.2 a	84.3 a	76.3 a	80.6 a	86.6 a	77.0 a
2660	43.9 b	62.5 b	52.8 b	58 1 b	52.3 b	53 9 b	59.5 a
5320	88 0 a	90 0 a	84 8 a	75 0 a	71 1 b	65 3 b	58.5 a
Mean	69 4	79 9	73.9	69 8	68 0	68 6	65.0
SED	3 2	3 2	3.1	2 5	5.2	5 6	3.3
C V %	22.9	31.8	31.8	23.7	30.8	29.5	62.8

Means followed by a similar letter within the coffee tree densities were not significantly different according to Tukey's Honestly Significant Test, 5% level.

However, during the second year, the amount of PAR reaching the intercropped food crops was significantly lower in high density coffee than in the two tree densities (Table 5.9). The amount of PAR reaching the intercropped food crops decreased when coffee tree density was increased from 1330 trees/ha to 2660 trees/ha (Table 5.9).

5.3.8 Effect of coffee plants on food crop yields

During the first year after change of cycle, the yields of food crops under high density coffee were generally higher than those at the other two tree densities (Table 5.10). During the same year, some of the intercrops yielded more than the purestand. In the second year, the yields of the intercrops decreased with increasing coffee tree density (Table 5.11). Cowpea and garden peas were the most affected intercrops.

5.3.9 Net income benefits of the coffee intercropping systems

The intercropping systems resulted in positive net returns in the first year of change of cycle (Table 5.10). The net benefits increased with increasing coffee tree densities.

During the second year of change of cycle, intercropping coffee with sweet potatoes and tomatoes resulted in positive net income benefit across the three coffee tree densities (Table 5.11). Intercropping beans and garden peas in coffee planted at conventional and hedgerow plantings in also in posive net returns. The coffee and cowpea intercropping system had a negative net benefit.

Table 5.10. Food crop yields and net benefits from food intercrops during the first year of change of cycle (1992)

Crop	Annual total yield Yield kg $ha^{-1}yr^{-1}$			Net benefits Ksh.$ha^{-1}yr^{-1}$			
	Trees ha^{-1}			Trees ha^{-1}			Purestand yields Kg/$ha^{-1}yr^{-1}$
	1330	2660	5320	1330	2660	5320	
Beans	1536	1618	3562	20,750	22,800	71,400	3399
Cowpea	1914	2033	2744	20,990	23,310	37,530	1150
Irish Potatoes	21204	16995	25222	29,020	7,975	49,110	33905
Tomatoes	9095	5100	14089	74,100	34,150	124,040	16907
Sweet potatoes	5867	6084	10678	24,585	25,670	48,640	5222
Garden peas	267	696	2040	-4,435	14,870	75,350	1800

Table 5.11. Food crop yields and net benefits from food intercrops during the second year of change of cycle (1993)

Crop	Annual total yield Yield kg $ha^{-1}yr^{-1}$			Net benefits Ksh.$ha^{-1}yr^{-1}$			
	Trees ha^{-1}			Trees ha^{-1}			Purestand yields Kg/$ha^{-1}yr^{-1}$
	1330	2660	5320	1330	2660	5320	
Beans	1403	1208	410	17425	12550	-7400	2537
Cowpea	62	36	5	-16110	-17170	-17250	1097
Irish Potatoes	8836	7323	3088	11360	-3770	-46120	27794
Tomatoes	10305	7314	5322	83455	56320	363700	34822
Sweet potatoes	4007	4610	3989	15285	18300	15195	42383
Garden peas	1913	705	92	69635	19775	-12310	1650

5.3.10 Land equivalent ratio (LER) of the coffee intercropping systems

During the first year, most of the intercropping systems except those where Irish potatoes and tomatoes were grown under high density coffee, had a LER of more than one (Table 5.12). During the second year, intercropping conventional and hedgerow coffee with food crops resulted in a yield advantage (LER of more than one) (Table 5.13). However, growing food crops under high density coffee resulted in LER's of less than one. The LER's decreased with increasing coffee tree densities.

5.4 Discussion

In this study, the food intercrops did not adversely affect coffee plant growth in height, diameter, primary extension and leaf area. In Brazil, intercropping pruned coffee with annual crops was observed not to affect the growth of coffee plants, although intercropping with tall plants like cotton and maize were observed to affect the development and production of coffee (Chaves and Guerreiro, 1989). This was attributed to shading effects by the taller crops. In the current study, the evaluated food crops were not taller than coffee and hence did not shade the coffee. This may explain the non adverse effect of food crops on coffee growth. Studies on intercropping in forest trees have also shown the non effect on tree growth by intercropped annual crops. Budowiski (1983) observed that intercropping *Gmelina arborea* with maize and beans did not affect its growth in height and that the stem diameter of *Eucalyptus deglupta* was not depressed by an intercropped maize crop.

Table 5.12 Land Equivalent Ratios of coffee and food intercrops during the first year of coffee change of cycle period (1992)

Intercrop	Trees ha^{-1} 1330			2660			5320		
	Part LER Coffee	Part LER Food crop	Total LER	Part LER Coffee	Part LER Food crop	Total LER	Part LER Coffee	Part LER Foo dcro p	Total LER
Beans	1.09	0 51	1.60	0.98	0 54	1.52	-	1.19	1.19
Cowpea	0 82	1.66	2 48	1.32	1.77	3.09	-	2 39	2.39
Irish potatoes	0 86	0 63	1.49	1.12	0 50	1.62	-	0.74	0.74
Tomatoes	1 16	0 54	1.70	1.00	0 30	1.30	-	0 83	0 83
Sweet potatoes	0 94	1.12	2.06	1.03	1.17	2 20	-	2.04	2.04
Garden peas	1.18	0.34	1.52	0.96	0.51	1.47	-	1.13	1.13
Sole coffee	1 0	-	1.00	1.00	-	1.00	-	-	-

ble 5.13 Land Equivalent Ratios of coffee and food intercrops during the second year of coffee change of cycle period (1993)

reatments	Trees ha⁻¹ 1330 Part LER Coffee	1330 Part LER Food crop	1330 Total LER	2660 Part LER Coffee	2660 Part LER Food crop	2660 Total LER	5320 Part LER Coffee	5320 Part LER Food crop	5320 Total LER
offee+Beans	1.13	0 55	1.68	0.75	0 48	1.23	0.78	0 16	0 94
+ Cowpea	1.11	0 06	1 17	0 93	0 03	0 96	0.67	0 00	0 67
+ I potatoes	0 80	0 32	1.12	1.05	0.26	1.31	0.14	0 11	0.25
+ Tomatoes	1.65	0.30	1 95	1.01	0.21	1.22	0.54	0.15	0.69
+ S potatoes	1.16	0.09	1 25	1.54	0.10	1.64	0.52	0.09	0.61
+ G peas	1.04	1.16	2 20	1.00	0 43	1.43	0.76	0 06	0 83
ole coffee	1 00	-	1.00	1.00	-	1.00	1.00	-	1.00

The non-effect of intercropped food crops to coffee growth observed in this study may also be attributed to the fact that the mature coffee had already well developed root system. This would extract nutrients from deeper soil layers, and hence reduce competition for nutrients and water with food crops as was observed in this study.

The soil moisture status after harvesting the food crops was not significantly affected by the food intercrops. The food crops were grown during the rainy season and were all short duration crops except sweet potatoes. The beans, cowpeas, garden peas, potatoes and tomatoes intercrops were harvested within three months after sowing. Although sweet potato vines were in the field for a whole year they also did not significantly affect the soil moisture status. Njoroge (1992) observed no effect on soil residue moisture by intercropped maize, beans, tomatoes and potatoes in young arabica coffee. The water requirements for the tall arabica coffee was studied in Kenya by and Blore (1966), and found that the average annual requirement of water was about 951 mm. Rainfall was fairly adequate during the trial period and exceeded the required amount for coffee except during the short rains 1993, when supplementary irrigation was given. There was therefore adequate moisture for the intercropped food crops.

The intercropped food crops did not adversely affect coffee nutrition as shown by the soil and leaf chemical analysis. Both the coffee and the food crops were fertilized as recommended for the purestand. The nutrient levels in the soil remained adequate for normal coffee growth and production. Njoroge (1992) observed that intercropping young coffee with food crops did not affect significantly coffee nutrition. This was attributed to the fact that at the early stages of coffee growth, the root feeding zone is not interfered with by the intercrops, when sufficient space between the intercrop and coffee is provided.

In this study, it was observed that in plots where phosphatic fertilizer was used to plant the food crops there was an increase in soil P concentration. The P level was significantly higher where Irish potatoes were planted. Njoroge (1992) had obtained similar results when intercropping young coffee with beans, potatoes and tomatoes. This increase is attributed to the P added by the fertilizers used for planting the food crops.

The soil pH remained below adequate levels for coffee growth on some plots. The pH was raised by addition of dolomitic limestone. It was observed that the growth of pH sensitive crops like beans and cowpeas were affected by the low pH. Njoroge (1992) had observed poor bean growth due to low soil pH. The presence of toxic aluminium and manganese in acid soils reduce and destroy root development resulting in the poor plant growth (de Geus, 1973).

The food intercrops were observed to insignificantly depress the yields of the first coffee crop. However during the second year, the coffee yield from the non-intercropped coffee tended to be higher than from the intercropped. After removal of old stems at the change of cycle, there was adequate space to grow the food crops. Coffee feeder roots are known to be limited to the coffee drip line (Willson, 1985b). With the cutting of the stems, the coffee canopy was reduced and therefore, where the food crops were planted, there was no competition with coffee. This may explain the non-significant effect of the intercropped crops on coffee yields. Field trials with young coffee in Kenya have shown a non-significant effect of intercropped food crops on coffee yields (Njoroge *et al.*, 1993; Njoroge and Kimemia, 1995).

The intercropped food crops did not significantly affect the size of coffee beans and the coffee bean raw, roast and liquor characteristics. This concurs with the findings of Njoroge *et al.*, (1993) and Njoroge and Kimemia (1995) who reported that intercropping young arabica coffee with food crops did not significantly affect the coffee bean and liquor quality.

During the first year after change of cycle, the yields of food crop tended to be higher under high density coffee than in the other two plant densities. Coffee planted at high density was clean stumped and so there was no shading effect to the intercropped food crops. The food crops intercropped received 100% of the solar radiation. In the other two lower plant densities, one stem was left, and hence the food crops grew under partial shade. During the second year, after change of cycle, the canopy in the high density had closed up allowing very little light (14%) to reach the food crops. Consequently, the yields of food crops declined at the high density planting. In fact, during the short rains of the second year after change of cycle, there was no yield from the intercrops under high density coffee trees. Intercropping of food crops with trees can only be successful during the early stages when the canopy has not yet fully developed (Blencowe, 1969; Harwood and Price, 1976). Injury to the food crops in terms of stunted growth occurs from the second year due to shading effects (Maghembe and Redhead, 1982 and Parmesh, 1987). In the current study, depression of the food crop yields was observed during the second year, when the coffee canopy started closing up.

The yield of intercrops was found to be comparable to the yields of purestand and, in some cases, the intercrops had higher yields than the purestands. The food intercrops may have benefitted from the fertilizer applied to the coffee and this may explain the observed higher yields. Yields of crops under trees has been observed to increase (Gill *et al.*, 1982; Chaturvedi, 1983; Vinaya and Suresh, 1988) and also to decrease (Dhillon *et al.*, 1982; Gupta 1986). This is attributed to the tree density adopted, age of the trees and distance from the intercrop to the coffee tree. In Kenya, Mwakha (1987) observed that yields of dry beans were depressed and the plants became etiolated when grown close to coffee. In the current study, the food crops were grown for more than 50 cm from the coffee tree, and therefore the adverse effects on the food crops could be attributed only to the coffee tree density and not to the proximity to the coffee trees.

During the first year of change of cycle, intercropping in conventional and hedgerow spaced coffee with food crops resulted in a yield advantage (LER < 1). Despite the fact that there was no coffee yield in the first year of change of cycle in the high density spacing, only intercropping coffee with Irish potatoes and tomatoes did not have a yield advantage. The other food crops had higher yields when intercropped than in their sole crops, resulting in partial LER of more than one, hence a yield advantage. During the second year, the yield advantage declined with increasing coffee tree densities due to the low intercrop yields.

Results from this study have shown that it is possible to intercrop mature coffee planted low and medium densities at the change of cycle period, with beans, cowpea, Irish potatoes, tomatoes, sweet potatoes and garden peas. This can be done for four consecutive seasons without affecting coffee yield and quality. The yield of the food crops were however depressed during the third and fourth seasons. Intercropping resulted in a yield advantage. Farmers,therefore may get the full coffee yield (as in non-intercropped coffee) and some additional yields of the intercropped food crop. There was a monetary advantage due to the intercrops. Njoroge (1992) and Njoroge and Mwakha, (1994) reported positive net economic benefits due to intercropping young coffee with food crops. This means that the income base of the farmer is increased by intercropping.

Intercropping food crops with high density coffee was only advantageous during the first year before the canopy closed up. Although the food crops continued producing during the second year, the yields were very low due to shading by the coffee. This is contrary to the Mwakha (1987) who observed that four consecutive bean crops could be intercropped in pruned high density coffee. Mwakha (1987) based his conclusion on yields alone. In this study the yield advantages were also considered. The length of the intercropping period could also be influenced by the prevailing weather conditions, the inherent soil fertility and the coffee management. All these factors influence the coffee growth rate.

5.5 Conclusions

The study showed that it is possible to utilise the interrow space during the change of cycle through intercropping. It is evident from this study that it is possible to grow successfully annual food crops at this stage of coffee growth.

This study also shows that for conventional and hedgerow coffee, it is possible to intercrop for the two year of change of cycle period. Intercropping high density coffee is possible only in the first year of change of cycle. In the second year, coffee canopy develops very fast and shades the food crops thus reducing food crops.

It is therefore concluded that beans, cowpeas, Irish potatoes, tomatoes, garden peas and sweet potatoes can be intercropped with conventional and hedgerow coffee during the two year change of cycle period. For high density coffee this is only possible during the first year of change of cycle.

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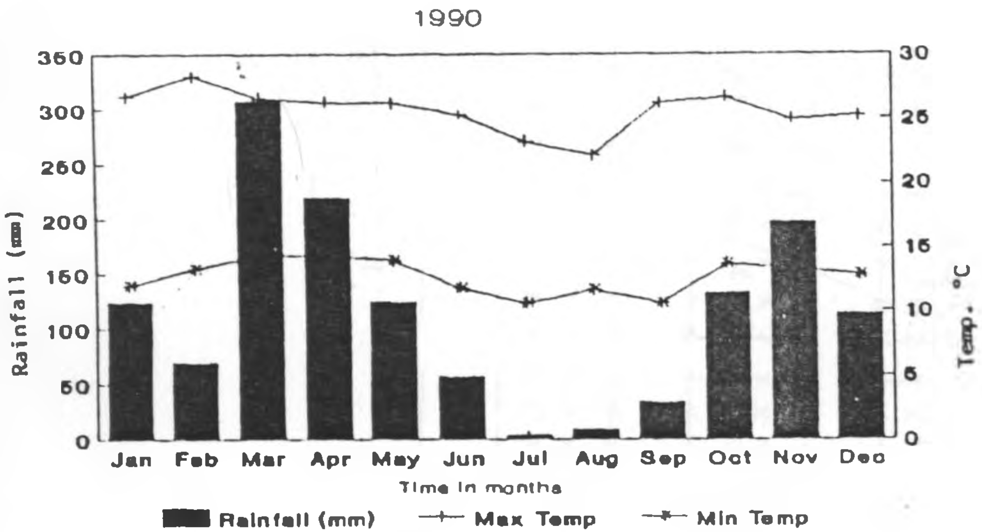
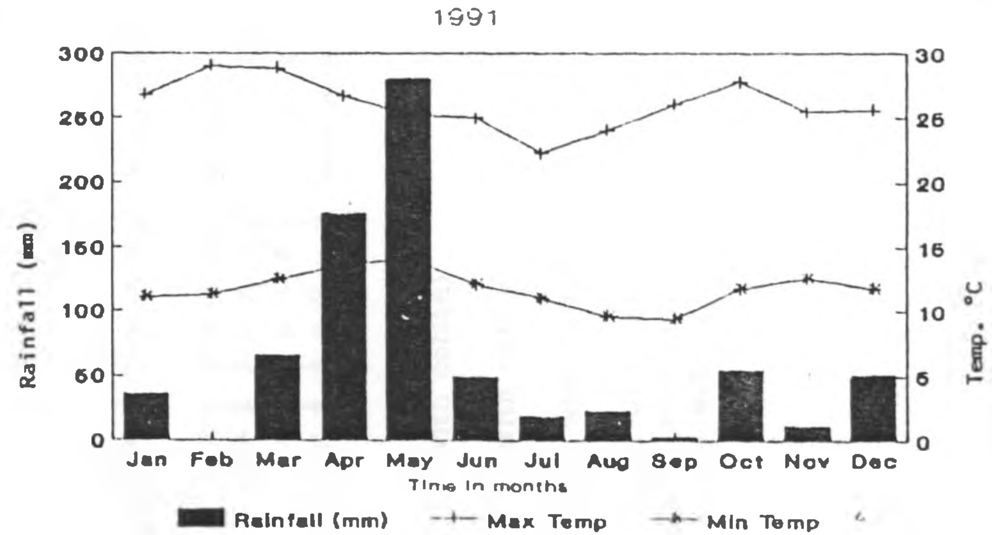
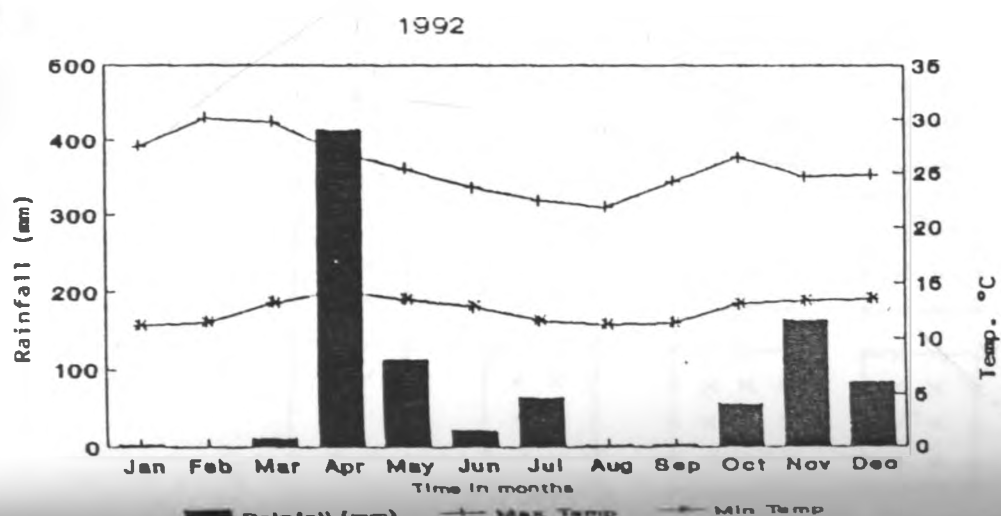
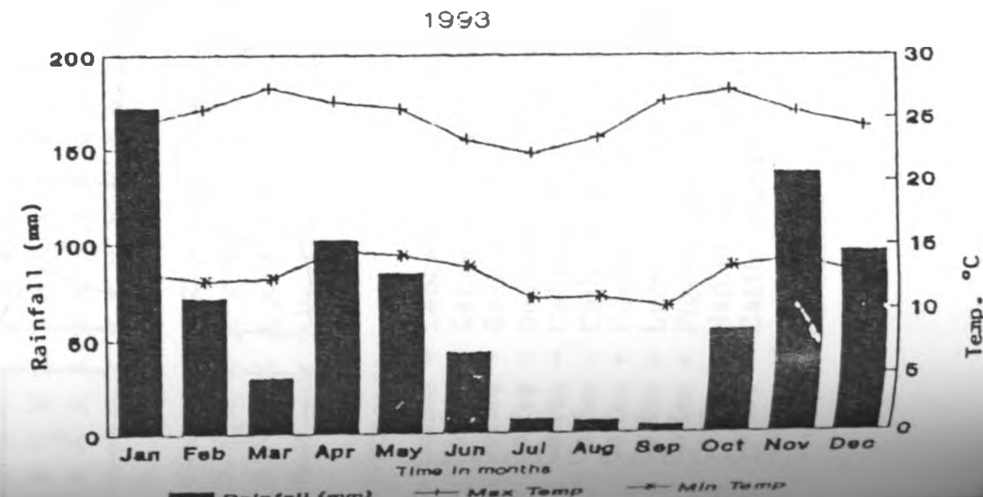
7.0 APPENDICES

Appendix 1: Meteorological records for Coffee Research Station, Ruiru 1° 06'S, 36° 45'E

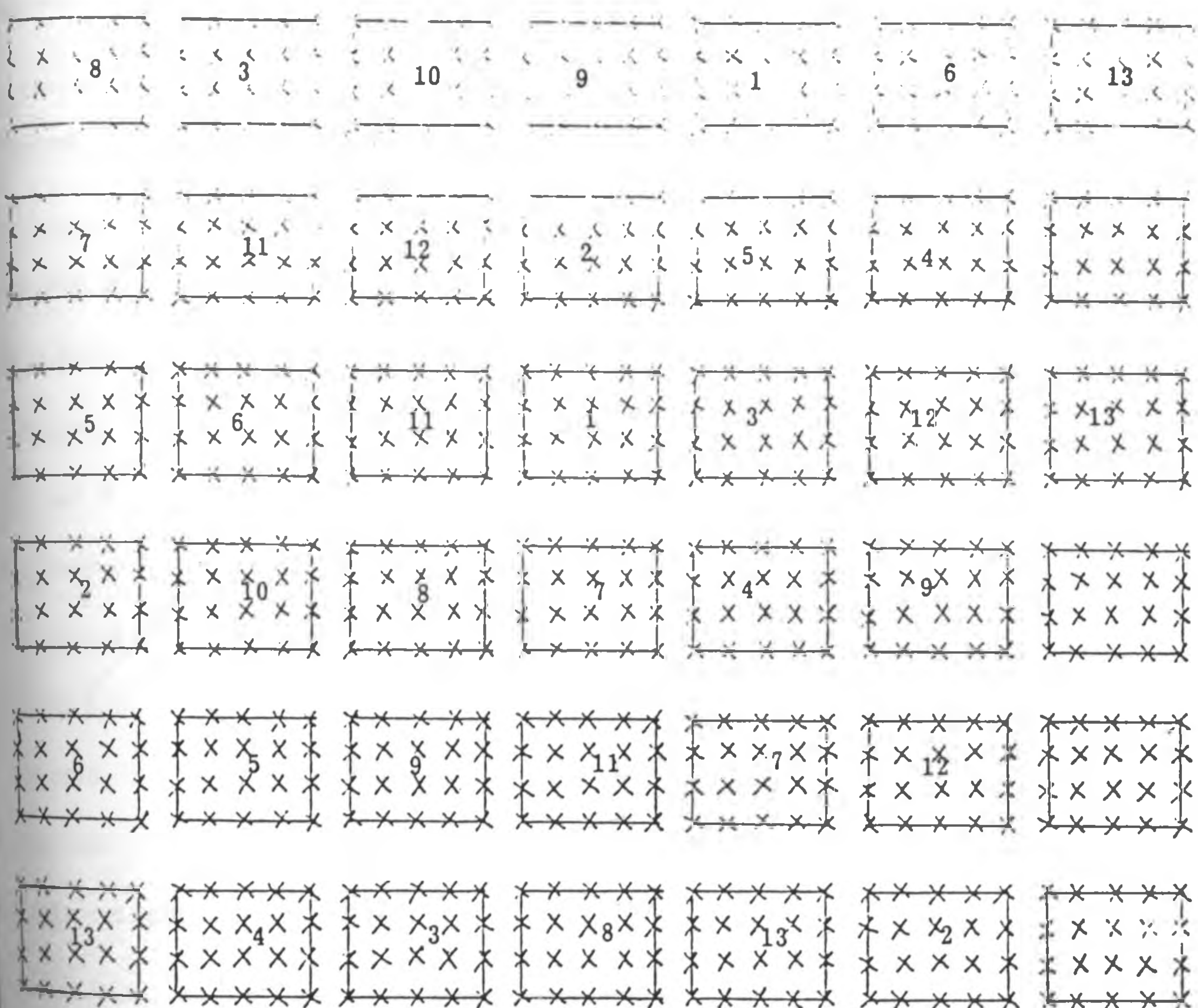








Appendix 2: Field layout of the green manuring trial



Treatments:

1. Coffee + Leucena mulch (Intercropped with coffee)
2. Coffee + Leucena mulch (Brought in)
3. Coffee + Sesbania mulch (Intercropped with coffee)
4. Coffee + Sesbania mulch (Brought in)
5. Coffee + Calliandra mulch (Intercropped with coffee)
6. Coffee + Calliandra mulch (Brought in)
7. Coffee + Desmodium mulch (Intercropped with coffee)
8. Coffee + Lucerne mulch (Intercropped with coffee)
9. Coffee + Pigeon pea mulch (Intercropped with coffee)
10. Coffee + Napier grass mulch
11. Coffee + Cattle manure
12. Conventional coffee
13. Unfertilized coffee

Appendix 3: Chemical analysis of the cattle manure and napier grass used in the green manuring trial

Element	Cattle manure	Napier grass
Nitrogen %	1.84	1.51
Phosphorous %	0.51	0.62
Potassium %	2.85	4.23
Calcium %	1.76	0.27
Magnesium %	0.37	0.25
Boron ppm	26	18
Copper ppm	16	25
Iron ppm	966	1300
Zinc ppm	94	132
Manganese ppm	632	157

Appendix 4: Nutrient composition of prunings of tree shrubs and green manure crops 1992 - 1993

Appendix 4a: Nutrient composition of prunings of tree shrubs and green manure crops - 1992

	N %	P %	K %	Ca %	Mg %
Calliandra	6.37	0.27	2.94	1.97	0.44
Sesbania	6.81	0.31	3.34	1.91	0.43
Leucaena	5.50	0.25	4.24	1.79	0.53
Pigeon pea	5.33	0.36	2.67	1.18	0.39
Lucerne	3.54	0.27	4.09	1.36	0.34
Desmodium	3.3	0.1	1.54	0.86	0.10

Appendix 4b: Nutrient composition of prunings of tree shrubs and green manure crops 1993

	N %	P %	K %	Ca %	Mg %
Calliandra	3.96	0.29	1.71	0.52	0.20
Sesbania	4.04	0.29	2.44	0.76	0.21
Leucaena	4.48	0.33	2.39	0.61	0.24
Pigeon pea	2.56	0.21	1.75	0.65	0.58
Lucerne	3.58	0.21	2.82	1.23	0.25
Desmodium	2.82	0.21	2.36	0.86	0.22

Appendix 5: Anova tables for green manure application to young coffee trial

Appendix 5.1: Nutrient yield 1992

a) % Nitrogen

Source	DF	SS	MS	F
Reps	2	26628.19	13314.094	1.28
Treats	8	1462960.27	182870.033	17.63 **
Error	16	165933.23	10370.827	
Total	26	1655521.68		

b) % Phosphorus

Source	DF	SS	MS	F
Reps	2	79.99	39.996	0.56
Treats	8	18832.98	2354.122	32.96**
Error	16	1142.66	71.416	
Total	26	20055.63		

c) Potassium

Source	DF	SS	MS	F
Reps	2	10265.03	5132.515	1.52
Treats	8	479223.78	59902.973	17.75*
Error	16	53998.42	3374.901	
Total	26	543487.23		

** Significant at P = 0.01
* Significant at P = 0.05

d) Calcium

Source	DF	SS	MS	F
Reps	2	2478.23	1239.116	1.59
Treats	8	160701.07	20087.633	25.72 **
Error	16	12497.18	781.074	
Total	26	175676.48		

e) Magnesium

Source	DF	SS	MS	F
Reps	2	208.50	104.250	1.49
Treats	8	7537.0907	942.137	13.47**
Error	16	1119.13	69.945	
Total	26	175676.48		

** Significant at P = 0.01

Appendix 5.2 Dry matter production and nutrient yield, 1993

a) Dry matter production

Source	DF	SS	MS	F
Reps	2	7336129.19	3668064.593	3.26
Treats	8	217733836.74	27216729.593	24.15**
Error	16	18030044.81	1126877.801	
Total	26	243100010.74		

b) Nitrogen

Source	DF	SS	MS	F
Reps	2	8581.31	4290.654	3.32
Treats	8	208792.08	26099.010	20.19**
Error	16	20681.76	1292.610	
Total	26	238055.15		

c) Phosphorus

Source	DF	SS	MS	F
Reps	2	62.60	31.299	2.97
Treats	8	1410.79	176.349	16.74**
Error	16	168.59	10.537	
Total	26	543487.23		

** Significant at P = 0.01

d) Potassium

Source	DF	SS	MS	F
Reps	2	3739.35	1869.675	3.01
Treats	8	101329.46	12666.182	20.38**
Error	16	9945.06	621.566	
Total	26	115013.87		

e) Calcium

Source	DF	SS	MS	F
Reps	2	459.36	229.681	2.44
Treats	8	14192.16	1774.020	18.83
Error	16	1507.52	94.220	
Total	26	16159.04		

f) Magnesium

Source	DF	SS	MS	F
Reps	2	13.34	6.671	0.55
Treats	8	5020.03	627.504	51.84
Error	16	193.69	12.106	
Total	26	5227.07		

** Significant at P = 0.01

Appendix 5.3 Nitrogen mineralization by decomposing leguminous green manures

a) One week

Source	DF	SS	MS	F
Reps	3	2.32	0.774	0.23
Treats	5	339.27	67.855	20.47**
Error	15	49.73	3.315	
Total	23	391.32		

b) Two Weeks

Source	DF	SS	MS	F
Reps	3	46.74	15.579	1.58
Treats	5	432.69	86.537	8.79**
Error	15	147.60	9.840	
Total	23	627.03		

c) Three weeks

Source	DF	SS	MS	F
Reps	3	59.37	19.790	2.22
Treats	5	595.91	119.182	13.40**
Error	15	133.44	8.896	
Total	23	788.72		

** Significant at $P = 0.01$

d) Four weeks

Source	DF	SS	MS	F
Reps	3	91.93	30.644	3.97
Treats	5	470.08	94.015	12.17**
Error	15	115.92	7.728	
Total	23	677.93		

e) Seven weeks

Source	DF	SS	MS	F
Reps	3	88.83	29.610	2.42
Treats	5	791.12	158.225	12.93**
Error	15	183.49	12.233	
Total	23	1063.44		

f) Eleven weeks

Source	DF	SS	MS	F
Reps	3	29.39	9.789	1.71
Treats	5	920.42	184.085	32.17**
Error	15	85.84	5.722	
Total	23	1035.63		

** Significant at P = 0.01

Appendix 5.4 Top Soil chemical status in September 1993

a) Exchangeable acidity (Hp)

Source	DF	SS	MS	F
Reps	2	0.01	0.005	0.50
Treats	12	0.11	0.009	0.94
Error	24	0.24	0.010	
Total	38	0.37		

b) % Nitrogen

Source	DF	SS	MS	F
Reps	2	0.00	0.002	2.20
Treats	12	0.01	0.001	1.55
Error	24	0.02	0.001	
Total	38	0.03		

c) Potassium

Source	DF	SS	MS	F
Reps	2	0.69	0.343	3.46*
Treats	12	3.48	0.290	2.93*
Error	24	2.38	0.099	
Total	38	6.54		

d) Ca+Mg/K

Source	DF	SS	MS	F
Reps	2	3.40	1.702	2.02
Treats	12	29.42	2.451	2.90 *
Error	24	20.26	0.844	
Total	38	53.08		

* Significant at P = 0.05

Appendix 5.5: Sub soil chemical status as affected by application of leguminous green manures in September 1993.

a) pH

Source	DF	SS	MS	F
Reps	2	0.25	0.127	1.71
Treats	12	1.02	0.085	1.14
Error	24	1.79	0.074	
Total	38	3.06		

b) Hp m.e %

Source	DF	SS	MS	F
Reps	2	0.05	0.024	3.72
Treats	12	0.11	0.009	1.36
Error	24	0.16	0.007	
Total	38	0.31		

c) % Carbon

Source	DF	SS	MS	F
Reps	2	1.54	0.769	4.99
Treats	12	2.80	0.233	1.51
Error	24	3.70	0.154	
Total	38	8.04		

d) % Nitrogen

Source	DF	SS	MS	F
Reps	2	1.00	0.001	1.48
Treats	12	0.02	0.001	1.60
Error	24	0.02	0.001	
Total	38	0.04		

e) Potassium ppm

Source	DF	SS	MS	F
Reps	2	0.65	0.324	3.88
Treats	12	2.33	0.194	2.33
Error	24	2.00	0.83	
Total	38	4.98	4.98	

f) Manganese ppm

Source	DF	SS	MS	F
Reps	2	0.36	0.181	3.56
Treats	12	0.49	0.041	0.81
Error	24	1.22	0.051	
Total	38	2.07	4.98	

g) Ca+Mg/K

Source	DF	SS	MS	F
Reps	2	5.93	2.964	2.37
Treats	12	29.14	2.428	1.94
Error	24	30.04	1.252	
Total	38	65.11	2.428	

Appendix 5.6: Subsoil water holding capacity 1991-93

a) December 1991

Source	DF	SS	MS	F
Reps	2	49.44	24.720	2.37
Treats	12	58.10	4.842	1.94
Error	24	100.59	4.191	
Total	38	208.13		

b) August 1992

Source	DF	SS	MS	F
Reps	2	13.74	20.441	0.42
Treats	12	245.29	16.195	1.26
Error	24	388.68		
Total	38	647.71		

c) March 1993

Source	DF	SS	MS	F
Reps	2	97.88	48.942	6.31
Treats	12	103.50	8.625	1.11
Error	24	186.22	7.759	
Total	38	387.61		

Appendix 5.7: Leaf nutrient concentration in September 1993

a) % Nitrogen

Source	DF	SS	MS	F
Reps	2	0.14	0.070	3.89
Treats	12	0.50	0.033	1.86
Error	24	0.54	0.018	
Total	38	1.18		

b) Manganese ppm

Source	DF	SS	MS	F
Reps	2	20542.17	10271.083	1.97
Treats	12	95085.00	6339.00	1.31
Error	24	156556.50	5218.550	
Total	38	272183.67		

c) Boron ppm

Source	DF	SS	MS	F
Reps	2	153.79	76.896	1.00
Treats	12	2004.81	133.654	1.74
Error	24	2300.88	76.696	
Total	38			

Appendix 5.8: Increase in coffee plant tree height

a) Jan - Dec 1992

Source	DF	SS	MS	F
Reps	2	107.15	53.574	0.82
Treats	12	808.92	67.410	1.04
Error	24	1560.25	65.010	
Total	38	2476.32		

b) Jan - Dec 1992

Source	DF	SS	MS	F
Reps	2	125.98	62.988	1.28
Treats	12	759.89	63.324	1.28
Error	24	1184.48	49.354	
Total	38	2070.35		

Appendix 5.9: Increase in coffee plant stem diameter

a) Jan - Dec, 1992

Source	DF	SS	MS	F
Reps	2	0.33	0.164	2.76
Treats	12	1.20	0.100	1.68
Error	24	1.42	0.059	
Total	38	2.95		

b) Jan - Dec 1993

Source	DF	SS	MS	F
Reps	2	0.05	0.023	0.96
Treats	12	0.79	0.066	2.76
Error	24	0.57	0.024	
Total	38	1.41		

Appendix 5.10: Increase in coffee plant primary branch length

a) Jan - Dec, 1992

Source	DF	SS	MS	F
Reps	2	47.07	23.536	0.83
Treats	12	947.89	78.991	2.80*
Error	24	677.57	28.232	
Total	38	1672.54		

b) Jan - Dec, 1993

Source	DF	SS	MS	F
Reps	2	45.09	22.545	2.87
Treats	12	170.50	14.208	1.81
Error	24	188.38	7.849	
Total	38	403.97		

Appendix 5.11: Increase in Area of Coffee plant leaves 1992

a) May - July 1992

Source	DF	SS	MS	F
Reps	2	75.77	37.883	0.54
Treats	12	2668.19	222.349	3.15*
Error	24	1694.17	70.590	
Total	38	4438.13		

b) October - December 1992

Source	DF	SS	MS	F
Reps	2	66.34	33.171	0.22
Treats	12	4669.12	389.094	2.53
Error	24	3690.54	153.773	
Total	38	8426.01		

* Significant at P = 0.05

Appendix 5.12: Increase in Area of Coffee plant leaves 1993

a) March - May 1993

Source	DF	SS	MS	F
Reps	2	469.15	234.573	10.05
Treats	12	903.36	75.280	3.22**
Error	24	560.33	23.347	
Total	38	1932.84		

b) July - August 1993

Source	DF	SS	MS	F
Reps	2	448.19	224.093	4.21
Treats	12	1266.25	105.521	1.98
Error	24	1276.71	53.196	
Total	38	2991.14		

c) September - November 1993

Source	DF	SS	MS	F
Reps	2	711.07	355.536	13.10
Treats	12	460.56	38.380	1.41
Error	24	651.37	27.140	
Total	38	1823.00		

** Significant at P = 0.01

Appendix 5.13: Midday coffee leaf water potential 1992

a) March 1992

Source	DF	SS	MS	F
Reps	2	51.42	25.708	9.89
Treats	12	61.99	5.166	1.99
Error	24	62.38	2.599	
Total	38	175.79		

b) August 1992

Source	DF	SS	MS	F
Reps	2	1.73	0.864	0.29
Treats	12	45.89	3.824	1.28
Error	24	71.75	2.989	
Total	38	119.36		

Appendix 5.14: Increase in yield components 1992

a) Total number of primary branches

Source	DF	SS	MS	F
Reps	2	15.38	7.692	1.51
Treats	12	120.31	10.026	1.96
Error	24	122.62	5.109	
Total	38	258.31		

b) Total number of Bearing primary branches

Source	DF	SS	MS	F
Reps	2	54.51	27.256	3.26
Treats	12	484.26	40.355	4.82
Error	24	200.82	8.368	
Total	38	739.59		

c) Total number of bearing nodes per primary branch

Source	DF	SS	MS	F
Reps	2	24.00	12.000	2.63
Treats	12	152.97	12.748	2.80
Error	24	109.33	4.556	
Total	38	286.31		

d) Total number of Nodes per primary branch

Source	DF	SS	MS	F
Reps	2	28.36	14.179	3.74
Treats	12	97.03	8.085	2.13
Error	24	90.97	3.791	
Total	38	216.36		

Appendix 5.15: Increase in yield components 1993

a) Total number of primary branches

Source	DF	SS	MS	F
Reps	2	22.53	11.267	0.60
Treats	4	223.60	55.900	2.97
Error	8	150.80	18.850	
Total	14	396.93		

b) Total number of Bearing primary branches

Source	DF	SS	MS	F	P
Reps	2	12.13	6.067	0.47	
Treats	4	23.73	5.933	0.46	
Error	8	103.87	12.983		
Total	14	139.73			

Appendix 5.16: Clean coffee and grade A beans 1993

a) Clean coffee

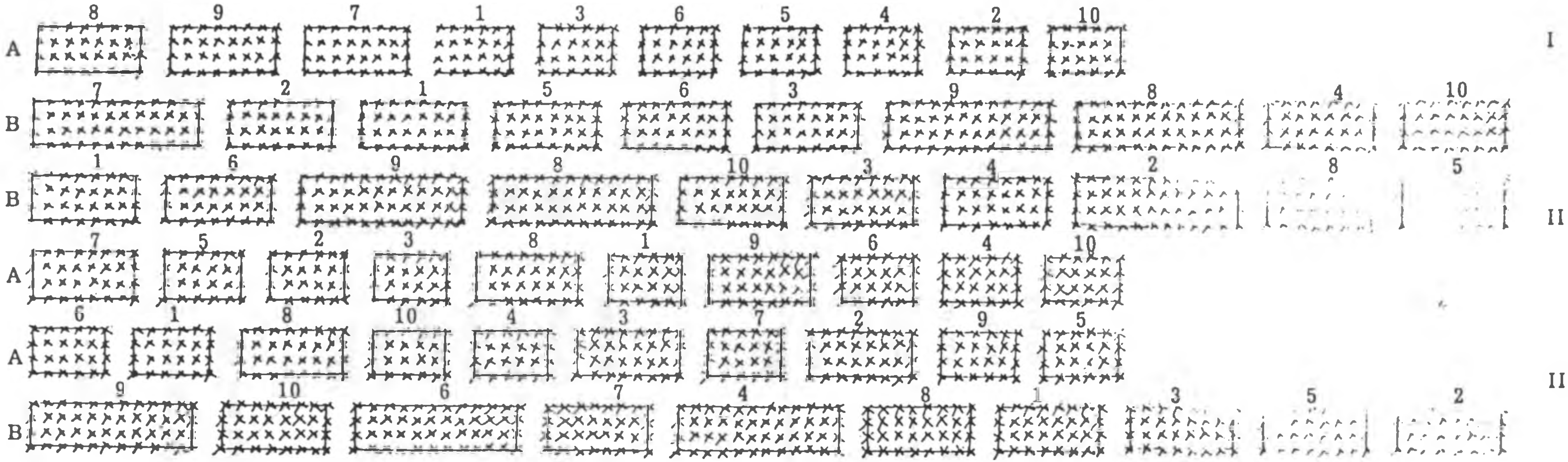
Source	DF	SS	MS	F
Reps	2	127984.05	63992.026	2.10
Treats	12	979170.10	81597.509	2.68*
Error	24	7317961.28	30490.053	
Total	38	1838915.44		

b) % Grade `A'

Source	DF	SS	MS	F
Reps	2	3276.21	1638.105	2.52
Treats	12	18619.59	1551.632	2.39
Error	24	15577.40	649.058	
Total	38	37473.20		

* Significant at P = 0.05

Appendix 6: Intercropping Arabica Coffee with fruit trees trial



COFFEE VARIETIES

A - SL 28

B - Ruiru 11

TREE CROP INTERCROPS

1 - Pawpaw

2 - Passion Fruit

3 - Apples

4 - Oranges

5 - Bananas

6 - Guavas

7 - Avocadoes

8 - Loquats

9 - Macadamia

10 - Sole Coffee

Appendix 7: ANOVA tables for the intercropping young arabica coffee with fruit trees trial

Appendix 7.1: Increase in coffee plant leaf area 1991

a) May - July

Source	DF	SS	MS	F
Rep	2	30.01	19.004	0.16
A	1	2003.96	200.396	1.68
Error	2	2388.20	119.410	
B	9	79.20	79.201	0.38
AB	9	1712.04	171.204	0.82
Error	36	4570.46	207.748	

b) October - December

Source	DF	SS	MS	F
Rep	2	35.46	17.730	0.17
A	1	1783.51	178.351	1.76
Error	2	2031.61	101.580	
B	9	932.63	932.631	9.96 **
AB	9	615.40	61.540	0.66
Error	36	2059.61	93.618	

* Significant at P=0.05
** Significant at P=0.01

Appendix 7.2: Increase in coffee plant leaf area 1992

a) June - September

Source	DF	SS	MS	F
Rep	2	85.94	42.968	0.62
A	1	1793.59	179.359	2.61
Error	2	1376.55	68.828	
B	9	983.84	98.38	10.00**
AB	9	701.39	70.1394	2.02
Error	36	765.33	34.788	

b) October - December

Source	DF	SS	MS	F
Rep	2	303.74	151.869	4.90
A	1	416.71	41.671	1.34
Error	2	620.49	31.024	
B	9	430.90	430.901	10.47 **
AB	9	360.38	36.038	0.88
Error	36	905.48	41.158	

Appendix 7.3: Increase in coffee plant leaf area 1993

a) February - April

Source	DF	SS	MS	F
Rep	2	1093.16	546.581	5.35
A	1	112.96	112.956	1.10
Error	2	204.51	102.254	
B	9	758.56	94.819	1.53
AB	9	612.72	76.589	1.24
Error	36	1980.13	61.879	

b) June - August

Source	DF	SS	MS	F
Rep	2	30.49	15.244	0.46
A	1	1515.27	1515.271	45.41
Error	2	66.74	33.370	
B	9	379.07	47.384	0.74
AB	9	351.03	43.879	0.69
Error	36	2043.20	63.850	

Appendix 7.4: Soil water holding capacity 1993

a) March (Top soil)

Source	DF	SS	MS	F
Rep	2	5.33	2.667	0.83
A	1	3.14	3.142	0.98
Error	2	6.42	3.209	
B	9	35.17	3.517	1.53
AB	9	18.72	1.872	0.81
Error	36	91.92	2.298	

b) March (Sub soil)

Source	DF	SS	MS	F
Rep	2	18.49	9.243	68.69
A	1	0.52	0.517	3.84
Error	2	0.27	0.135	
B	9	77.44	8.604	3.74*
AB	9	18.32	2.035	0.89
Error	36	82.78	2.299	

Appendix 7.5: Top soil chemical properties December 1991

a) Hp

Source	DF	SS	MS	F
Rep	2	0.01	0.003	0.10
A	1	0.05	0.055	2.20
Error	2	0.05	0.025	
B	9	0.31	0.031	2.46
AB	9	0.16	0.016	1.29
Error	36	0.50	0.013	

b) Na m.e %

Source	DF	SS	MS	F
Rep	2	0.02	0.008	1.30
A	1	0.00	0.000	0.05
Error	2	0.01	0.006	
B	9	0.02	0.002	1.13
AB	9	0.01	0.001	0.92
Error	36	0.06	0.001	

c) Ca m.e %

Source	DF	SS	MS	F
Rep	2	37.72	18.858	2.93
A	1	0.03	0.030	0.00
Error	2	12.88	6.441	
B	9	69.68	6.968	1.91
AB	9	31.90	3.190	0.87
Error	36	146.17	3.654	

d) Mg m.e %

Source	DF	SS	MS	F
Rep	2	0.57	0.284	1.23
A	1	0.16	0.164	0.71
Error	2	0.46	0.231	
B	9	6.61	0.661	1.12
AB	9	4.08	0.408	0.69
Error	36	23.54	0.589	

e) Pppm

Source	DF	SS	MS	F
Rep	2	4249.67	2124.833	3.51
A	1	109.47	109.470	0.18
Error	2	1212.39	606.197	
B	10	2425.70	242.570	1.24
AB	10	1535.70	153.570	0.78
Error	40	7826.61	195.665	

Appendix 7.6: Sub soil chemical properties December 1991

a) Hp

Source	DF	SS	MS	F
Rep	2	0.000	0.002	0.14
A	1	0.000	0.000	0.02
Error	2	0.002	0.011	
B	9	0.02	0.022	1.40
AB	9	0.10	0.010	0.65
Error	36	0.62	0.015	

b) Na m.e %

Source	DF	SS	MS	F
Rep	2	0.03	0.13	4.66
A	1	0.00	0.001	0.29
Error	2	0.01	0.003	
B	9	0.01	0.001	1.00
AB	9	0.01	0.001	0.71
Error	36	0.06	0.001	

c) Mg m.e %

Source	DF	SS	MS	F
Rep	2	2.72	1.361	1.18
A	1	0.15	0.148	0.13
Error	2	2.30	1.150	
B	9	4.15	0.415	0.99
AB	9	4.41	0.441	1.05
Error	36	16.75	0.419	

d) Mn m.e %

Source	DF	SS	MS	F
Rep	2	2.68	1.338	7.86
A	1	0.01	0.013	0.08
Error	2	0.34	0.170	
B	9	2.85	0.285	1.80
AB	9	1.83	0.183	1.16
Error	36	6.35	0.159	

e) Ca+Mg/K

Source	DF	SS	MS	F
Rep	2	56.36	28.182	3.15
A	1	1.80	1.800	0.20
Error	2	17.91	8.957	
B	9	31.89	3.189	0.84
AB	9	36.14	3.614	0.95
Error	36	151.59	3.790	

Appendix 7.7: Top soil chemical properties September 1993

a) Hp

Source	DF	SS	MS	F
Rep	2	0.08	0.038	0.81
A	1	0.00	0.000	0.00
Error	2	0.09	0.047	
B	9	0.08	0.089	1.13
AB	9	0.56	0.062	0.79
Error	36	2.83	0.079	

b) K m.e %

Source	DF	SS	MS	F
Rep	2	0.39	0.196	12.63
A	1	0.24	0.241	15.51
Error	2	0.03	0.016	
B	9	4.70	0.522	3.11
AB	9	1.21	0.135	0.80
Error	36	6.04	0.168	

c) Ca m.e %

Source	DF	SS	MS	F
Rep	2	9.03	4.514	1.90
A	1	1.67	1.667	0.70
Error	2	4.74	2.371	
B	9	38.54	4.283	1.43
AB	9	18.76	2.084	0.69
Error	36	107.99	3.000	

d) Mn m.e %

Source	DF	SS	MS	F
Rep	2	1.48	0.738	4.29
A	1	0.20	0.196	1.14
Error	2	0.34	0.172	
B	9	0.35	0.039	1.41
AB	9	0.22	0.025	0.89
Error	36	1.00	0.028	

e) Pppm

Source	DF	SS	MS	F
Rep	2	3544.03	1772.017	60.17
A	1	2.40	2.400	0.08
Error	2	58.90	29.450	
B	9	2520.73	280.081	1.11
AB	9	1989.93	221.104	0.87
Error	36	9103.73	252.881	

f) Ca+Mg/K

Source	DF	SS	MS	F
Rep	2	2.98	1.490	0.97
A	1	0.35	0.351	0.23
Error	2	3.06	1.532	
B	9	34.84	3.871	1.74
AB	9	10.06	1.117	0.5
Error	36	80.00	2.222	

Appendix 7.8: Sub soil chemical properties September 1993

a) pH

Source	DF	SS	MS	F
Rep	2	0.21	0.106	4.58
A	1	0.00	0.001	0.03
Error	2	0.05	0.023	
B	9	1.69	0.187	0.83
AB	9	2.60	0.289	1.28
Error	36	8.13	0.226	

b) Hp

Source	DF	SS	MS	F
Rep	2	0.02	0.011	0.33
A	1	0.14	0.140	4.20
Error	2	0.07	0.033	
B	9	0.42	0.047	0.59
AB	9	0.97	0.108	1.36
Error	36	2.86	0.079	

c) K m.e %

Source	DF	SS	MS	F
Rep	2	0.12	0.058	7.78
A	1	0.03	0.026	3.45
Error	2	0.01	0.007	
B	9	1.33	0.148	1.19
AB	9	0.75	0.083	0.67
Error	36	4.48	0.124	

d) Pppm

Source	DF	SS	MS	F
Rep	2	3603.70	1801.850	6.52
A	1	117.60	117.60	0.43
Error	2	552.70	276.350	
B	9	1532.27	170.252	1.04
AB	9	1778.40	197.600	1.21
Error	36	5876.93	163.248	

e) Ca+Mg/K

Source	DF	SS	MS	F
Rep	2	9.14	4.569	1.30
A	1	16.88	16.875	4.80
Error	2	7.03	3.515	
B	9	67.20	7.467	1.21
AB	9	99.57	11.064	1.79
Error	36	222.37	6.177	

Appendix 7.9: Coffee leaf nutrient concentration September 1993

a) N m.e %

Source	DF	SS	MS	F
Rep	2	0.17	0.083	21.11
A	1	0.01	0.014	3.54
Error	2	0.01	0.004	
B	9	0.21	0.021	1.76
AB	9	0.04	0.004	0.37
Error	36	0.47	0.012	

b) P ppm

Source	DF	SS	MS	F
Rep	2	0.01	0.007	0.72
A	1	0.00	0.000	0.01
Error	2	0.02	0.010	
B	9	0.01	0.001	1.72
AB	9	0.01	0.001	1.11
Error	36	0.02	0.000	

c) K m.e %

Source	DF	SS	MS	F
Rep	2	0.16	0.082	0.09
A	1	0.66	0.660	0.7
Error	2	1.88	0.942	
B	9	0.37	0.037	1.18
AB	9	0.30	0.030	0.97
Error	36	1.25	0.031	

d) Ca m.e %

Source	DF	SS	MS	F
Rep	2	0.49	0.246	6.96
A	1	0.01	0.007	0.20
Error	2	0.07	0.035	
B	9	0.53	0.053	1.00
AB	9	0.50	0.050	0.93
Error	36	2.14	0.053	

e) Bo ppm

Source	DF	SS	MS	F	P
Rep	2	297.09	148.545	0.49	
A	1	70.06	70.061	0.23	
Error	2	612.48	306.242		
B	9	471.03	47.103	0.70	
AB	9	807.27	80.727	1.20	0.317
Error	36	2682.42	67.061		

f) Cu ppm

Source	DF	SS	MS	F	P
Rep	2	47122.30	23561.152	0.20	
A	1	84387.88	84387.879	0.70	
Error	2	241109.94	120554.970		
B	9	15308.36	1530.836	0.81	
AB	9	32038.79	3203.879	1.71	0.113
Error	36	75143.76	1878.594		

g) Mn ppm

Source	DF	SS	MS	F
Rep	2	10004.48	5002.242	0.51
A	1	6801.52	6801.515	0.69
Error	2	19789.94	9894.970	
B	9	21952.48	2195.248	1.00
AB	9	17741.82	1774.182	0.81
Error	36	87888.24	2197.206	

Appendix 7.10 Yield of Clean Coffee

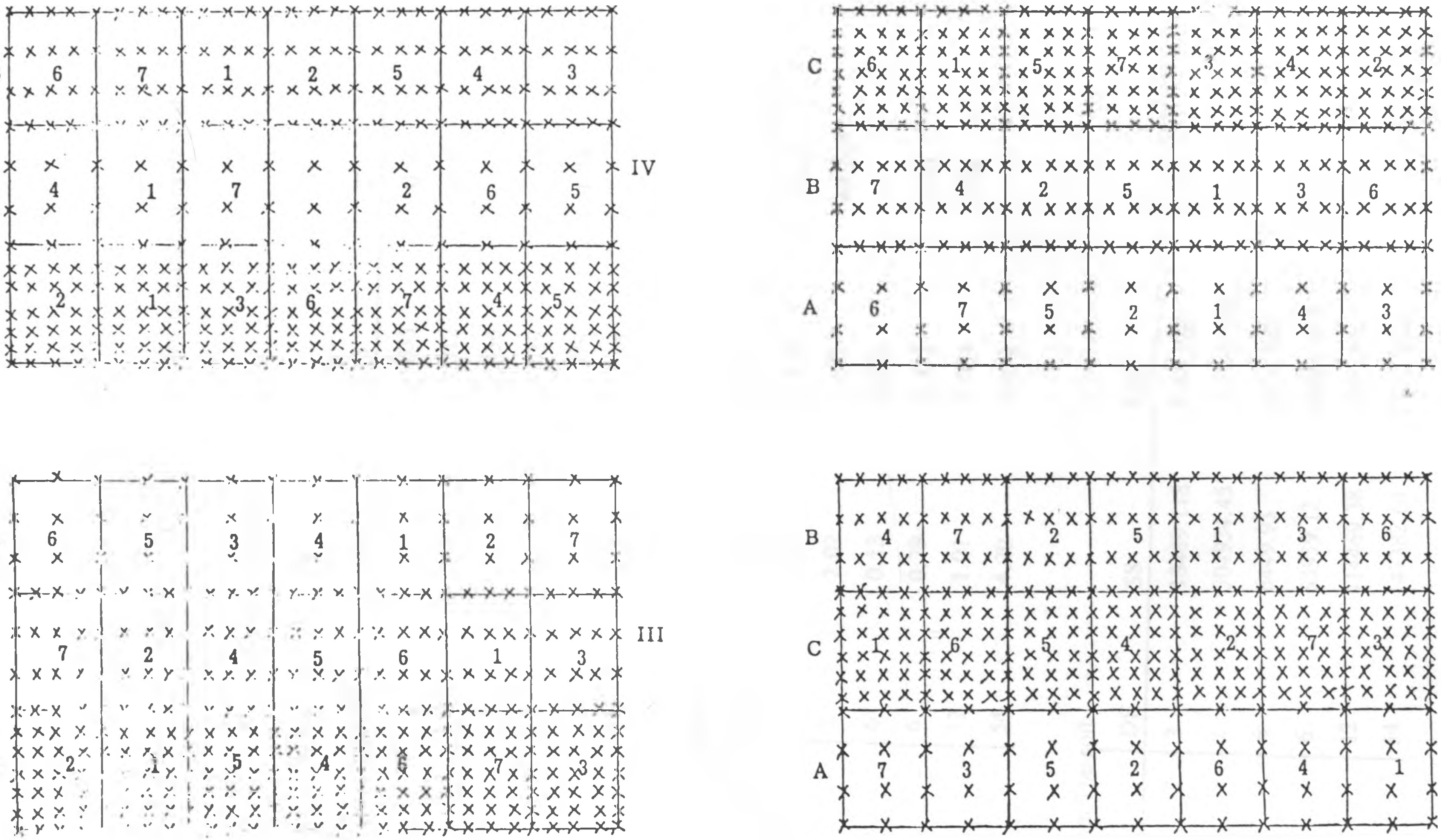
a) 1991

Source	DF	SS	MS	F
Rep	2	38178.26	19089.130	0.46
A	1	4455391.13	4455391.130	106.99
Error	2	83282.93	41641.463	
B	9	1072056.48	134007.060	1.64
AB	9	2078558.70	259819.838	3.18
Error	36	2618057.48	81814.296	

b) 1993

Source	DF	SS	MS	F
Rep	2	1872116.10	936058.050	10.07
A	1	842298.02	6842298.017	9.06
Error	2	185955.83	92977.917	
B	9	4772922.02	530324.669	2.80
AB	9	1671075.48	185675.054	0.98
Error	36	6827251.40	189645.872	

Appendix 8: Intercropping food crops with traditional Arabica coffee Cv. SL28 at c. .nge of cycle and at three ce densities



COFFEE TREE DENSITIES

A - 1330 trees/ha
B - 2660 trees/ha

FOOD CROPS

1 - Field beans
2 - Cow Peas
3 - Irish Potatoes
4 - Tomatoes
5 - Sweet Potatoes
6 - Garden Peas
7 - Sole Coffee

Appendix 9: ANOVA tables for intercropping coffee at change of cycle trial

Appendix 9.1: Soil Chemical Properties

a) Hp m.e % Top soil

Source	DF	SS	MS	F
Rep	3	0.10	0.035	0.97
A	2	0.02	0.012	0.32
Error	6	0.22	0.036	
B	6	0.77	0.129	2.33
AB	12	0.89	0.074	1.34
Error	54	2.98	0.055	

b) K m.e % Top soil

Source	DF	SS	MS	F
Rep	3	1.85	0.616	29.42
A	2	2.02	1.009	48.20*
Error	6	0.13	0.021	
B	6	0.79	0.132	1.70
AB	12	1.01	0.084	1.09
Error	54	4.20	0.078	

c) P ppm Top soil

Source	DF	SS	MS	F
Rep	3	18489.118	6163.060	5.73
A	2	304934.45	152467.226	141.83**
Error	6	6449.93	1074.988	
B	6	63959.12	10659.853	3.91*
AB	12	414469.38	3455.782	1.27
Error	54	147382.64	2729.308	

d) Hp m.e % Sub soil

Source	DF	SS	MS	F
Rep	3	0.47	0.155	0.26
A	2	1.06	0.530	0.88
Error	6	3.59	0.599	
B	6	2.38	0.396	0.97
AB	12	9.05	0.754	1.84
Error	54	22.14	0.410	

e) K m.e % Sub soil

Source	DF	SS	MS	F
Rep	3	0.82	0.275	6.31
A	2	0.49	0.247	5.67
Error	6	0.26	0.044	
B	6	0.95	0.158	1.70
AB	12	0.23	0.019	0.21
Error	54	5.01	0.093	

f) P ppm Sub soil

Source	DF	SS	MS	F
Rep	3	14757.19	4919.063	9.09
A	2	129601.02	64800.512	119.80**
Error	6	3245.45	540.909	
B	6	8967.74	1494.623	0.70
AB	12	20882.48	1746.206	0.82
Error	54	115248.36	2134.229	

Appendix 9.2: Yield Components 1992 - 93

a) Total number of primary branches

Source	DF	SS	MS	F
Rep	3	118.57	39.524	2.95
A	2	229.12	38.187	2.85
Error	6	241.26	13.403	
B	6	50.45	25.226	1.24
AB	12	171.38	14.282	0.70
Error	54	852.17	20.290	

b) Total number bearing primary branches

Source	DF	SS	MS	F
Rep	3	61.33	20.444	2.23
A	2	71.31	11.885	1.30
Error	6	165.17	9.176	
B	6	52.79	26.393	1.84
AB	12	100.05	8.337	0.58
Error	54	602.50	14.345	

Appendix 9.3: Clean coffee yield and % grade `A' beans 1992

a) Yield of Clean coffee

Source	DF	SS	MS	F
Rep	3	72975.81	243250.937	1.42
A	2	16606155.07	8303077.536	48.50*
Error	6	1027225.40	171204.234	
B	6	41513.14	6918.857	0.07
AB	12	651285.93	54273.827	0.58
Error	54	5075171.79	93984.663	

b) % grade `A' beans

Source	DF	SS	MS	F
Rep	3	43.89	14.631	0.40
A	2	3.06	3.064	0.08
Error	6	109.39	36.463	
B	6	940.13	156.688	2.47*
AB	12	290.06	48.344	0.76
Error	54	2283.09	63.419	

Appendix 9.4 Yield of clean coffee and % grade `A' beans 1993

a) Clean coffee yields

Source	DF	SS	MS	F
Rep	3	1598158.38	532719.460	3.86
A	2	1194668.81	199111.468	1.44
Error	6	2484893.29	138049.627	
B	6	37547558.02	18773779.012	114.76**
AB	12	7112308.98	592692.415	3.62
Error	54	6870754.33	163589.389	

b) % grade `A' beans

Source	DF	SS	MS	F
Rep	3	25.42	8.472	0.10
A	2	877.32	438.661	5.19
Error	6	506.98	84.497	
B	6	487.59	81.264	1.40
AB	12	715.21	59.601	1.03
Error	54	3130.95	57.981	

Appendix 9.5 Percent Light Interception 1992

a) 22/6/92

Source	DF	SS	MS	F
Rep	3	1103.05	367.684	8.44
A	2	263.80	87.932	2.02
Error	6	391.87	43.541	
B	6	8349.55	8349.551	50.74**
AB	12	394.68	131.560	0.80
Error	54	1974.69	164.557	

b) 20/7/92

Source	DF	SS	MS	F
Rep	3	2390.99	796.995	2.42
A	2	602.43	200.809	0.61
Error	6	2964.64	329.404	
B	6	4873.31	4873.313	8.59**
AB	12	960.59	320.197	0.56
Error	54	6808.28	567.357	

c) 17/8/92

Source	DF	SS	MS	F
Rep	3	2018.29	672.263	4.37
A	2	1926.89	642.296	4.17
Error	6	1384.94	153.883	
B	6	7925.41	7925.406	34.62**
AB	12	525.60	175.201	0.77
Error	54	2747.05	228.921	

d) 12/9/92

Source	DF	SS	MS	F
Rep	3	284.81	94.9375	0.14
A	2	1089.09	363.031	0.54
Error	6	6102.94	678.105	
B	6	2655.38	2655.383	10.47*
AB	12	62.77	20.922	0.08
Error	54	3043.80	253.650	

e) 26/10/92

Source	DF	SS	MS	F
Rep	3	4972.30	1657.433	19.17
A	2	234.81	78.271	0.91
Error	6	778.25	86.472	
B	6	6409.95	6409.950	15.25**
AB	12	191.91	63.969	0.15
Error	54	5044.93	420.411	

f) 23/11/92

Source	DF	SS	MS	F
Rep	3	7505.09	2501.697	6.65
A	2	1970.56	656.852	1.75
Error	6	3387.21	376.357	
B	6	8541.25	8541.25	19.93**
AB	12	1745.18	1745.18	1.36
Error	54	5143.44	5143.44	

g) 21/12/92

Source	DF	SS	MS	F
Rep	3	1710.22	570.072	1.73
A	2	1264.55	421.516	1.28
Error	6	2957.72	328.636	
B	6	2450.00	2450.000	1.33
AB	12	3650.46	1216.821	0.66
Error	54	22051.09	1837.591	

Appendix 10: Critical soil and coffee leaf nutrient levels for optimum growth and production in Kenya

(a) Leaf-

	Percent DM 4th leaf pair						ppm dm 4th leaf pair				
	N	P	K	Ca	Mg	S	B	Cu	Fe	Mn	Zn ppm
Deficient (D)	<2.5	<0.15	<2.2	<1.0	<0.25	<0.15	<40	<20	<50	<50	<10
Normal	2.0	0.15	2.2	1.0	0.25	0.15	40	20	50	50	10
or	to	to	to	to	to	to	to	to	to	to	to
Adequate (A)	3.0	0.30	3.0	2.0	0.40	0.30	100	100	200	200	30
Excess (E)	>3.0	>3.0	>3.0	>2.0	>0.40	>0.30	>100	>100	>200	>200	>30

(b) Soil

	pH	Hp	Na	K	Ca	Mg	Mn	P ppm	$\frac{Ca+Mg}{K}$
Deficient (D)	<4.4			<0.4	<1.6	<0.8		<20	<4
Normal	4.4			0.4	1.6	0.8		20	4
or	to			to	to	to		to	to
Adequate (A)	5.4			2.0	10.0	4.0		100	10
Excess (E)	>5.4		>0.2	>2.0	>10	>4.0		>100	>10