RESPONSE OF PIGEONPEA (Cajanus cajan (L.)Millsp) TO PHOSPHATE AND NITROGEN FERTILISERS AND ANIMAL MANURE.

by

CHRISTOPHER BUNDI MUKINDIA.

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Department of Crop Science
Faculty of Agriculture.

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DECLARATION

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

Name : MUKINDIA, CHRISTOPHER BUNDI.

Signature ____________________ Date 10 - 10 - 1993

This thesis has been submited with our approval as University supervisors.

Sign. ________ Sign. ________

Date 25-10-93 Date 23/12/93

Dr. D.R. Basiime
Department of Crop Science
Faculty of Agriculture
University Of Nairobi.

Dr. P.M. Kimani
Department of Crop Science
Faculty of Agriculture
University Of Nairobi.

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TABLE OF CONTENTS

LIST OF FIGURES

LIST OF TABLES

ABSTRACT

Pigeonpea yields in East Africa are usually low ranging between 600-700 kg /ha. This has been attributed to a number of factors of which soil factors such as nutrient levels is one of them. Comparatively little research on the nutrition of pigeonpea appear to have been conducted.

An experiment was conducted for two seasons, at Kiboko and Machakos in the first season, long rains 1989, and at Kiboko and Thika for the second season, short rains 1989/90, to determine the response of two pigeonpea cultivars, Katheka and NPP 670 to fertilizer and manure application. Nitrogen was applied at 15, 30 and 45 kg N/ha as urea (46% N). Phosphate was applied as triple superphosphate (45% P_2O_5) at the rates of 40, 80 and 120 kg/ha; while cow manure was applied at 5 and 10 tons/ha. Control plots where no fertilizer or manure were added were also maintained. The experimental design was a split-split block design with cultivars in the main plots, fertilisers in the sub-plots and fertiliser levels in sub-sub plots.

At Thika in the short season 1989/90, the fertiliser and manure applications did not have any significant effect on most of the parameters measured. However urea application of 45 kg N/ha significantly increased the pods dry matter and number of pods per plant.

At Kiboko in the long rains 1989, urea application of 15, 30 and 45 kg N/ha increased grain yield by 5.4, 115.3, and 191 percent respectively, while in the short rains 1989/'90, the same urea applications increased grain yield by 79.2, 52, and 84.6 percent respectively.Only urea application 30 and 45 kg N/ha showed significant effect over the control. Manure application of 5 and 10 tons/ha in the long rains 1989, increased grain yields by 35.1 and 62.8 percent, respectively.Urea application of 30, 45 kg N/ha and manure application of 10

tons/ha increased the stems and branches, pods dry matter and the number of primary branches.

In the short rains 1989/'90, at Kiboko, phosphate application of 40, 80 and 120 kg P_2O_5/ha, increased grain yields by 102.7, 80.3 and 11.6 percent respectively. Significant differences in, plant height, number of days to 50% flowering and number of days to 50% maturity were observed between sites, cultivars and seasons. Katheka was significantly taller than NPP 670 in the two sites and took significantly longer period to reach 50% flowering and subsequently longer period to reach 50% maturity. At Kiboko both NPP 670 and katheka grown in the short rains 1989/90 were significantly taller than those grown in the long rains 1989. Katheka plants grown at Kiboko in the short rains 1989/90 were tallest (366.5 cm) followed by those grown at Thika in the short rains 1989/90 (304.2 cm) with those grown at Kiboko long rains were shortest (211.5 cm). NPP 670 plants grown at Kiboko in both seasons were significantly taller than those grown at Thika (66.5 cm). The one grown in short rains (124.9 cm) were taller than those grown in the long rains 1989 (106 cm).

1.0 INTRODUCTION

1.1 General

In Kenya pigeonpea (*Cajanus cajan (L.) Millsp*) is ranked as the second most important pulse crop after field beans (*Phaseolus vulgaris).* It is grown on an estimated 115,000 ha and Kenya is the worlds' second largest producer after India (Anon, 1980).

Agricultural production in Kenya depends largely on about 21% of the land, classified as having high to medium rainfall and to a lesser extent on the vast expanse of land falling in the category of semi-arid to arid areas. It is in the latter regions that pigeonpea is the leading pulse crop because of its drought tolerance. The special value of pigeonpea lies in their ability to produce some yield even in exhausted soils of these semi-arid and arid areas where few alternative crops are available (Nyabundi,1980). In Kenya it is grown mainly in Eastern and drier parts of Central and Coast Province (Onim, 1977).

Kenya's agricultural sector is the driving force for economic growth, provision of employment and generation of foreign exchange from exports. Since agricultural land is limited and is even getting scarcer with rapid population growth , future agricultural growth has to be accomplished through intensification of agricultural production. This requires among other measures, increased use of agricultural inputs, especially fertilisers.

1.2 Uses and importance of pigeonpea

Pigeonpeas are primarily grown for their dry seeds. These are usually either boiled mixed with maize or fried and eaten as a vegetable when green. In the coastal region of Kenya the dry seeds are cooked in coconut oil and eaten with either bread, 'chapati' or 'mandazi' especially for breakfast (Ogembe, 1978; Nyabundi, 1980). The green immature seeds are occasionally harvested and eaten as a vegetable. In India, the dry seeds are split and made into 'dhal'.The dried husks, seeds and broken 'dhal' are also used as cattle feed in India. The top of the plants with fruits provide excellent fodder and are also made into hay and silage (Ogombe, 1978).

Pigeonpeas are especially useful assoil improving plants and are frequently planted at the end of the rotation as a fertility restoring crop. This is because of it's deep root system which is able to absorb nutrients from the deep soil layers and deposit them at the soil surface when the leaves drop or when the roots rot, in addition to its ability to fix nitrogen.

Pigeonpeas are often grown as boundary plants, hedges or windbreaks. Dried stalks are used as firewood, construction material, fencing material, charcoal making, walling sides of carts and basket making.

Pigeonpea is a protein supplier to both man and animals. The protein content of the dry seeds ranges from 17.5 to 28% with a mean of 20.9%. Aykroyd and Doughty, 1964; F.A.O.,1970; Hulse, 1975) The protein is of good quality and compares well with that of other legumes, such as common beans and cowpeas. The chemical composition of pigeonpea at mature green stage as reported by Litzenberger (1974) is, over 22% protein, 60%carbohydrates, 1.5% fats and 3.5% mineral matter. The content of calcium, phosphorus and iron are also high.

1.3 Climatic and edaphic requirements

Pigeonpea shows a wide range of climatic and edaphic adaptability, but is more associated with the drier than the wetter tropics. The crop can be grown very successfully even in very poor soils under semi-arid conditions with less than 600 mm mean annual rainfall. It is normally thought to be one of the most drought torelant grain legume. This is possibly due to the plant's deep tap root system (Cobley, 1956; Purseglove ,1968; Pathak ,1970: Smart , 1976). Most cultivars, particularly the tall late maturing ones exhibit a photoperiodic phenomenon. They are short day plants. This affects the time to maturity and also the height of the plant according to the date of sowing.

Pigeonpea can be grown in a wide range of soil types, but it gives optimum yeilds in deep loam almost neutral soils. Excessive acidity inhibits nodulation and plants may become chlorotic or suffer die back when grown on soils outside pH 5-7 or when there is a deficiency of phosphorus or manganese (Kay, 1979).

Pigeonpea does not stand soils deficient in lime or that are water logged. Soils in the semi-arid areas are not only poor in moisture retention but also generally low in nitrogen and phosphorus. Because of the cost of chemical fertilisers, most farmers in these areas do not apply them. Animal manures which are readily available are used, but often in inadequate quantities (Kimani, 1987).

1.4 Factors affecting yields of pigeopea

Yields of pigeonpea per unit area are usually low due to various opposing factors. Yield estimates for Africa are 400 to 570 kg/ha; Asia 350-725 kg/ha and Americas 540 to 2200 kg/ha (Vander Maesen, 1980). In Eastern Africa yields are usually low, ranging from 450 to 670 kg/ha. but yields of upto 2600 kg/ha have been obtained in farmers' fields growing the new cultivars(NPP 670) in Kitui and Machakos Districts in Kenya (Kimani, 1986). The low yields have been attributed mainly to; lack of suitable varieties, several diseases that reduce their productivity, insect damage, moisture stress/drought, labour competition, poor soil fertility, poor crop husbandry and social economic factors (Kimani, 1987) .

Many researchers on the response of pigeonpea to nutrients application have expressed the view that grain legumes grown in the tropics do not respond to fertilisers (Edwards, 1981) . Effect of fertilisers application on grain yield of pigeonpea has been described as erratic (Dalal ,1980) and difficult to obtain (Rachie, et al, 1974). The response of pigeonpea to fertilisers tends to be variable and sometimes poor (Kulkarni, et al ,1980). In seeking an explanation for the failure of grain legume in tropics to respond to fertilisers, it must be borne in mind that legumes can only fix sufficient nitrogen for maximal growth when they are adequately supplied with all essential elements including micronutrients and when nodulated with the appropriate strains of *Rhizobium* (Hallsworth, 1972).

Another reason for the variable and sometimes poor response of pigeonpeas to fertilisers, may be due to limitation by the rainfall pattern and available moisture in the soil profile, hence the variability in response from year to year (Kulkarni, et al, 1980). Nutrient deficiencies lead to substantial yield reductions and affect the growth of the plant as a whole. This often limits the potential economic yields that would have been obtained if these nutrients were supplied.

The recorded grain yield responses of pigeonpea to fertilizer application have ranged from zero in several studies to 114 % (1290 to 2760 kg/ha) yield increase achieved by Chowdhury and Bhatia (1971) with application of 44 kg P/ha as superphosphate. Ngugi (1977) reported that pigeonpea grain yields increased from 2770 to 4258 kg/ha as phosphate fertilizer application increased from 0-90 kg P_2O_5/ha (0-39 kg P/ha).

This shows that there is potential of increasing pigeonpea yield through use of fertilizer. With improved new varieties, there is also a possibility of producing pigeonpea under intensive conditions in the high rainfall areas, or as an irrigated crop with the use of fertilizers and other agricultural inputs.

Legumes are considered as soil recuperative crops and are generally grown without fertilization under rainfed conditions (Kalyan and Rajendra, 1976) Information on nutrient uptake however reveal that sufficient amounts of nutrient are removed by pulse crops. On average legumes remove 150 to175 kg N, 15 to 20 kg P and 60 to115 K kg/ha (Romaine, 1957). Adequate fertilization is necessary for optimum yield of grain legumes with good quality proteins. It is however unlikely that farmers in semi-arid areas will apply fertilizers unless there is real cost benefit advantages in applying the fertilizers.

Little work has done in Kenya to determine the response of pigeonpea to fertiliser application. Hence the need for the present study.

The objectives of the study therefore were:

1. To determine the response of pigeonpea to application of phosphate and nitrogenous chemical fertilisers and animal manure.
2. To identify the pigeonpea yield components which are mostly affected by chemical fertiliser and manure application.
3. To determine the effect of fertiliser application on the soil.

2.0 LITERATURE REVIEW

2.1 Origin and description

Many reports have shown that *Cajanus* is a native of Africa with India as a secondary centre of origin. But according to Van der Maesen (1980) *Cajanus cajan* (L) Millsp, the pigeonpea being cultivated widely in the semi-arid tropics originated from India, which is still the main area of production, but moved to East Africa about 4,000 years ago, where a secondary centre of diversity developed. From Africa the pigeonpea was taken to the West Indies and spread all over tropical America.

Pigeonpea is widely cultivated in the world and is known by many other common names such as red gram, Congo pea, no'eye pea, Angola pea, tur, arhar, gandul, poispigeon, mbaazi, nzuu, njugu and obong'. Pigeonpea is a tropical perennial or annual legumious woody shrub spread widely in tropics and subtropics and grows to a height of half a metre to five metres tall (Cobley, 1956; Goodling, 1962; Purseglove, 1968; Dunbar, 1969; Acland ,1971; West - Phal ,1974). The growth habit of pigeonpeas is generally erect, although some cultivars have spreading branches. Pigeonpea has pronounced deep tap root with long laterals. Young stems are angular and hairy, while leaves are trifoliate and spirally arranged. The inflorescences are small, terminal and/or axillary racemes 4 to 12 cm long with several flowers. The flowers are yellow sometimes tinged red or purple. The pods are hairly, green, dark, maroon or blotched with maroon and are flattened with diagonal depressions between seeds which are 2 to 8 in number. The seeds vary in size, shape and colour, are usually round or oval about 8 mm in diameter, white, greyish, red, brown, purplish or speckled with a small hilum. In general, cultivars of pigeonpea differ in height, time of maturity, colour, size and shapes of the pods and seeds (Ogombe, 1978).

2.2 Fertiliser response

There is conflicting evidence from Puerto-Rico and India, where most of the work on fertiliser response of pigeonpeas in terms of seed yield have been done. The work done in Puerto-Rico suggests that pigeonpeas do not show significant response to any fertiliser application, while on the other hand, data from India clearly indicate that pigeonpea show a positive response to fertiliser application. Landrau and Samels (1959) applied up to 250 kg N, 109 kg P and 208 kg K per/ha in clay soils in Puerto-Rico and found that there was no favourable green pod yield response. These results were confirmed by Pietri, et al, (1971) who applied up to 168 kg each of N,P and K per hectare with and without magnesium, calcium or silicon to pigeonpeas on oxisols and observed no significant response. Abrams (1975) also reported that pigeonpeas did not respond to fertiliser application in Puerto-Rico.

Bhatawadeker, et al ,(1966) working on mixed cropping of *Pennisetum typhoides* and pigeonpea in India found that pigeonpea responded positively only to phosphorus but that with an increase in nitrogen level seed yield in pigeonpea decreased and that optimum fertiliser rate for the mixed crop was 22 kg N plus 21.8 P/ha. Chowdhury and Bhatia (1971) reported marked responses to application of fertilisers on sandy loam soils.
They found that application of 44 kg p/ha as super phosphate increased yield by 114% (1290 to 2760 kg/ha). Ogombe (1978) working at Kabete, Kenya, reported no response to phosphate fertiliser application on the growth, flower and pod abscission, yield and yield components of pigeonpea while Ngugi (1977) working at Katumani,Kenya, reported a response of 53 % increase in yields with application of 90 kg P_2O_5/ha.The level of available phosphorus in the soil was 51 and 47 ppm for the depths 0-15 and 15-30 respectively.

2.3 Response to Nitrogenous Fertiliser

Plants require nitrogen for the manufacture of proteins, enzymes and growth regulators. Use of quickly available nitrogenous fertilisers in crops has resulted in considerable increased in vegetative growth, the response being evident in taller, larger in size and darker in colour crops than those of unfertilised crops. Yield which is a product of fruit bud formation, fruit setting and grain development naturally is often increased greatly by nitrogenous fertiliser application. Nitrogen deficiences lead to stunted plants with yellowish leaves with poor growth and often giving very low or no yields (Pillai, 1967).

Pigeonpea like other legumes has the ability to fix free nitrogen when in association with the right *Rhizobium* strains (Hallsworth 1972). However, young seedlings normally require a starter dose of nitrogen (Kulkarni and Panwar, 1980). The ability of pigeonpea to fix free nitrogen also depends on other nutrientsthat are necessary for nodulation. Nichols (1965) demonstrated that deficiences of calcium, phosphorus and magnessium had a direct and greater effect on reducing plant growth and nodulation than nitrogen, potassium or iron deficiences.

Nitrogen fixation and transfer of nitrogen to other parts of the plant are quite efficient according to experiments carried out in Nigeria by Oke (1967). The researcher found that nitrogen fixation reached a maximum of 14.5 mg/day in *Cajanus* spp compared with 10.3 and 4.6 mg/plant/day for *cerstroma* and *stylosanthes* spp, respectively. Younger plants are more effective than older ones in fixing nitrogen.

In India, Kumar Rao (1980) estimated that pigeonpea could fix upto 69 kg N/ha per season, which accounted for 52% of the total N uptake.

Studies on response of pigeonpea to nitrogen application have been shown to be negative (Sigh and Rathi, 1972, Panwar and Misra, 1973, Panwar, 1975). However on sandy loam soils poor in nitrogen and organic matter a starter dose of 20 to 25 kg N/ha increased the yield of pigeonpea (Ram and Giri 1973, Lenka and Satpathy 1976). At the same centre no significant response to 25 kg N/ha was reported by Kalyan, et al. (1975) but rhizobial culture produced significant response.Chowdhury (1968) and Sewaram, et al, (1973) on the other hand reported that application of 40 kg N/ha depressed yields.

The literature review generally indicates that in many situations a starter dose of 20-25 kg N/ha would be essential for increased yields depending upon the initial fertility status and moisture conditions of the soil.

2.4 Response to Phosphate Fertiliser

Phosphorus is present in plants in nuclei acid, phospholipids and phosphorylates enzymes. It is important in energy storage and transfer. Phosphorus enhances root production, stimulates seed production and at later stages hastens ripening.Deficiency of phosphorus is indicated by a slowing down of growth, stems are slender and often woody, roots are under developed fruit trees drop off their blossoms, fruits are small and mature slowly (Pillai 1967).

Rao, et al, (1980) reported that application of 35 kg P/ha also stimulated nitrogen fixation in cowpeas with a 115% increase in dry matter over plants grown in unamended alfisol soils and a 24% increase in vertisols.

The total amount of phosphorus absorbed by crops is seldomly less than 11.1 or greater than 55.6 kg P_2O_5 per ha per crop.The amount absorbed rises with crop yields (Pillai, 1967). The rate of absorption reaches it's maximum earlier in the growth cycle than does the growth rate. The seedlings absorb phosphorus at a aster rate from fertiliser than from the soil . As the plant develops, the amount of soil phosphorus absorbed increases (Nye , 1961). By the time plants have produced 25% of their dry matter,they have accumulated as much as 75% of their phosphorus needs (Brady, 1984). Total phosphorus in an hectare slice of soil averages about 0.007%, ranging from 0.003to 0.015%in some soils (Pillai, 1967).Soil phosphorus status tends to fall with time due to immobilization in the soil and removal by harvested crop, the magnitude of which rises with crop yields (FAO, 1988).

Most studies indicate phosphorus to be the first limiting element under tropical conditions and recommend applying 20-80kg P_2O_5/ha (BhataWadeker, et al ,1966).

Singh, et al , (1957) noted that application of ammonium phosphate or compost had little effect on the yield of pigeonpea in India,and that response to super-phosphate was not generally visible. Ogombe (1978) also reported lack of response by pigeonpea to phosphate fertiliser on pigeonpea growth in Kabete, Kenya. He observed that phosphate fertiliser increased the number of flower buds initiated per plant but most of these were shed before they even set pods,hence no effect on the number of mature pods per plant and on percentage flower and pod abscission. In India responses to phosphate have been generally positive and in some cases highly significant. At Delhi, India, pigeonpea dry seed yield was increased from 1290 to 2760 kg/ha by application of upto 100 kg P_2O_5/ha (Chowdhury, et al,1971).

In a multi-national trial on different research farms in Ultar Pradesh, India, pigeonpea T-21 type responded upto 40 kg P_2O_5/ha in loamy clay soil and upto 80 kg P_2O_5/ha in light loam soil (Panwar and Misra, 1973; Rathi and Tripathi,1978; Rathi, et al ,1974). High responses have been obtained in sandy loam soils low in available phosphorus, at the Indian Agricultural Research Institute New Delhi; (Bains, 1970; Chowdhury, et al ,1971;

Singh, et al ,1976; Manjhi, et al ,1973).

The average response obtained by most of these researchers was a yield of 440 kg of grain/ha with application of 44 kg P_2O_5/ha.

In Ibadan, Nigeria, application of 34 kg P_2O_5/ha gave the greatest dry matter yield of pigeonpea (Oguwale et al, 1978). Their work also revealed that application of phosphorus in excess of 69 kg P_2O_5/ha was not beneficial. Similarly Singh, et al ,(1957) reported that application of 30 kg P_2O_5/ha increased most growth and yield attributes and increased grain yield significantly over the control to which no phosphorus was applied. However increasing applied phosphorus to 60 kg P_2O_5/ha gave no additional yield. The highest yielding cultivar BS-1 benefited most from phosphate application. Ahlwat, et al ,(1981) also reported that application of phosphorus improved plant growth, plant height, number of primary branches per plant, stem girth, number of pods per plant, number of grains per pod, grain yield and 1000 grain weight. He however found that increasing phosphorus from 39 to 78 kg P_2O_5/ha did not give any improvements in the above characters, except for height and number of branches. In India Chowdhury, et al ,(1971), observed that with application of 34,68, and 102 kg P_2O_5/ha, pigeonpea grain yield response were 2030, 2340, and 2760 kg of grain/ha respectively. Lenka, et al , (1976) reported that grain yield increased linearly at a rate of 128 kg of grain per every 40 kg of P_2O_5 applied upto 120 kg P_2O_5/ha. Similar response to grain yield of pigeonpea has been reported by Raheja (1956), Chowdhury, (1968) and Sewaram and Giri, (1973).

Pigeonpea grain yield were increased from 1.46 to 1.83 tons/ha with application of 40 kg P_2O_5/ha. Increasing the application to 60 kg P_2O_5/ha did not increase yields further. (Rajpurohit ,et al ,(1986). In trials with two pigeonpea cultivars grown in the winter season, Puste et al (1988) found that application of 0, 35, and 70 kg P_2O_5/ha gave grain yield ranges of 1.22-1.29, 1.43-1.51, and 1.61-1.64 ton/ha respectively, with no further grain yield increase when 105 kg P_2O_5/ha was applied. A dose of 40 kg P_2O_5/ha has been recommended for pigeonpea at New Delhi, India (Rao, 1974, Ahlawat , 1976).

2.5 Response to Manure

The soils in the tropics and sub-tropics are poor in nitrogen and organic matter content as compared to those in temperate climates. This is not only because of high temperatures but also because a high proportion of crop residues are used as cattle feed, fuel or thatching material and not returned to the soil (FAO, 1988). The value of compost in improving the soil productivity is well known. Besides supplying nitrogen, phosphorus, sulphur and potash, organic manures also add the necessary micro-nutrients which are usually lacking in various fertilisers (Brady, 1984).

Soil organic matter represents an accumulation of partially decayed and partially synthesised plant and animal residues. The material is continually being broken down as a result of soil micro-organisms. It is a transitory soil constituent and must be renewed constantly by addition of plant and/or animal residues. The organic matter content of a soil is small varying from 2 to 6 % by weight in typical well drained mineral soils (Brady, 1984). Its influence on the properties and consequently on plant growth, however, is far greater than the low percentage would indicate.

Organic matter acts as a granulator of mineral particles, being largely responsible for the loose, easily managed condition of productive soils. This granulation also improves soil aeration hence better root growth, improves soil drainage and to some extent reduce soil erosion. Through its effect on the physical condition of soils, organic matter also increases the amount of water a soil can hold and the proportion of this water available for the plant growth. In Ghana, soil water holding capacity decreased from 57to 37 % when the organic matter content decreased from 5 to 3 %,(FAO, 1988).

Humus, which is organic soil colloids consist of highly charged anions usually surrounded by a swarm of adsorbed cations. The negative charge on humus colloids are mostly pH dependant , it therefore, exhibits a low cation adsorptive capacity under low pH. The humus commonly accounts for at least half the cation exchange capacity of the surface soils and is responsible for the stability of soil aggregates (Brady 1984). The slow release of nitrogen and sulphur from organic matter by mineralization offers well defined advantages over the soluble fertilisers which are especially susceptible to leaching, volatilisation or fixation losses. Organic matter forms complexes with iron and aluminium oxides. This decreases their concentration in the soil solution hence reducing their toxicity to plants and phosphorus fixation.Organic matter also forms complexes with micro-nutrients and therefore prevent their leaching and improving their availability (Brady 1984).

Organic matter also provides a soil cover preventing the build up of high temperatures in the top soil so that roots develop more freely in this zone. The Experiments done on farm-yard manure in Britian have given the estimates of the nutrients supplied. For instance 25 tons/ha of farm-yard manure will supply to a first year crop 40 kg N, 20 kg P and 80 kg K/ha , (Cooke,1972). Compared wit h chemical fertilisers on a unit weight basis, animal manure is low in plant nutrients especially in phosphorus.Thus it is customarily applied at relatively much high rates probably 50 to 100 times more than chemical fertilisers (Vladimr, 1952).

FAO (1980) showed that crop residues incorporation in the soil improved productivity and fertiliser use efficiency. After incorporating crop residues for five years in a coarse textured alfisol soil, the soil organic matter content was increased from 0.55 to 0.99 %and yields of cowpea and millet increased by 14 and 19 % respectively. The fertiliser use efficiency of the two crops was improved by 8 and 16 % respectively, relative to fertiliser application without crop residues. An experiment done by Veerasway, et al, (1972) on response of red-gram (*Vigna aureus)* to manure and phosphoric acid showed that, over the four years experimental period, the average yield increase was 7% for 5tons/ha, 8.9% for 22.5 kg P_2O_5/ha and 13% for a combination of both 5 tons/ha of manure and 22.5 kg P_2O_5/ha. Evans, et al (1962) similarly reported that pigeonpea showed appreciable and significant response to farm-yard manure. The application of 12.35 and 24.7 tons/ha gave grain yield increase of 1158 and 1370 Kg/ha respectively compared to the control with no manure. Grimes, et al ,(1962) concluded that farm-yard manure was as effective as artificial fertiliser in sustaining crop yields. They recommended application of 7.4 tons/ha of farm-yard manure to each rotation of maize, sweet potatoes and cassava.

Application of manure is limited by the low availability and low nutrient levels per unit weight necessitating application of very large quantities to supply sufficient amounts of nutrients. This leads to high costs of handling, storage, transport and application. However as the review shows, application of organic matter is very essential to maintain soil fertility. It maintains the right soil physical properties and supplies micro-nutrients to the soil.With the escalating prices of commercial fertilisers, manure is likely to become a main alternative for providing plant nutrients. In the semi-arid and arid areas where mixed farming is practised, manure being a by-product of animals can easily be used to improve soil fertility status and hence improve crop yields.

2.6 Effect of Fertilisers on Soils

Most of the nitrogen in the soil occurs in the organic matter and is not available to plants when in organic combination. Unavailable nitrogen in the soil is mineralised to available forms (NH_4^+ and NO_3^-) by action of microbes, but the available nitrogen in the soil at any one tme forms avery small fraction of the total N and can fluctuate quite quickly. Application of nitrogenous fertilisers that supply ammonia or produce ammonium ion (NH_4^+) when added to the soil tend to develop an acid residue in the soil (Brady 1984).The major acidifying effect of ammonium ions is exerted when they are nitrified. Application of fertiliser like urea therefore tends to lower the soil pH.

After nitrogen phosphorus is the second most important plant nutrient. In the soil phosphorus occurs in two main forms, namely inorganic and organic phosphorus. Plants absorb phosphorus from the soil in the form of ortho -phosphate ($H_2PO_4^-$ and HPO_4^{2-}). The phosphate ion $H_2PO_4^-$, is the form which is mostly available in the pH range of most agricultural soils (around pH 6.5). Unlike nitrogen, phosphorus losses by leaching are rather low. This is partly because the concentration of phosphorus in the soil solution is low, usually 0.1 micro-grams /ml and is rarely more than 1 micro-gram /ml . The major problem of phosphorus in some soils arises due to fixation. The 1:1 clays are known to fix more phosphorus than the 2:1 clays because they are usually high in oxides of aluminium and manganese which participate in phophorus fixation. Soil pH is another factor to consider as far as phosphorus fixation is cocerned. In most soils phosphorus availability is at maximum in pH range 5.5 to 7.0 and decreases as pH drops below 5.5(due to increase in the solubility of aluminium and iron which fix phosphorus) and also decrases again above pH 7.0due to presence of calcium compounds.

Application of phosphorus fertiliser generally exceeds that removed by crops. Research has quantified this inefficiency by showing that less than 15 % of the fertiliser applied phosphorus is normally taken up by the crop during the year it is applied. Since phosphorus is only sparingly removed by leaching,this leads to an increase in the soil phosphorus (Douglas, 1982).

Applicaton of organic matter increases soil water holding capacity, cation exchange capacity, blackens the soil and also enhances aeration and granulation of the soil. It supplies nitrogen, phosphorus, sulfur, micro-nutrients and has easily replaceable cations.

Haas (1957) reported that maintaining of high crop yields through fertiliser addition may be as effective as adding manure of other organic residues. In some cases organic matter can be maintained by simply raising bumper crops. Optimum yields usually meanmore residues to return to the soil and certainly increase the amount of root remaining after harvest (Brady 1984).

Due to the constancy of C:N ratio, addition of nitrogen to the soil can increase the soil nitrogen through increased biomass production and subsequent increase in organic matter. An increase of organic matter in the soil through use of nitrogen fertiliser can increase soil nitrogen. This is possible because the C:N ratio is constant for any soil, therefoer an increase in the organic matter also leads to an increase in nitrogen.

2.7 Use of Pigeonpea as Firewood

Four out of five families in the third World, roughly half of the world's people, rely on traditional fuels namely; wood fuels, dried cow dung and crop residues. Traditional fuels are virtually the only fuels utilized by perhaps 90% of all the people living in the rural villages and small towns of the developing countries. Local supplies of wood are being consumed faster than they can grow. Consumption increases at about 1.5-2.0 % annually in the developing countries. In certain areas availability of wood is affected either by the distance from the source or the usage exceeds the regrowth capacity. People are, therefore, forced to use alternative fuels. Where people cannot afford alternative commercial fuels, and unless such fuels are available, they must turn to other traditional fuels like cow dung and crop residues.

In Kenya it is estimated that, overall, wood fuel usage accounts for about 75 percent of the total energy used (Kamweti, 1979). The use of wood fuel may continue to rise as the prices of oil continue to escalate.
As mentioned above, most families are turning to use of cow dung and crop residues, as the availability of wood continue to diminish either due to consumption being higher than regrowth and/or increasing distance that has to be covered to collect the fuel wood.
Unlike most other crops grown in Kenya today, pigeonpea is a woody crop, which is very suitable for providing firewood in addition to the grains. There is, therefore, need to evaluate the energy content of this crop's stems, and compare it with other sources of fuel energy. Table 1 shows the energy content of materials commonly used for domestic supply in Kenya.

Table 1. Energy content of materials commonly used for domestic energy supply in Kenya

Material	Energy content (KCal/g)
LP. Gas	10.8
Paraffin	11.4 (9.5 KCal/Litre)^
Charcoal	7.8
Kahawa Charcoal*	7.1
Bamboo	3.7
Crop Waste (Sisal)	3.3
Cow dung	3.1

Source: The Beijer Institute and the Scandinavian institute of African Studies.

*K.P.C.U. Personal Communication.
^ The average specific density of paraffin used is 0.83 8/cm3

(Kamweti, 1979). The law and management of forest in Kenya. M.Sc. Thesis. University of Nairobi

3.0 MATERIALS AND METHODS

3.1 Locations

The experimental sites were, National Horticultural Research Centre - Thika; Machakos Farmers Training Centre and Kiboko Range Dryland Research Station.

National Horticultural Research Centre - Thika is situated in Muranga District in Central province, with co-ordinates $00^{O}59$'S; $37^{O}04$'E. It is about 5 km North of Thika town. The station is in ecological zone III with P/E^{O} =56% i.e.[Mean monthly rainfall in mm/ mean monthly potential evapotranspiration in mm]. It is about 1549 m above sea level. For the last seven years (1983-1989) the average annual rainfall was 911.3mm (Appendix 1a) and average mean maximum and minimum temperature 25.4 and 13.9°C, respectively (Appendix 1b and 2c). The soils are very deep, well drained, dusky red to dark reddish brown, friable clay with moderate fertility (Siderius and Muchana. 1977).Table 2 shows the various nutrients levels of this site done before planting.

Machakos Farmers Training Centre (M.F.T.C.) is situated in Machakos District in Eastern province and lies on latitude $01^{O}33$'S, longitude $37^{O}14$'E . The site is about 70 km south east of Nairobi and 7 km south of Machakos town. The centre is in the ecological zone IV with P/E^{O}=40%. It's altiude is 1596 m above sea level. For the last seven years, (1984-1990), the average annual rainfall was 807.8 mm (Appendix 2a) and average mean maximum and minimum temperature 25.9 and 19.0°C respectively (Appendix 2b and 2c). The predominant soil type is well drained dark reddish brown sandy clay.

Table 2. Soil characteristics at the three experimental sites before planting

	Depth	H (water)	pH (CaCl2)	%Organic Carbo	% Total Nitrog	C:N ratio	P (ppm)	EC (g/100g Soil)
Machakos								
Long rains '89	0-30 cm	5.7	5.4	1.33	0.134	9.9	70.1	16.7
Machakos								
Short rains '89/'9	0-30 cm	5.9	5.4	1.33	0.116	11.5	80	10.8
	30-60 cm	5.8	5.3	0.78	0.1	8.7	36.8	18.5
Thika								
Short rains '89/'9	0-30 cm	5.5	4.8	1.57	0.163	9.6	16	15.4
	30-60 cm	5.5	4.8	1.34	0.132	10.2	4	11.3
Kiboko								
Long rains '89	0-30 cm	6.7	6.1	0.90	0.104	8.7	42	16.5
Kiboko								
Short rains '89/'9	0-30 cm	6.4	6.1	0.81	0.091	8.9	35	10.1
	30-60 cm	6.4	6.2	0.54	0.07	7.7	21.1	19.9

the soil levels of nitrogen and phosphorus have been described as deficient (Siderius and Muchana, 1977).

Range Dryland Research Station -Kiboko, is situated in Makueni District, Eastern Province and lies between latitude $02^{o}10$'S and $02^{o}25$'S and longitude $37^{o}40$'E and $37^{o}55$'E the station is located about 156 km from Nairobi along the Nairobi-Mombasa highway. It is in the ecological zone V with P/Eo=30%. It is 980 metres above sea level. The average annual rainfall over the last seven years (1983-1989) was 507.2 mm (Appendix 3a) and mean maximum and minimum temperature of 29.6 and 17.1^{o}C respectively (Appendix 3b and 3c) The predominant soil type is luvisols, red to dark reddish brown from firm sandy clay with a top soil of loamy sand, derived mostly undifferentiated basement system rocks (Michieka, et al ,1977). Phosphorus and potassium are low and nitrogen deficient.(Siderius, and Muchana, 1977).

Table 2. shows soil characteristics of the three experimental sites.

The nutrient levels were determined from soil sampled before planting.

3.2 Plant Material

The two cultivars of pigeonpea (*Cajanus cajan* (L) Millsp) planted in the experiment were NPP 670 and Katheka.

Cultivar NPP 670 is an early maturing improved cultivar developed by the University of Nairobi (4.5-5.5 months) that is high yielding with large cream white seeds. It is a popular cultivar with a determinate/semi-determinate growth habit. It has good yield (1500-2600 kg/ha), earliness and desirable seed characteristics. It is drought tolerant and can be harvested twice in a year. It normally grows erect to a height of about 1.2m but this varies with altitude and climatic conditions. Cultivar Katheka is late maturing unimproved local cultivar (9-11 months) with large cream white seeds. It is a hardy cultivar, quite tolerant to pests, diseases and weeds. It is drought tolerant and gives only one crop per year. It's stem are used as firewood and for construction. It normally grows erect to a height of about 2.5-3 m but this varies with altitude and climatic conditions also.

3.3 Fertiliser and Manure Application Rates

Two fertilisers namely, urea to supply nitrogen and triple superphosphate to supply phosphorus and animal (cattle) manure were applied at different rates as the test treatments to the two pigeonpea cultivars mentioned above.

Urea (46% N) was applied at rates of 15, 30, and 45 kg N/ha. On application, urea hydrolyses into a ammonical form which is then adsorbed onto the soil colloids, limiting losses through leaching and hence keeps the nitrogen available to the slow growing pigeonpea seedlings. On the other hand prior to hydrolysis, urea descends into the soil and this permits, especially in the event of rain,a better and deeper distribution of nitrogen and of it's localization in the deep root zone.

Triple superphosphate(45% P_2O_5) was applied at rates of 40, 80, and 120 kg P_2O_5/ha. Triple superphosphate contains more phosphorus on a weight basis than single superphosphate and has no gypsum.

Cattle manure collected from a 'boma' (place where cattle spend the night) of beef cattle that feed mainly on kikuyu grass (*Pennisetum cladestanum*) was applied at 5 and 10 tons/ha. Control plots, where no fertiliser or manure were applied were also maintained.

3.4 Experimental Design

The experimental design was a split -split plot design with cultivars in the main plots, fertiliser and manure in subplots and their levels in sub-sub plots. The sub-subplots measured 3x6 m subplots 3x21 m and the main plots

11x21 m. The experiment was replicated three times at every site. There were 18 treatments.

3.5 Cultural Practices

Land was ploughed, harrowed and then marked out into sub-subplots. Four furrows of 6 metres long spaced at 75 cm were dug in each sub-subplot and appropriate amounts of fertilisers or manure applied evenly along the furrow and mixed with the soil. Furadan was also applied with the fertiliser and manure along the furrows at a rate of 2 grams per metre to control nematodes and cut worms. Four to five seeds were placed in the furrows at a spacing of 30 cm apart and covered with soil.

After emergence and establishment, the plants were thinned to one plant per hill. The plots were kept weed free by use of manual labour. The crop was sprayed with Dithane M45 at 1.75 kg/ha to control Mycovellosiella leaf spots and other fungal infections. Rogor L40 at 0.7 litres/ha and Thiodan 35 EC at 3.7litres/ha were also sprayed to control pod sucking bugs, podfly and pod boring larvae. The crop depended on natural rains for the two seasons at the three sites.

3.6 Data collection

3.6.1 Meteorological data

Data on the amount of rainfall, minimum and maximum temperatures from nearby meterological data collection sites were collected during the experimental period. Data for the last 7 years were also collected for calculating the monthly means for each site. The rainfall pattern in all the three sites is bimodal with short rains lasting from October to December and long rains occuring between March and May. (Appendix 1a - 3c)

3.6.2 Crop Data

Data collection on crop parameters commenced at flowering time. The number of days from planting to 50% flowering for each plot were determined and recorded. Then five plants from the two inner rows in each plot were randomly selected tagged and their height along the main axis, i.e. from the base to the top, measured and number of primary branches, arising from the main stem counted. Two plants, each from the outer rows in sub- subplots were cut at the ground level. The cut plants were then separated into leaves, stems and pods and put in labelled polythene bags and carried to the laboratory, where all the leaves fresh weight and the weight of 15 representative leaves were taken. The leaf area of the 15 leaves was measured using a leaf area meter (LI 3100) and the area of the leaves per plant calculated. The leaves, stalks and pods were put in paper bags , labelled and dried in an oven at 80^{O}C for about 48 to 72 hours to constant dry weight. This process was repeated at two weeks intervals upto harvest time.

During harvesting the height of the five tagged plants was measured. All the pods from each of these plants were harvested and put in individual labelled paper bags. The five plants were then cut whole at ground level and put in individual paper bags. The pods were sun dried and weighed. The stem, branches and remaining leaves were dried at 80^{O}C to a constant weight. The number of pods from each individual plant were counted. The pods were then threshed and the grains weighed. Then 100 seeds were counted at random from each grain sample and weighed. A random representative sample of grains was taken and its moisture content determined. The average grain yield per plant was extrapolated to give the average grain yield per hactare. During the second season a sample of the two cultivars stems from the ground level to about 30 cm high were cut, chopped and ground. This material was used to determined the energy content of the stem by calorimetric method (J.I Richards. Depart. of animal prodn. U.O.N. Students practicals in nutrients analysis pp 28-33).

3.7 Soil Sampling and Analysis

Soil samples were taken at depths of 0-30 and 30-60 cm at planting and harvest time. At planting time soil samples were taken from six auger holes evenly distributed in each replication i.e. one auger hole for every subplot. These were then put in labelled polythene bags and transported to the laboratory for analysis. The samples were air dried and thoroughly mixed to make a composite from which a sub-sample was taken. Half of this sub-sample was sieved with 0.5 mm sieve and the other half with a 2 mm sieve. The sieved samples were kept in labelled bags for nutrient level analysis. At harvest time soil samples were taken from two auger holes in each sub-subplot. These were also treated as mentioned above.

3.7.1 Soil pH

Soil pH is a measure of activity of ionized hydrogen atoms H+ in the soil solution. Whether a soil is acidic, neutral or basic has much to do with the solubility of the various compounds,the relative bonding of ions to exchange sites, and the activity of various micro-organisms, (McLean, 1982). Thomas (1969) noted that three soil pH ranges are particularly informative, a pH of less than 4 indicates the presence of free acids generally from oxidation of sulfides; a pH of less than 5.5 suggests the likely occurance of exchangeable Aluminium and a pH of 7.8 to 8.2 indicates the presence of calcium carbonate($CaCO_3$). Since the avaliability of most plant essential elements depends on the soil pH, it is a relative indication of relative availability of plant nutrients. Thus soil pH is generally both a symptom of the soil's condition and a cause of the many reactions that occur.

pH measurement was made by electrometric method. pH as measured in water is affected to some extent by the presence of salts in the soil,whose content undergoes seasonal variation, being about the highest in the dry season and lowest towards the end of wet season due to removal by rains. Thus the pH too as measured in a suspension would vary with seasons, (Coleman, et al, 1964). To eliminate this seasonal effect, pH is measured in a solution of potassium chloride or calcium chloride. The pH as measured in a 1 N KCl solution is commonly 1.0-2.0 pH units lower than in water. The differences between the pH of the soil as measured in 0.01M $CaCl_2$ and as measured in water solution is much less. The pH as measured in the laboratory in 0.01M $CaCl_2$ is thought to represent more accurately the pH of the soil in he field and the H+ ions environment of plants roots and micro-organisms than the pH as measured in a 1:2 soil water suspension, (Woodruff, 1967).

3.7.2 Soil Carbon

Many important soil properties are dependent to some degree on the quantity of organic matter present. These properties include the following; absorption and retention of water, reserves of exchangeable bases, the capacity to supply nitrogen, phosphorus and other elements to growing crops, stability of soil structure and adequacy of aeration, (Brady, 1984). This is particularly true in tropical region where the fertility status of a soil is usually dependent on the organic matter content. Soil organic matter includes fresh plant and animal residues, humus and inert forms of carbon such as charcoal, coal and graphite, (SSS, 1979). Soil organic analysis generally consists of a carbon analysis. The organic matter present in soil can be determined by Walky-Black method, which involves the reduction of dichromate ion $Cr_2O_7^{2-}$

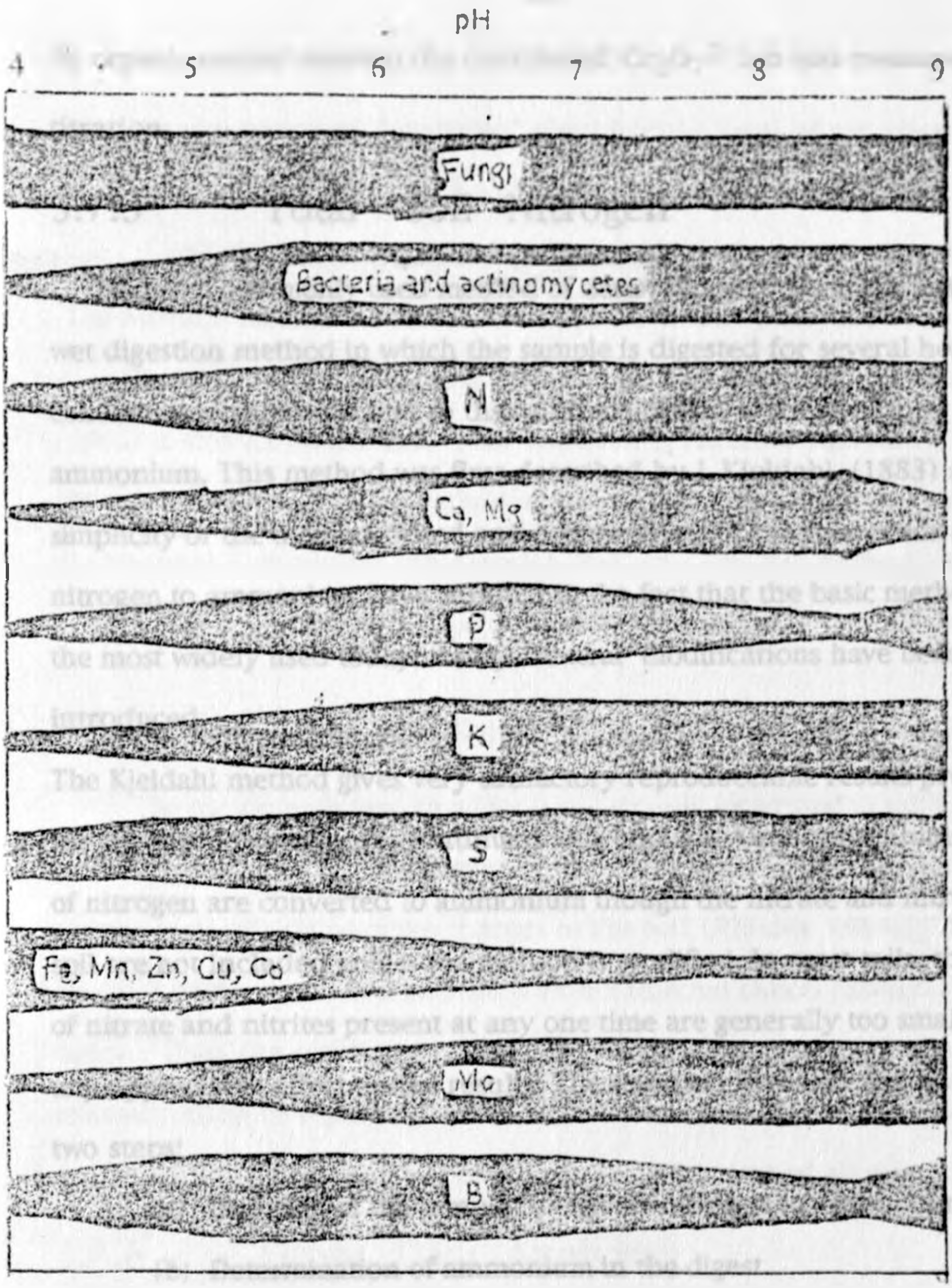

Fig. 1. Relationships existing between pH and the activity of microorganisms and availability of plant nutrients. The wide portions of the band show the zones of greatest microbal activity and nutrient availabity. If soil pH is suitably adjusted for phosphorus, the other plant nutrients, if present in adequate amounts, will be satisfactorily available in most cases

Source: Brady, pp 207 (1984)

by organic matter wherein the unreduced $Cr_2O_7^{2-}$ ion was measured by titration.

3.7.3 Total Soil Nitrogen

The most commonly used method of determining total nitrogen is a wet digestion method in which the sample is digested for several hours with concentrated sulphuric acid so that all the nitrogen is coverted into ammonium. This method was first described by J. Kjeldahl (1883) and the simplicity of the method, speed and completeness of the conversion of nitrogen to ammonium have resulted in the fact that the basic method is still the most widely used today; though several modifications have been introduced.

The Kjeldahl method gives very satifactory reproduceable results provided that the digestion procedure is continued long enough. Almost all combined forms of nitrogen are converted to ammonium though the nitrate and nitrite in the soil are not included unless the method is modified. In most soils, the amounts of nitrate and nitrites present at any one time are generally too small to have any appreciable effect on the results. The standard Kjedahl analysis involves two steps:

(a) Digestion of the sample to convert nitrogen to ammonium and

(b) Determination of ammonium in the digest.

The term digestion is used to describe the process in which the soil sample is heated with concentrated supluric acid to convert organic nitrogen to ammonium.

3.7.4 "Available" Phosphorus in Soil

Most determination of "available" phosphorus consist of two phases:

(a) the preparation of a solution containing phosphorus.

(b) the quantitative determination of the phosphorus in solution.

The Mehlich method for determination of available phosphorus.

The Mehlich method is a modification of that developed by *Nelson et al (1953)* to extract phosphorus from some North Carolina soils which fix phosphorus strongly. This method was introduced into Kenya by Mehlich at the National Agricultural Laboratories, Nairobi. In this method, double acid (0.05N HCl in 0.025N H_2SO_4) is used as the extractant.

3.7.5 Cation Exchange Capacity [CEC]

The cation exchange capacity (CEC) usually expressed in milli-equivalents per 100 grams of soil is a measure of the quantity of readily exchangaeble cations neutralising negative charges in the soil, (Rhodes, 1984). The colloidal complex of the soil is first saturated with a selected cation called the saturating cation. Then the saturating cation is displaced quantitatively by another selected cation or replacing cation. The amount displaced is measured and expressed in terms of milli-equivalents per 100 grams of air dried soil.

3.7.6 Crops Data Analysis

All the data on crops growth parameters, crops yield components and soil nutrients levels have been analysed using analysis of variance with 5% taken as the test for the level of significacne.

4.0 RESULTS AND DISCUSSION

4.1.0 EFFECT OF FERTILIZER AND MANURE TREATMENTS ON TWO PIGEONPEA CULTIVARS

4.1.1 Leaf area

At Thika the fertilizer and manure applications did not have any significant effect on the leaf area of the two cultivars. At flowering time, (18 weeks from planting), NPP 670 had an average leaf area of 2030 cm^2 per plant (Fig. 2a). This declined gradually over a period of about 8 weeks to about 0 cm^2 per plant at harvest time when all the leaves had been shed. The crop had been attacked by *Mycovelosiella cajani* which was not effectively controlled even after spraying with Dithane M45. This may have contributed to the decline in leaf area. Consequently this didnot allow enough time for proper grain filling hence the low 100-seed weight and low yields.The lack of response of leaf area to the fertilizer and manure treatments may explain the lack of reponse of grain yield to these treatments also. At 18 weeks from planting Katheka had an average leaf area of about 4000 cm^2 per plant (Fig 2b). There was an increase during the next 4 weeks to about 7600 cm^2 per plant then decline to about 5,400 cm^2 per plant in following 4 weeks, followed by a sharp increase to 17,600 cm^2 per plant at 31 weeks from planting.

This then declined sharply to 2,000 cm^2 per plant at harvest time (Fig. 2b). The decline of leaf area from 7,600 cm^2 per plant to about 5,400 cm^2 per plant was due to leaf fall and lack of initiation of new leaves caused by the dry period experienced in March at this site. The sudden increase of leaf area was

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Growth and yield paremeters from flowering time on,for Machakos, are not reported on because the crops were destroyed by wild animals.

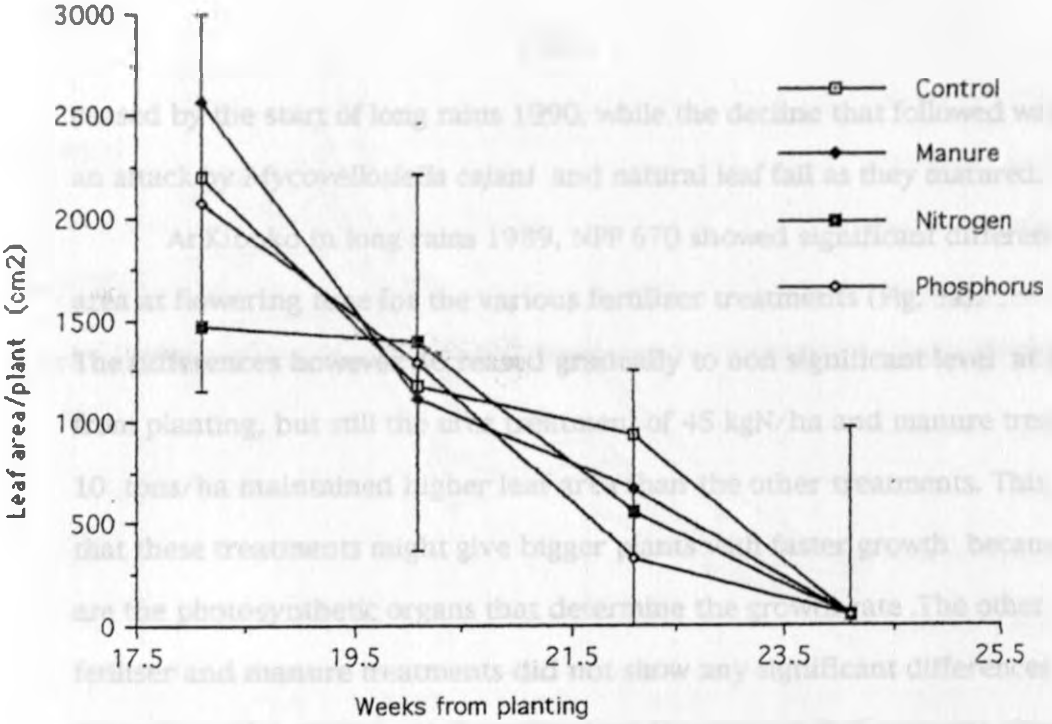

Figure 2a. Effect of type of fertilizer and manure on leaf area of NPP 670 grown at Thika in the short rains 1989/'90.

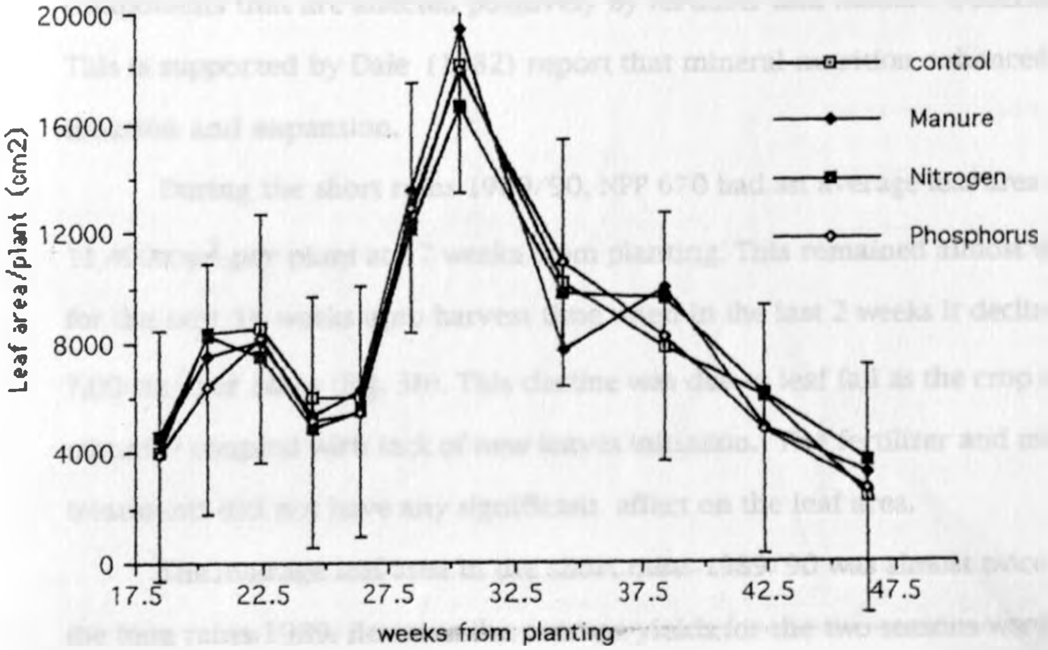

Figure 2b. Effect of type of fertilizer and manure on the leaf area of Katheka grown at Thika in the short rains 1989/'90.

caused by the start of long rains 1990, while the decline that followed was due to an attack by *Mycovellosiella cajani* and natural leaf fall as they matured.

At Kiboko in long rains 1989, NPP 670 showed significant difference in leaf area at flowering time for the various fertilizer treatments (Fig. 3a). The differences however decreased gradually to non significant level at 20 weeks from planting, but still the urea treatment of 45 kgN/ha and manure treatments of 10 tons/ha maintained higher leaf area than the other treatments. This indicates that these treatments might give bigger plants with faster growth because leaves are the photosynthetic organs that determine the growth rate .The other fetiliser and manure treatments did not show any significant differences throughout this period. At flowering time the average leaf area was about 6,600 cm^2 per plant and declined almost linearly to 1,060 cm^2 per plant at harvest time in about 10 weeks (fig.3a). The fertilizer treatments that showed higher leaf area also had significantly higher grain yields. Therefore leaf area is one of yield components that are affected positively by fertilizer and manure treatments. This is supported by Dale (1982) report that mineral nutrition enhanced leaves intiation and expansion.

During the short rains 1989/90, NPP 670 had an average leaf area of about 11,400 cm^2 per plant at 17 weeks from planting. This remained almost the same for the next 16 weeks upto harvest time when in the last 2 weeks it declined to 7,00 cm^2 per plant (Fig. 3b). This decline was due to leaf fall as the crop reached maturity coupled wirh lack of new leaves initiation. The fertilizer and manure treatments did not have any significant effect on the leaf area.

The average leaf area in the short rains 1989/90 was almost twice that in the long rains 1989. However the average yields for the two seasons were not significantly different from one another. The short rains of 1989/91 crop had a prolonged vegetative phase hence the high leaf area. The advantage of a long

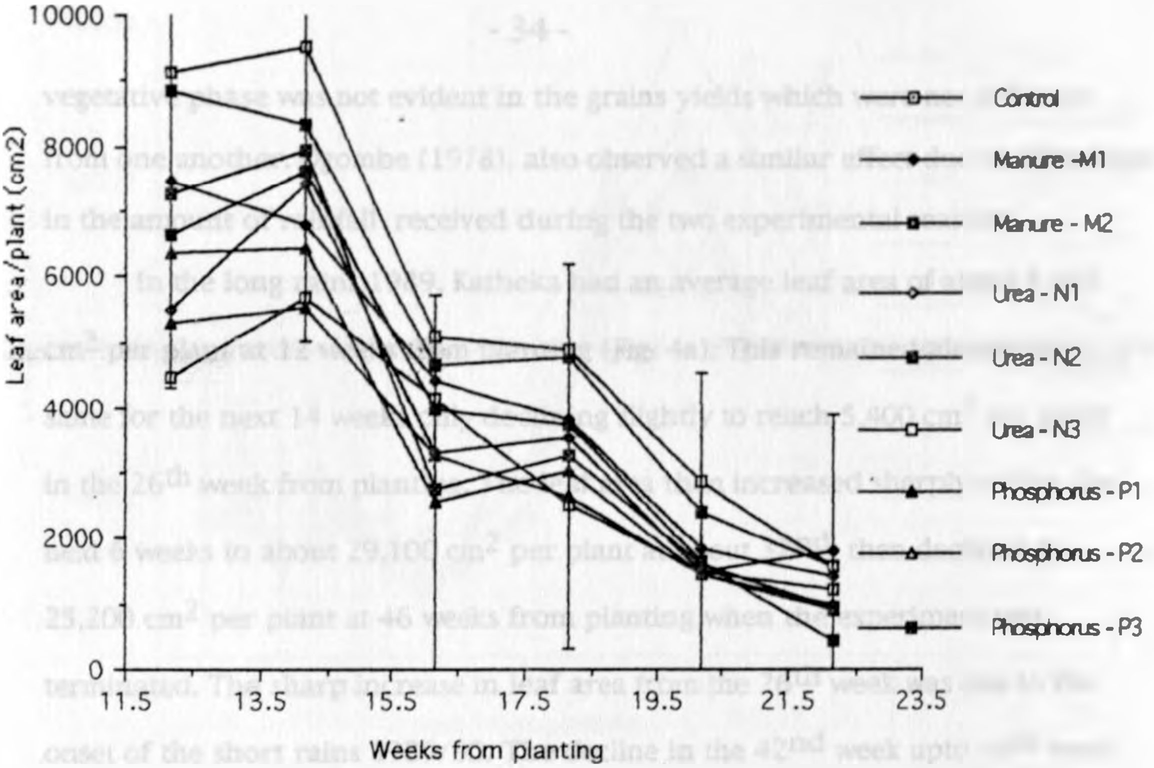

Figure 3a. Effect of type of fertilizer and manure on leaf area of NPP 670 grown at Kiboko in long rains 1989.

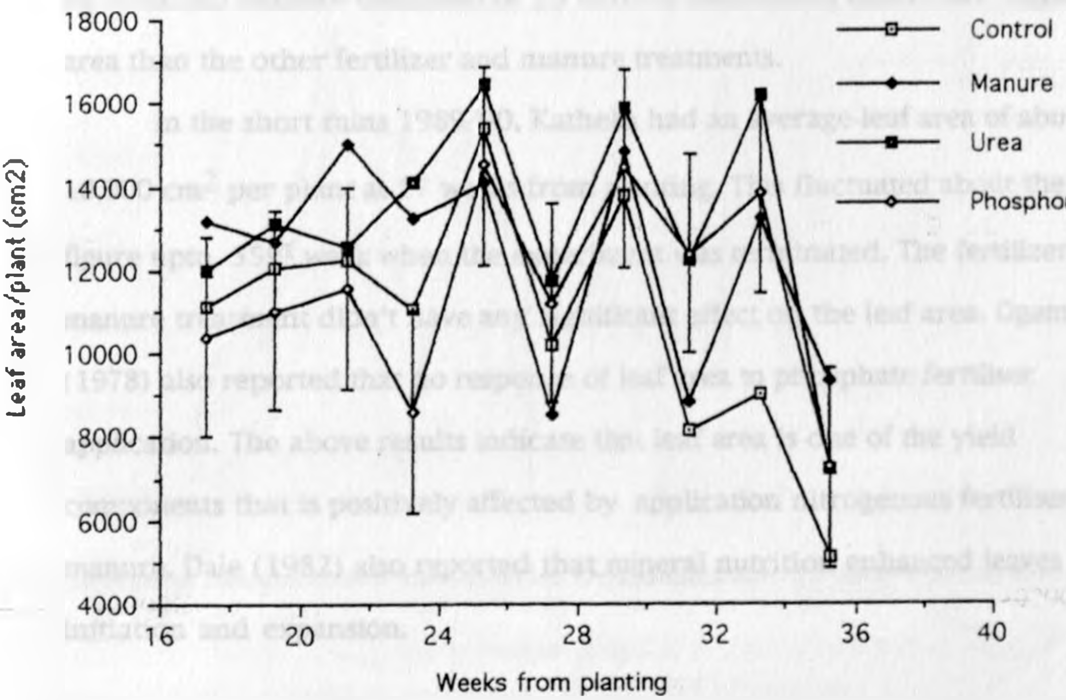

Figure 3b. Effect of type of fertilizer and manure on leaf area of NPP 670 grown at Kiboko in the short rains 1989/'90.

vegetative phase was not evident in the grains yields which were not different from one another. Ogombe (1978), also observed a similar effect due to diferecnes in the amount of rainfall received during the two experimental seasons.

In the long rains 1989, Katheka had an average leaf area of about 8,600 cm^2 per plant at 12 weeks from planting (Fig. 4a). This remained almost the same for the next 14 weeks only declining slightly to reach 5,400 cm^2 per plant in the 26^{th} week from planting. The leaf area then increased sharply within the next 6 weeks to about 29,100 cm^2 per plant at about 32^{nd}, then declined to 25,200 cm^2 per plant at 46 weeks from planting when the experiment was terminated. The sharp increase in leaf area from the 26^{th} week was due to the onset of the short rains 1989/90. The decline in the 42^{nd} week upto 46^{th} week was due to dry period experienced in January/February.

Fertilizer and manure treatment didn't have any significant on leaf area from about the 12^{th} week to the 46^{th} week after which the urea treatment of 45 kg N/ha and manure treatment of 10 tons/ha maintained significant higher leaf area than the other fertilizer and manure treatments.

In the short rains 1989/90, Katheka had an average leaf area of about 10,000 cm^2 per plant at 17 weeks from planting. This fluctuated about the same figure upto 35^{th} week when the experiment was terminated. The fertilizer and manure treatment didn't have any significant effect on the leaf area. Ogembe (1978) also reported that no response of leaf area to phosphate fertiliser application. The above results indicate that leaf area is one of the yield components that is positively affected by application nitrogenous fertiliser and manure. Dale (1982) also reported that mineral nutrition enhanced leaves initiation and expansion.

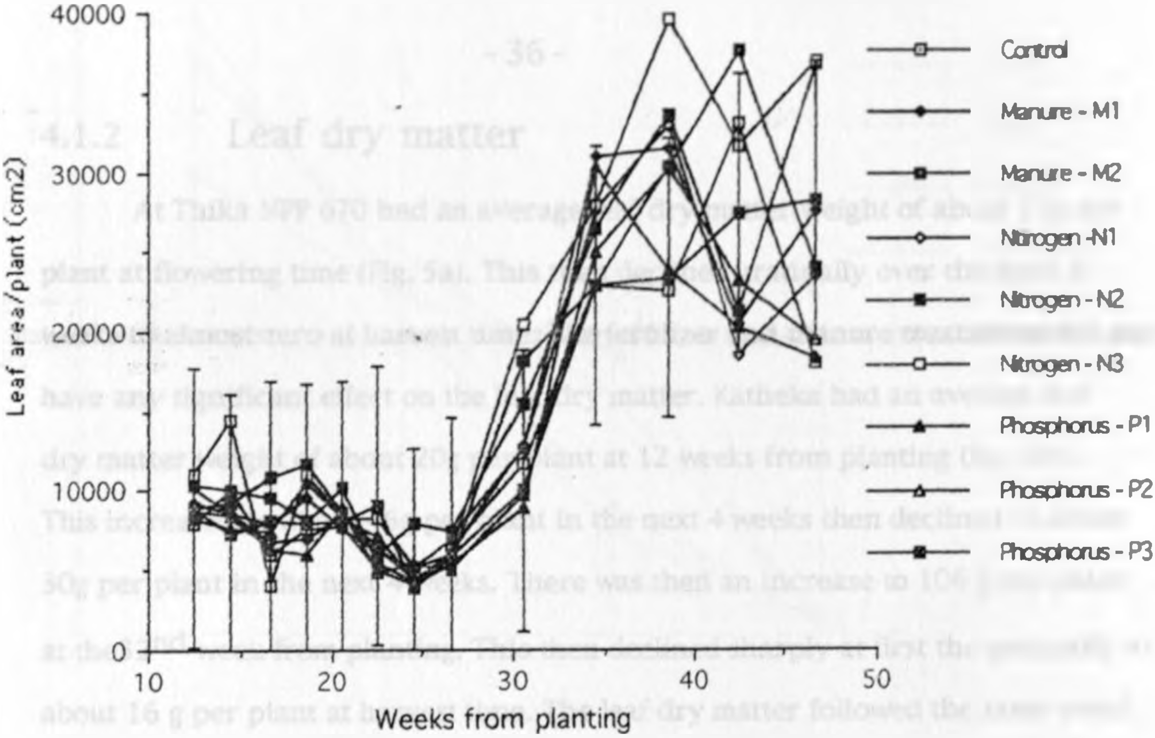

Figure 4a. Effect of type of fertiliser and manure on leaf area of Katheka grown at Kiboko in the long rains 1989.

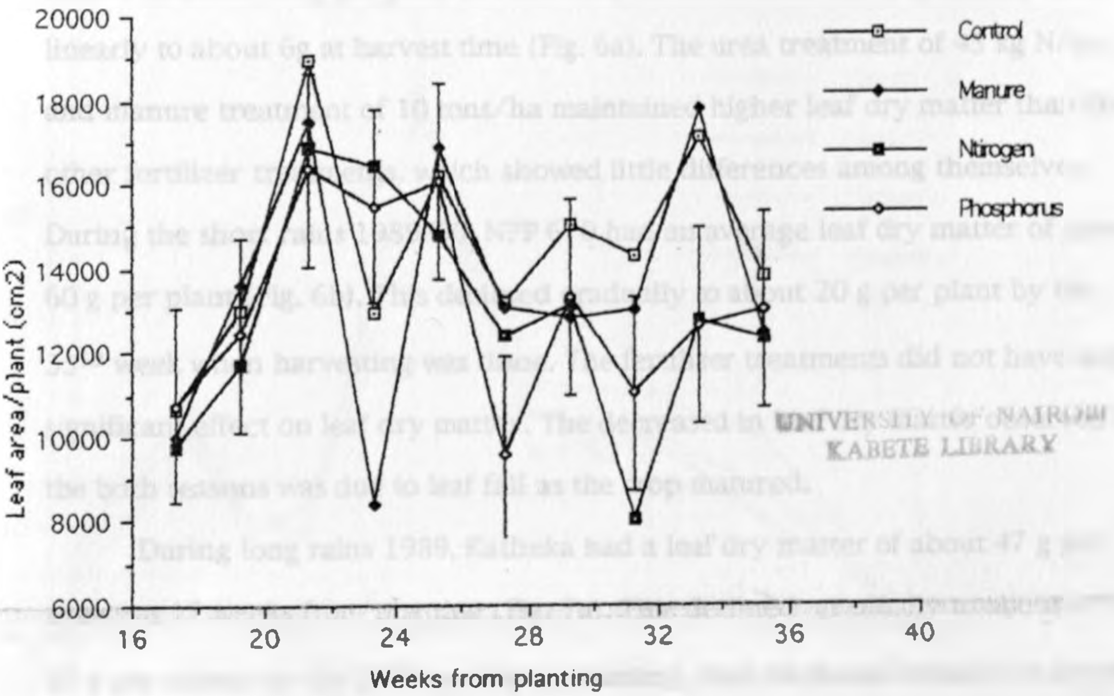

Figure 4b. Effect of fertiliser and manure on leaf area of Katheka grown at Kiboko in the short rains 1989/1990

4.1.2 Leaf dry matter

At Thika NPP 670 had an average leaf dry matter weight of about 17g per plant at flowering time (Fig. 5a). This then declined gradually over the next 6 weeks to almost zero at harvest time. The fertilizer and manure treatments did not have any significant effect on the leaf dry matter. Katheka had an average leaf dry matter weight of about 20g per plant at 12 weeks from planting (Fig. 5b). This increased to about 46g per plant in the next 4 weeks then declined to about 30g per plant in the next 4 weeks. There was then an increase to 106 g per plant at the32nd week from planting. This then declined sharply at first the gradually to about 16 g per plant at harvest time. The leaf dry matter followed the same trend as the leaf area. The decline in leaf dry matter was due to leaf fall. The increase observed for Katheka was due to the onset of the long rains, 1990 (fig. 5b).

At Kiboko during the long rains 1989, NPP 670 had an average leaf dry matter of about 48 g per plant at flowering time. This decreased gradually and linearly to about 6g at harvest time (Fig. 6a). The urea treatment of 45 kg N/ha and manure treatment of 10 tons/ha maintained higher leaf dry matter than the other fertilizer treatments, which showed little differences among themselves. During the short rains 1989/90, NPP 670 had an average leaf dry matter of about 60 g per plant (Fig. 6b). This declined gradually to about 20 g per plant by the 35th week when harvesting was done. The fertilizer treatments did not have any significant effect on leaf dry matter. The decreased in leaf dry matter observed in the both seasons was due to leaf fall as the crop matured.

During long rains 1989, Katheka had a leaf dry matter of about 47 g per plants at 12 weeks from planting (Fig. 7a). This declined gradually to about 35 g per plants by the 26th week from planting, then increased steadily to about 150 g per plant at the 46th week. The urea treatment of 45 kg N/ha and manure

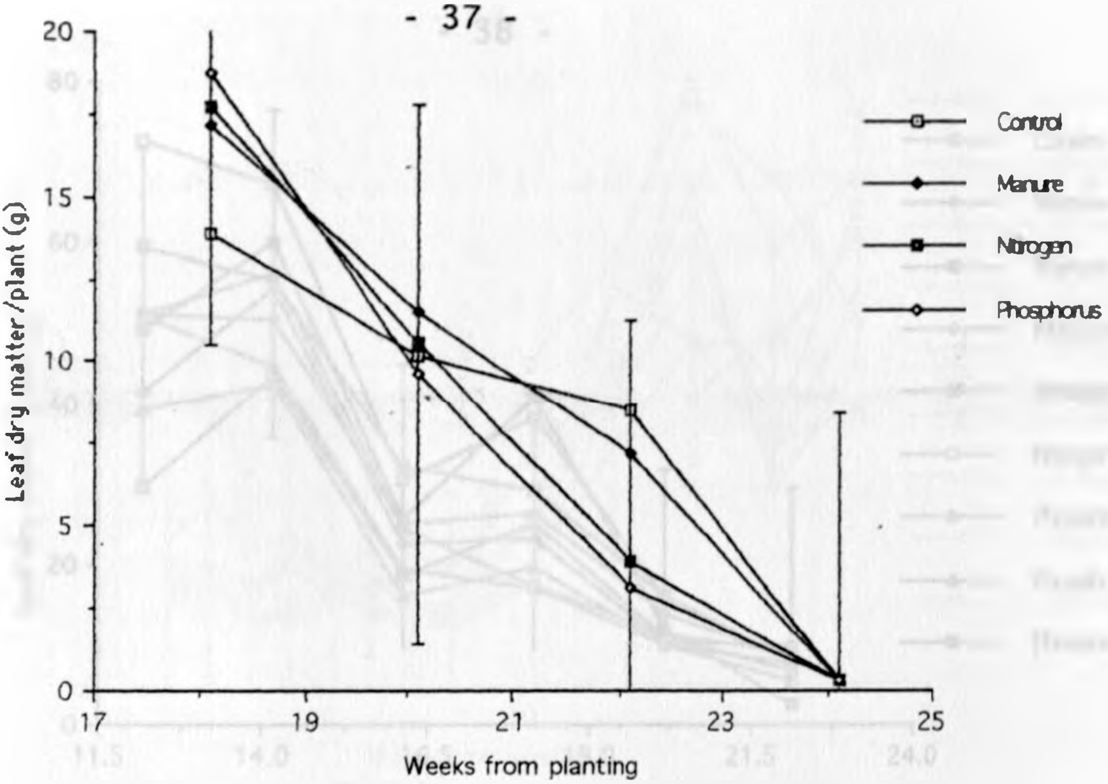

Figure 5a. Effect of type of fertiliser and manure on leaf dry matter of NPP 670 grown at Thika in the short rais 1989/1990.

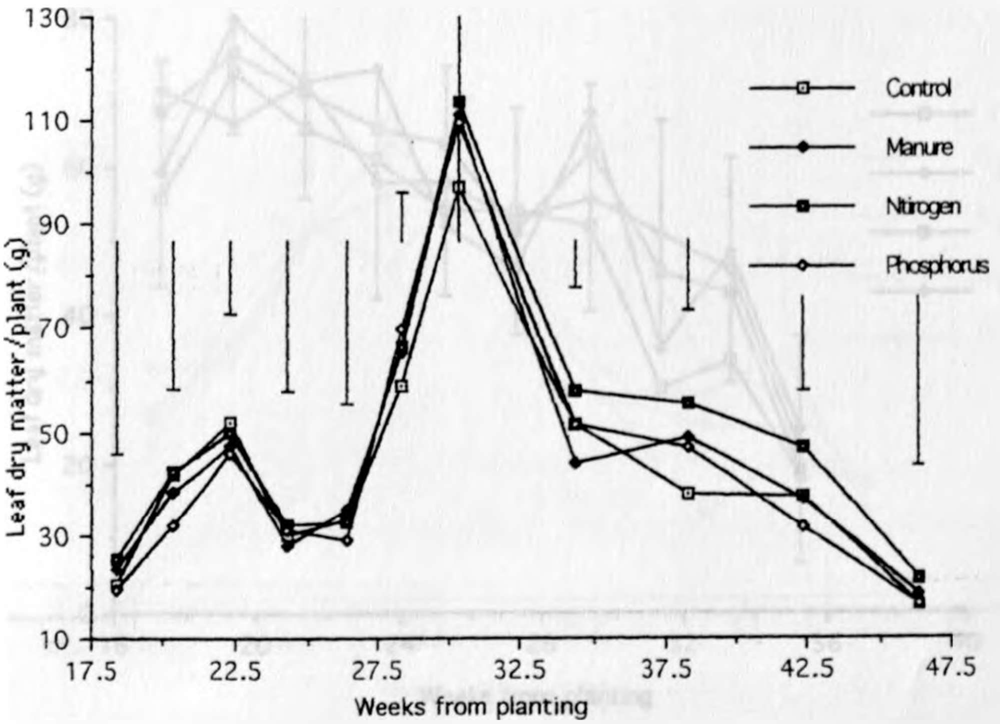

Figure 5b. Effect of type of fertiliser and manure on leaf dry matter of Katheka grown at Thika in the short rains 1989/1990.

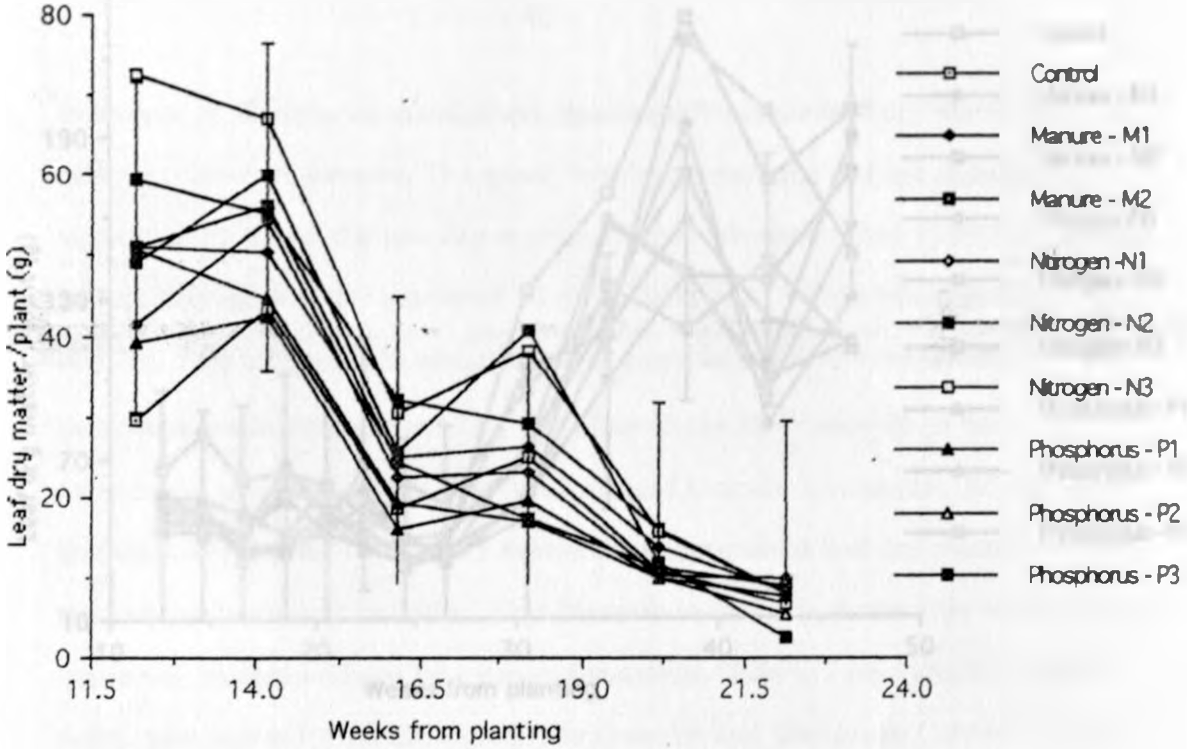

Figure 6a. Effect of type of fertiliser and manure on leaf dry matter of NPP 670 grown at Kiboko in the long rains 1989.

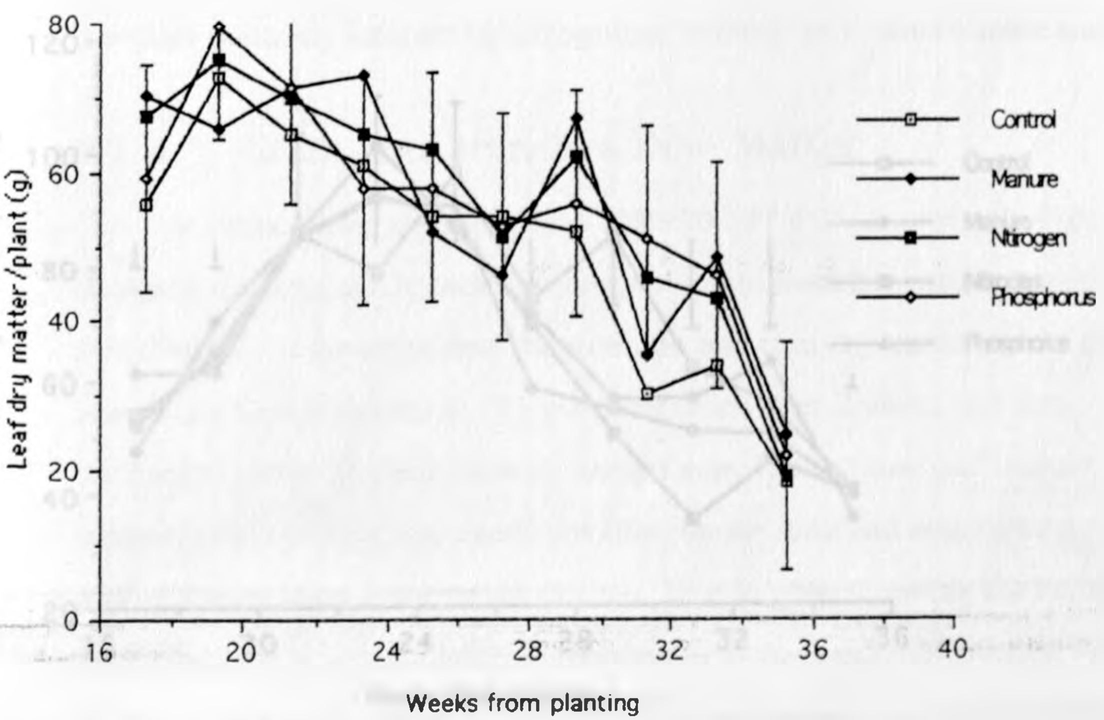

Figure 6b. Effect of type of fertiliser and manure on leaf dry matter of NPP 670 grown at Kiboko in the short rains 1989/90.

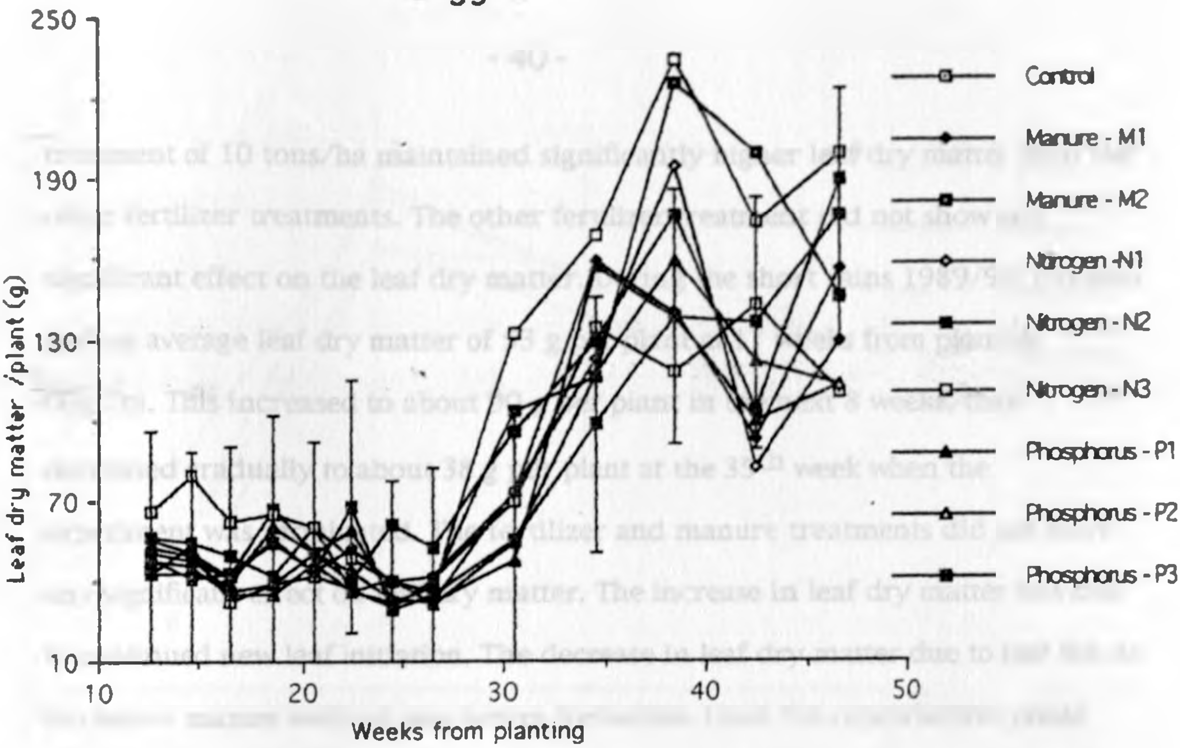

Figure 7a. Effect of type of fertiliser and manure on leaf dry matter of Katheka grown at Kiboko in the long rains 1989.

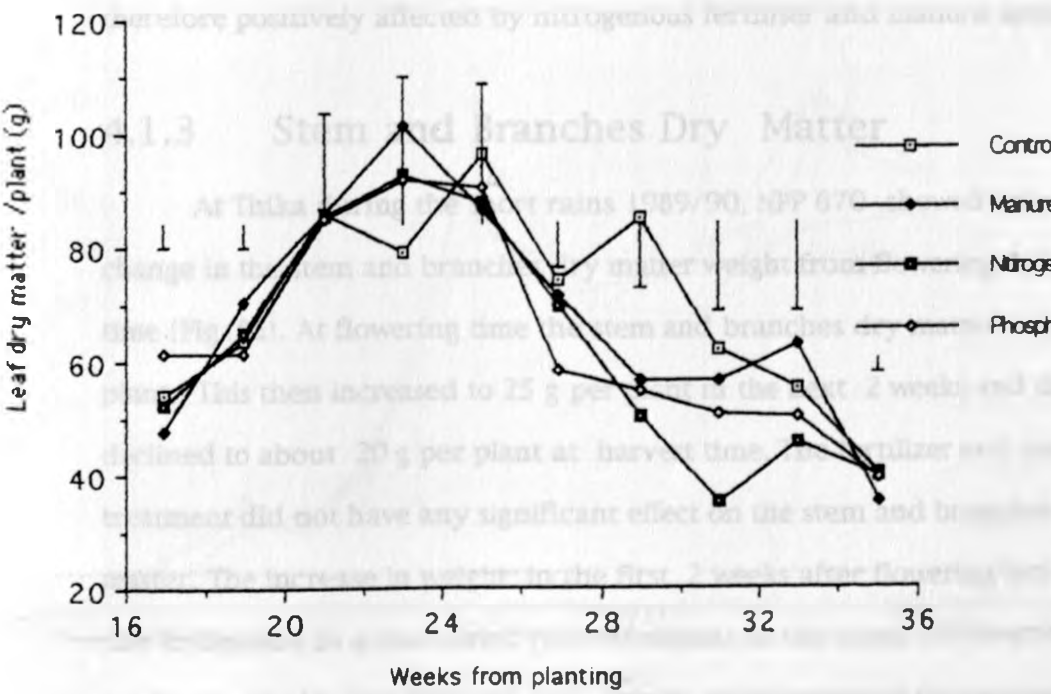

Figure 7b. Effect of type of fertiliser and manure on leaf area of katheka grown at Kiboko in the short rains 1989/1990

treatment of 10 tons/ha maintained significantly higher leaf dry matter than the other fertilizer treatments. The other fertilizer treatment did not show any significant effect on the leaf dry matter. During the short rains 1989/90, Katheka had an average leaf dry matter of 53 g per plant at 17 weeks from planting (Fig.7b). This increased to about 90 g per plant in the next 8 weeks, then decreased gradually to about 38 g per plant at the 35th week when the experiment was terminated. The fertilizer and manure treatments did not have any significant effect on leaf dry matter. The increase in leaf dry matter was due to continued new leaf initiation. The decrease in leaf dry matter due to leaf fall as the leaves mature without new leaves formation. Once the reproductive phase starts, new leaves formation ceases. Narayanann and Sheldrake (1974/75), and Ogombe (1978) reported of the same trend in growth in a number of pigeonpea cultivars with a initial lag phase followed by rapid increase in leaf dry matter then a decline as the plants age. Leaf dry matter is directly correlated to leaf area and is therefore positively affected by nitrogenous fertiliser and manure application.

4.1.3 Stem and Branches Dry Matter

At Thika during the short rains 1989/90, NPP 670 showed only slight change in the stem and branches dry matter weight from flowering to harvest time (Fig. 8a). At flowering time the stem and branches dry matter was 14 g per plant. This then increased to 25 g per plant in the next 2 weeks and then declined to about 20 g per plant at harvest time. The fertilizer and manure treatment did not have any significant effect on the stem and branches dry matter. The increase in weight in the first 2 weeks after flowering was mainly due to increase in accumulated photosynthetes in the stems and braches. The decline in weight that followed was due to mobilization of the accumulated photosynthetes to the rapidly growing pods.(Narayanann and Sheldrake ,1974/75)

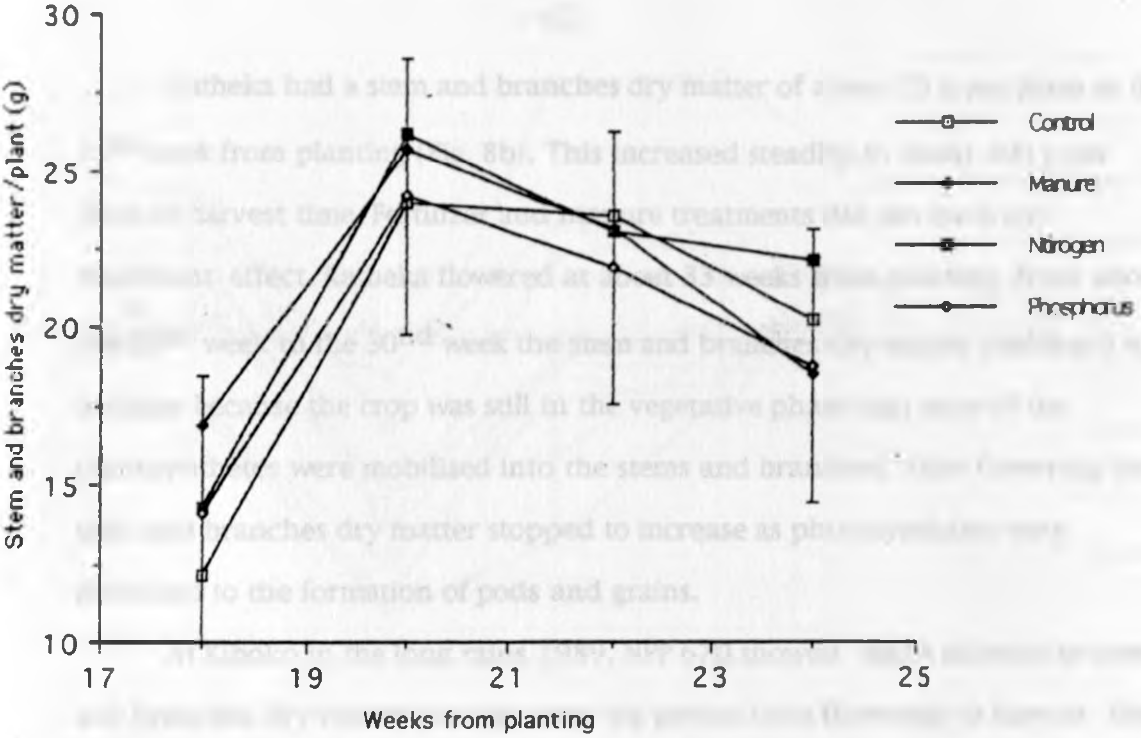

Figure 8a. Effecf of type of fertiliser and manure on stem and branches dry matter of NPP 670 grown at Thika in the short rains 1989/1990.

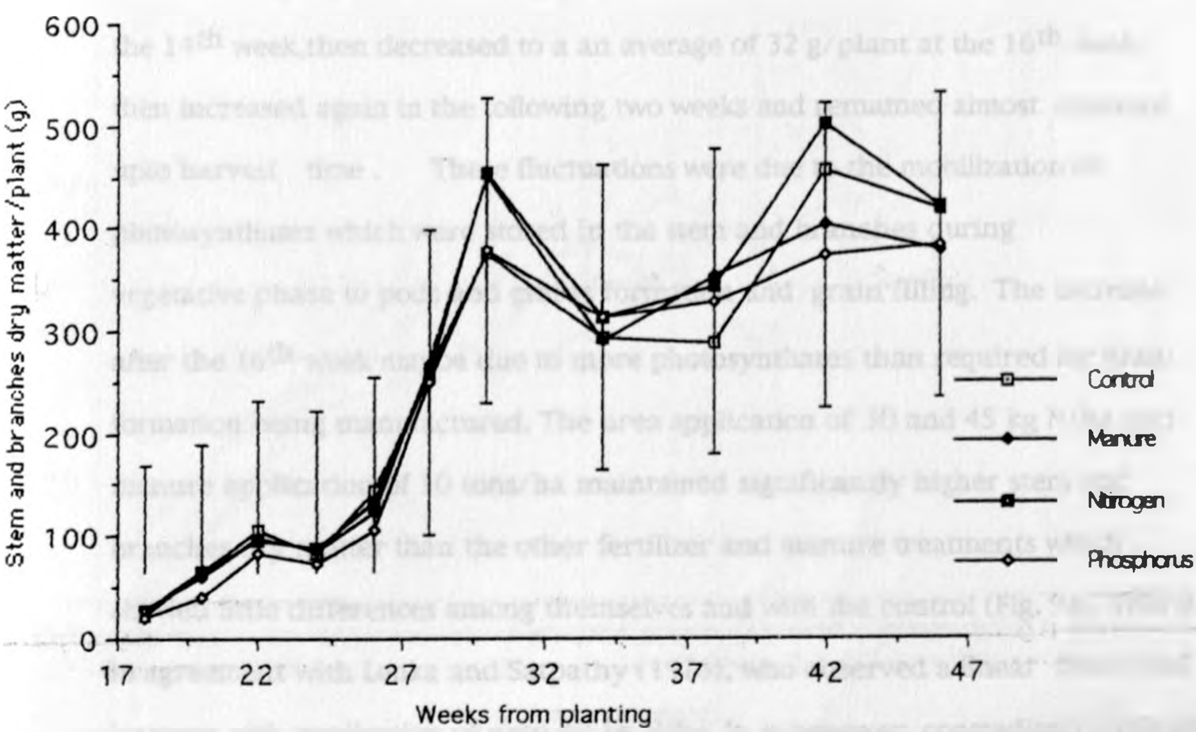

Figure 8b. Effect of type of fertiliser and manure on stem and branches dry matter of Katheka grown at Thika in the short rains 1989/1990.

Katheka had a stem and branches dry matter of about 25 g per plant at the 18^{th} week from planting (Fig. 8b). This increased steadily to about 400 g per plant at harvest time. Fertilizer and manure treatments did not have any significant effect. Katheka flowered at about 33 weeks from planting. From about the 18^{th} week to the 30^{nd} week the stem and branches dry matter continued to increase because the crop was still in the vegetative phase and most of the photosynthetes were mobilised into the stems and branches. After flowering the stem and branches dry matter stopped to increase as photosynthates were mobilised to the formation of pods and grains.

At Kiboko in the long rains 1989, NPP 670 showed slight increase in stem and branches dry matter increase over the period from flowering to harvest time (Fig. 9a). The stem and branches dry matter at flowering time was about 43 g per plant and at harvest time (22^{nd} week) about 54 g per plant. The dry matter increased slightly after flowering (12^{th} week) to an average of 50 g per plant at the 14^{th} week,then decreased to a an average of 32 g/plant at the 16^{th} week, then increased again in the following two weeks and remained almost constant upto harvest time . These fluctuations were due to the mobilization of photosynthates which were stored in the stem and branches during vegetative phase to pods and grains formation and grain filling. The increase after the 16^{th} week maybe due to more photosynthates than required for grain formation being manufactured. The urea application of 30 and 45 kg N/ha and manure application of 10 tons/ha maintained significantly higher stem and branches dry matter than the other fertilizer and manure treatments which showed little differences among themselves and with the control (Fig. 9a). This is in agreement with Lenka and Satpathy (1976), who observed a linear stem yield increase with application of upto 40 kg N/ha. It is however contraditory to Singh, et al ,(1957) observation that application of upto 13 kg P/ha increased most

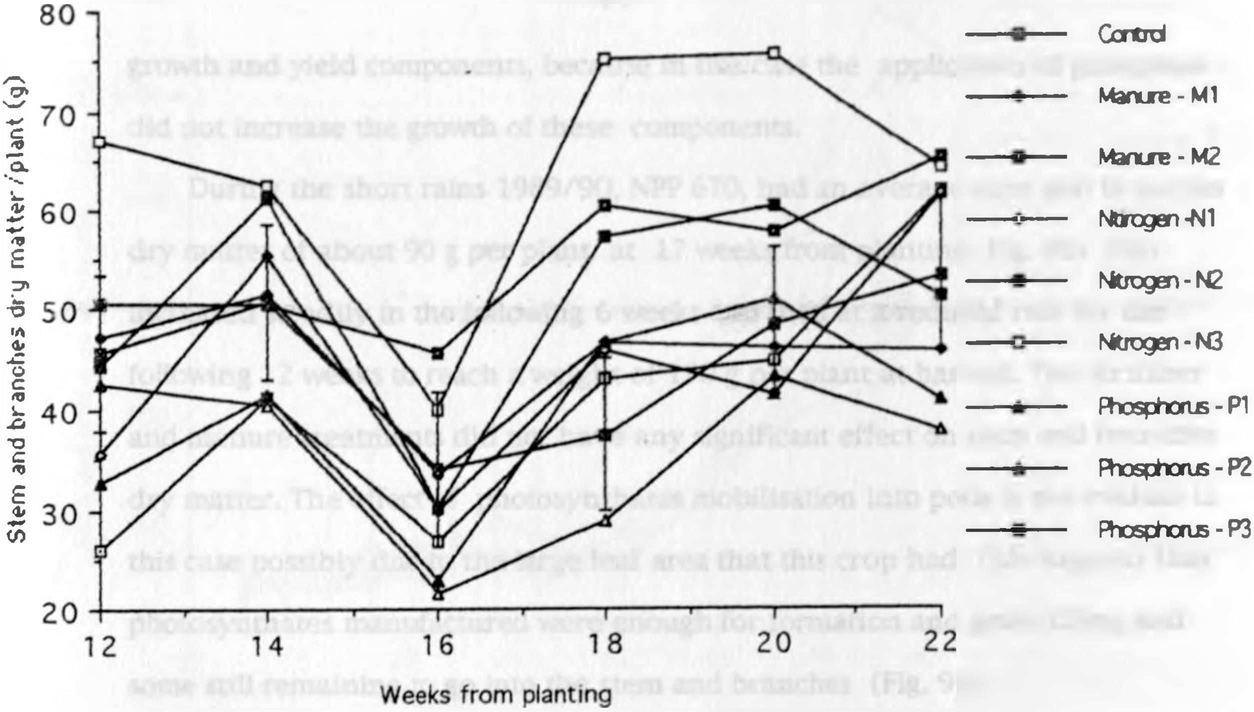

Figure 9a. Effect of type of fertiliser and manure on stem and branches dry matter of NPP 670 grown at kiboko in the long rains 1989.

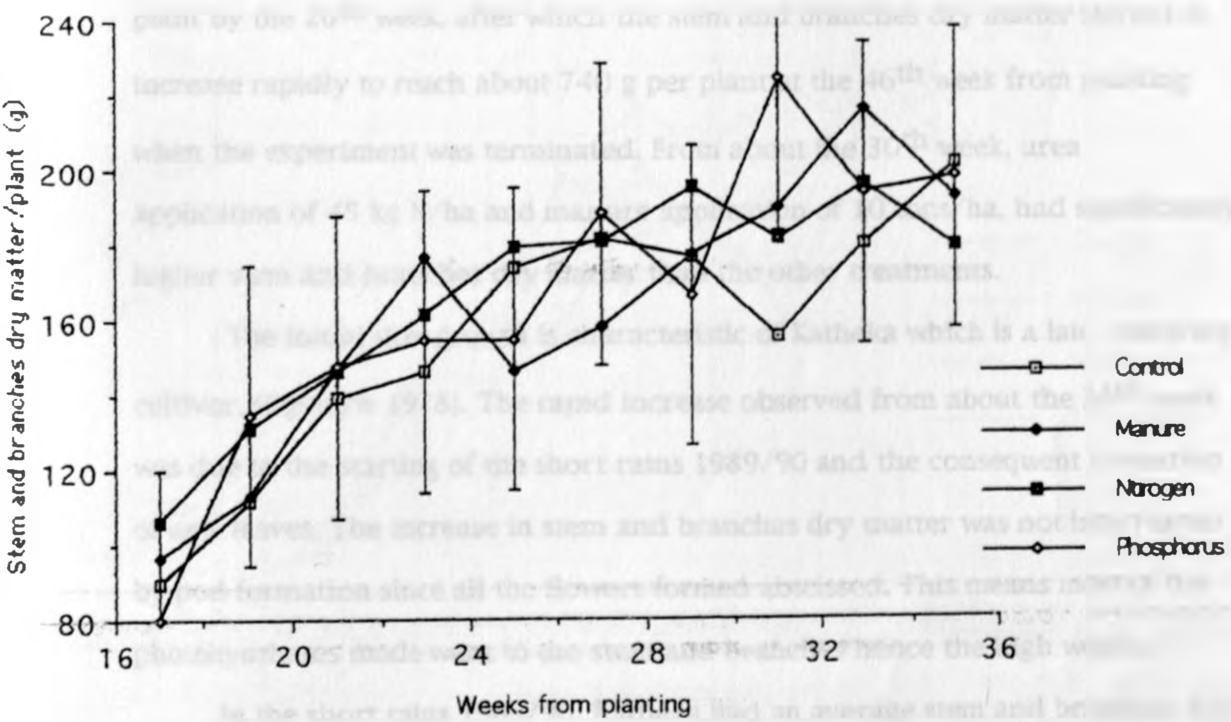

Figure 9b. Effect of type of fertiliser and manure on stem and branches dry matter of NPP 670 grown at Kiboko in the short rains 1989/1990.

growth and yield components, because in this case the application of phosphate did not increase the growth of these components.

During the short rains 1989/90, NPP 670, had an average stem and branches dry matter of about 90 g per plant at 17 weeks from planting (Fig. 9b). This increased steadily in the following 6 weeks and then at a reduced rate for the following 12 weeks to reach a weight of 190 g per plant at harvest. The fertilizer and manure treatments did not have any significant effect on stem and branches dry matter. The effect of photosynthates mobilisation into pods is not evident in this case possibly due to the large leaf area that this crop had. This suggests that photosynthates manufactured were enough for formation and grain filling and some still remaining to go into the stem and branches (Fig. 9b).

During the long rains 1989, Katheka had an average stem and branches dry matter of about 50 g per plant at 12 weeks from planting (Fig. 10a). This increased gradually for the following 14 weeks reaching an average of 106 g per plant by the 26th week, after which the stem and branches dry matter started to increase rapidly to reach about 740 g per plant at the 46th week from planting when the experiment was terminated. From about the 30th week, urea application of 45 kg N/ha and manure application of 10 tons/ha, had significantly higher stem and branches dry matter than the other treatments.

The initial slow growth is characteristic of Katheka which is a late maturing cultivar, (Ogombe 1978). The rapid increase observed from about the 26th week was due to the starting of the short rains 1989/90 and the consequent formation of new leaves. The increase in stem and branches dry matter was not interrupted by pod formation since all the flowers formed abscissed. This means most of the photosynthates made went to the stem and branches hence the high weight.

In the short rains 1989/90, Katheka had an average stem and branches dry matter of 114 g per plant at the 17 week from planting (Fig. 10b). This continued

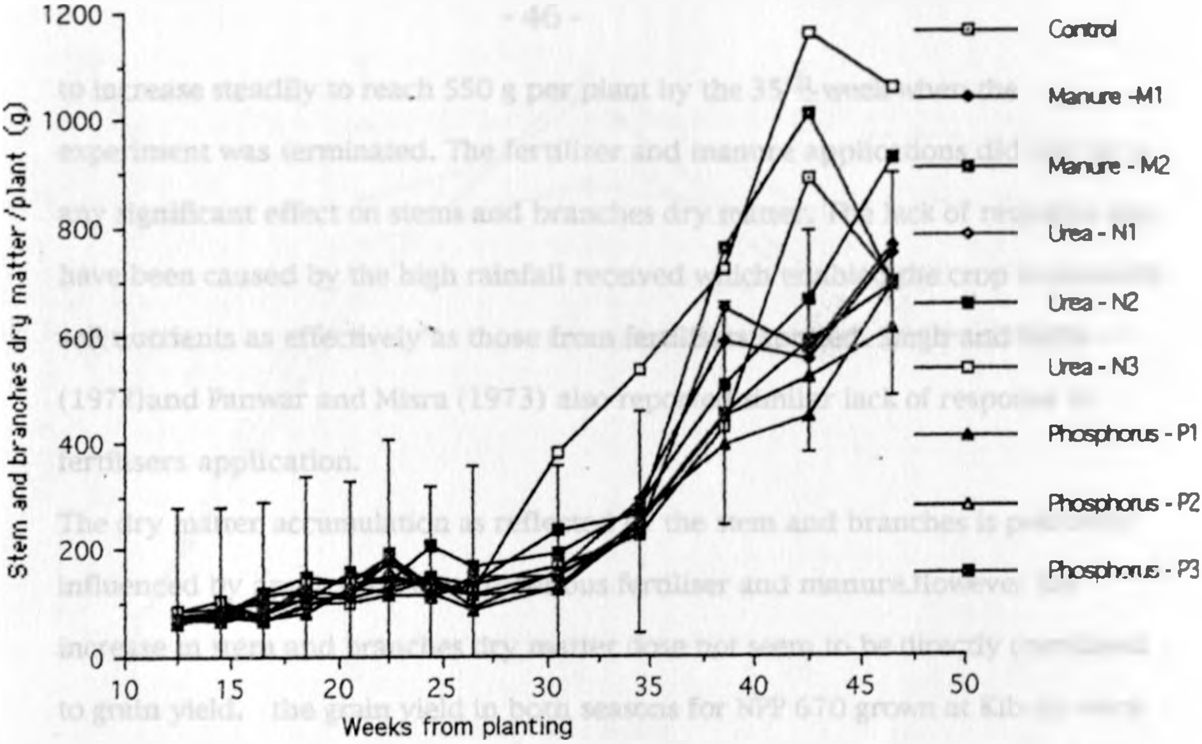

Figure 10a. Effect of type of fertilizer and manure on stem and branches dry matter of Katheka grown at Kiboko inthe long rains 1989.

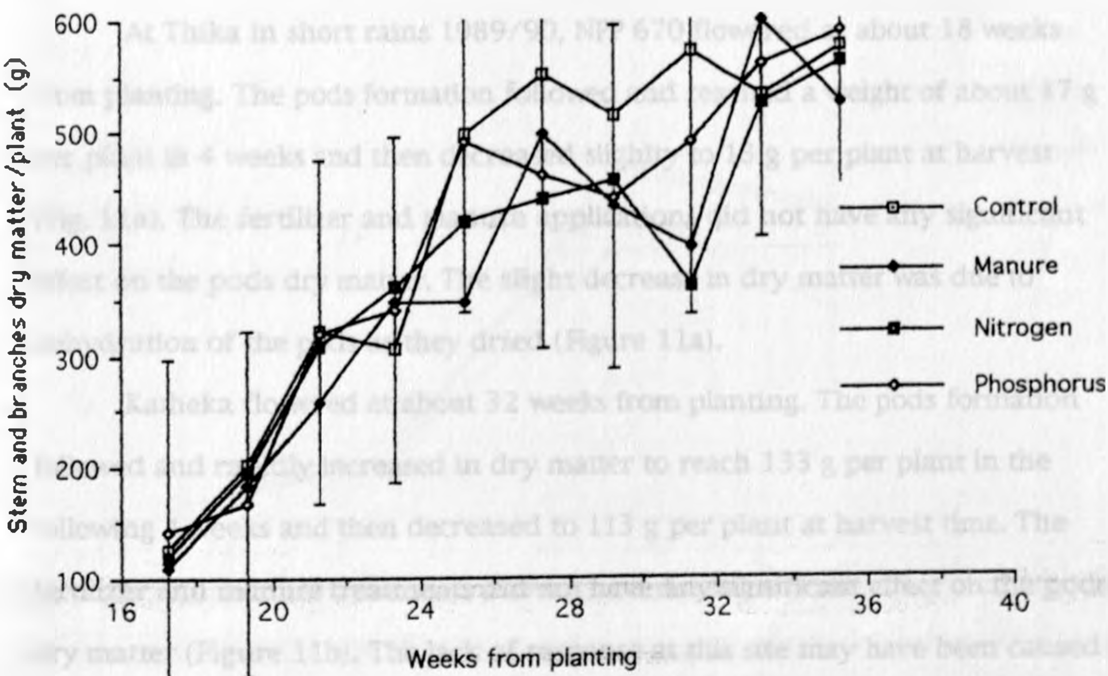

Figure 10b. Effect of type of fertilizer and manure on stem and branches dry matter of Katheka grown at Kiboko in the short rains 1989/'90.

to increase steadily to reach 550 g per plant by the 35th week when the experiment was terminated. The fertilizer and manure applications did not have any significant effect on stems and branches dry matter. The lack of response may have been caused by the high rainfall received which enabled the crop to absoerb soil nutrients as effectively as those from fertilisers applied. Singh and Rathi (1972)and Panwar and Misra (1973) also reported similar lack of response to fertilisers application.

The dry matter accumulation as reflected by the stem and branches is positively influenced by application of nitrogenous fertiliser and manure.However the increase in stem and branches dry matter dose not seem to be directly correlated to grain yield. the grain yield in both seasons for NPP 670 grown at Kiboko were similar, but the short rains 1989/90 crop had significantly higher stem and branches dry matter(Table 14).

4.1.4 Pod Dry Matter

At Thika in short rains 1989/90, NPP 670 flowered at about 18 weeks from planting. The pods formation followed and reached a weight of about 17 g per plant in 4 weeks and then decreased slighlty to 13 g per plant at harvest (Fig. 11a). The fertilizer and manure applications did not have any significant effect on the pods dry matter. The slight decrease in dry matter was due to dehydration of the pods as they dried (Figure 11a).

Katheka flowered at about 32 weeks from planting. The pods formation followed and rapidly increased in dry matter to reach 133 g per plant in the following 4 weeks and then decreased to 113 g per plant at harvest time. The fertilizer and manure treatments did not have any significant effect on the pods dry matter (Figure 11b). The lack of response at this site may have been caused by other factors limi6ting production other than nutrients. The soil at this site also

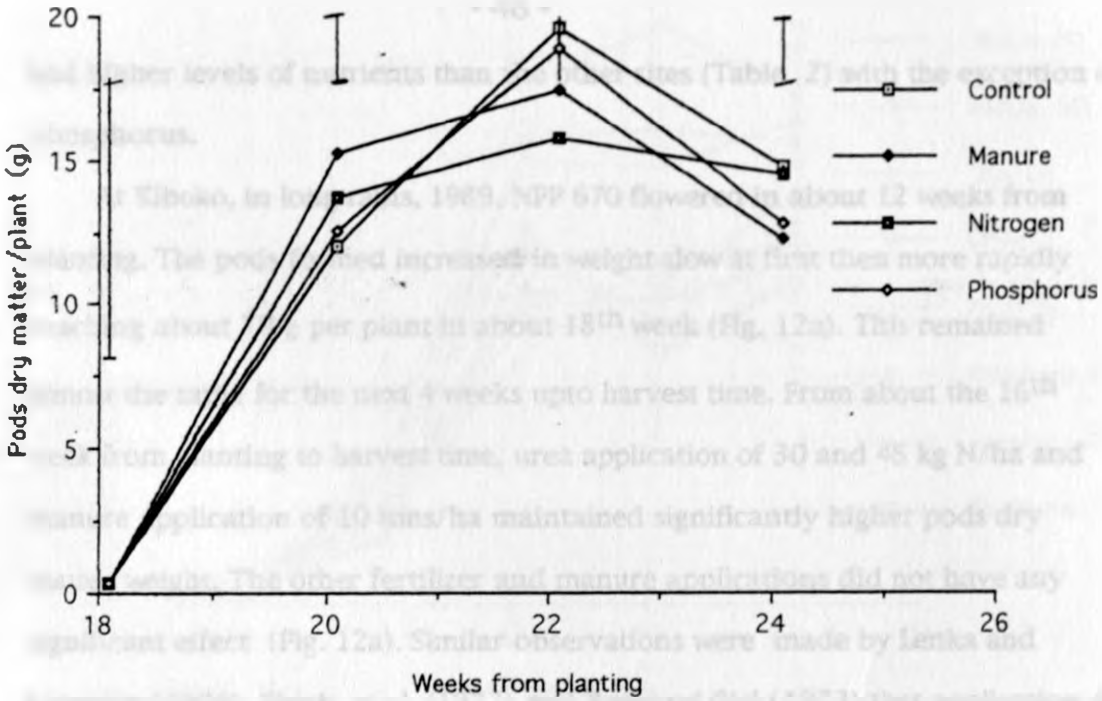

Figure 11a. Effect of type of fertilizer and manure on pods dry matter of NPP 670 grown at Thika in the short rains 1989/'90.

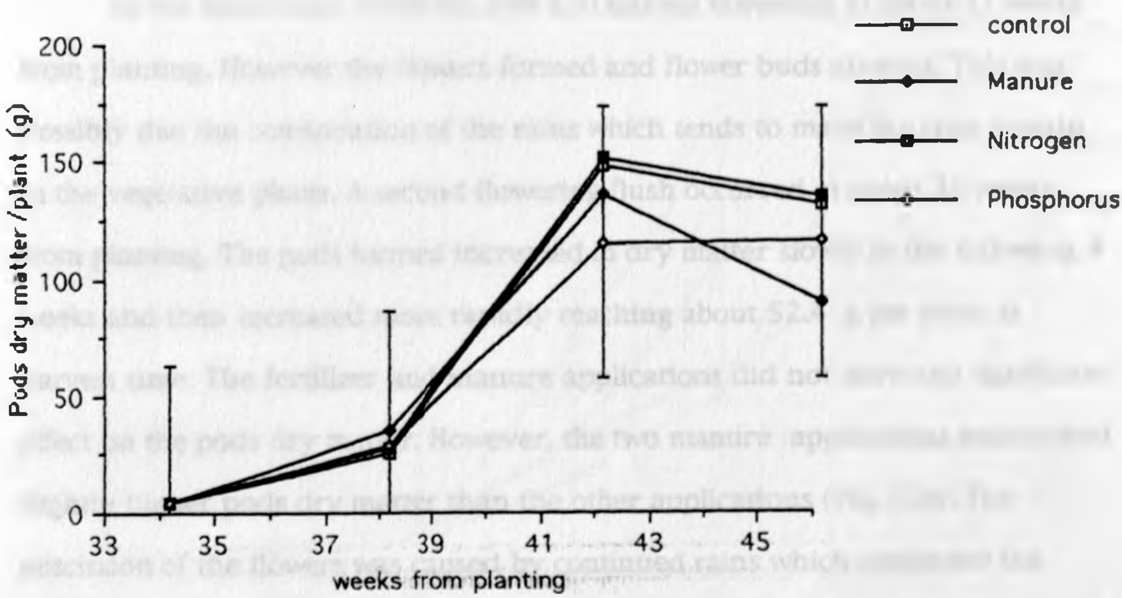

Figure 11b. Effect of type of fertilizer and manure on the pods dry matter of Katheka grown at Thika in the short rains 1989/'90.

had higher levels of nutrients than the other sites (Table 2) with the exception of phosphorus.

At Kiboko, in long rains, 1989, NPP 670 flowered in about 12 weeks from planting. The pods formed increased in weight slow at first then more rapidly reaching about 79 g per plant in about 18^{th} week (Fig. 12a). This remained almost the same for the next 4 weeks upto harvest time. From about the 16^{th} week from planting to harvest time, urea application of 30 and 45 kg N/ha and manure application of 10 tons/ha maintained significantly higher pods dry matter weight. The other fertilizer and manure applications did not have any significant effect (Fig. 12a). Similar observations were made by Lenka and Satpathy (1976), Singh, et al, (1972) and Ram and Giri (1973) that application of nitrogen incresed grains yield. Dalal (1974) also reported that application of 40 kg N/ha increased vegetative growth ,height, yield of stems and branches and number of branches.

In the short rains 1989/90, NPP 670 started flowering at about 12 weeks from planting. However the flowers formed and flower buds aborted. This was possibly due the continuation of the rains which tends to make the crop remain in the vegetative phase. A second flowering flush occurred at about 25 weeks from planting. The pods formed increased in dry matter slowly in the following 4 weeks and then increased more rapidly reaching about 52.4 g per plant at harvest time. The fertilizer and manure applications did not have any significant effect on the pods dry matter. However, the two manure applications maintained slightly higher pods dry matter than the other applications (Fig. 12b). The abscission of the flowers was caused by continued rains which prolonged the vegetative phase. This shows that pigeopea required a dry period to enhance pod formation (Kimani ,personal communication ,1990).

Katheka did not form any pods in both seasons and remained vegetative.

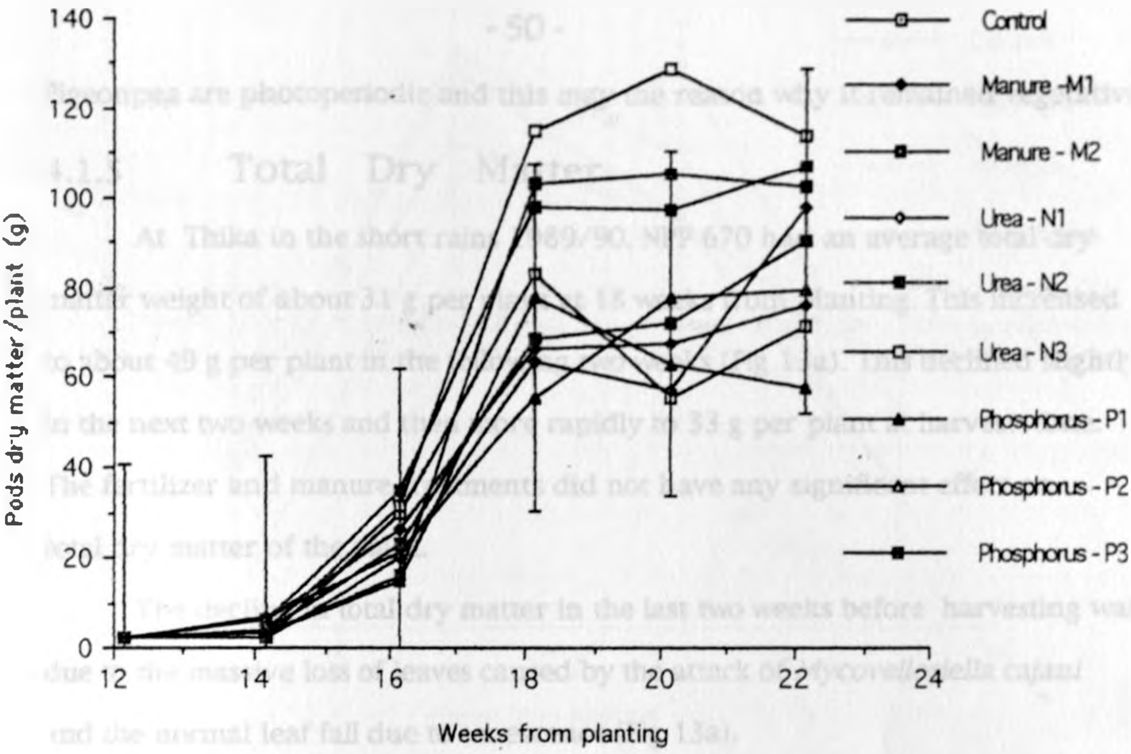

Figure 12a. Effect of type of fertilizer and manure on pods dry matter of NPP 670 grown at Kiboko in the long rains 1989.

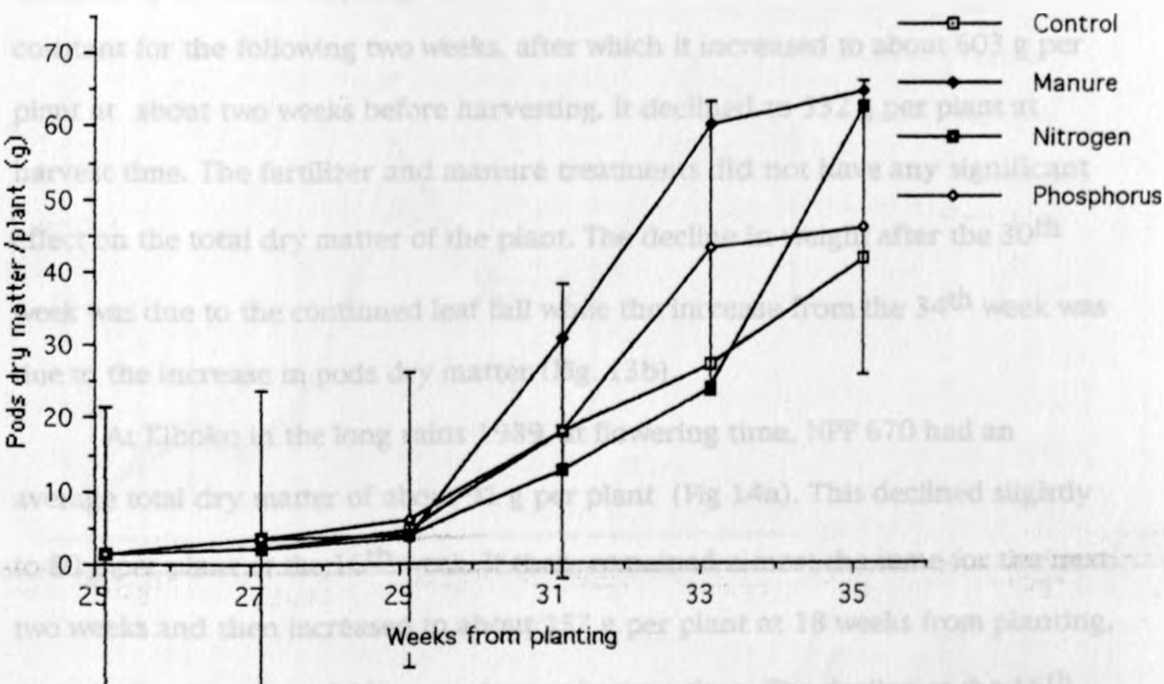

Figure 12b. Effect of type of fertilizer and manure on pods dry matter of NPP 670 grown at Kiboko in the short rains 1989/'90.

Pigeonpea are photoperiodic and this may the reason why it remained vegetative.

4.1.5 Total Dry Matter

At Thika in the short rains 1989/90, NPP 670 had an average total dry matter weight of about 31 g per plant at 18 weeks from planting. This increased to about 49 g per plant in the following two weeks (Fig 13a). This declined slightly in the next two weeks and then more rapidly to 33 g per plant at harvest time. The fertilizer and manure treatments did not have any significant effect on total dry matter of the plant.

The decline in total dry matter in the last two weeks before harvesting was due to the massive loss of leaves caused by the attack of *Mycovellosiella cajani* and the normal leaf fall due to senescence (Fig 13a).

Katheka had total dry matter weight of 45 g per plant at 18 weeks from planting. This increased slowly for the next 8 weeks and then more rapidly reaching about 520 g per plant by the 30th week from planting. This then declined to about 354 g per plant in the next two weeks and remained almost cosntant for the following two weeks, after which it increased to about 603 g per plant at about two weeks before harvesting. It declined to 532 g per plant at harvest time. The fertilizer and manure treatments did not have any significant effect on the total dry matter of the plant. The decline in weight after the 30^{th} week was due to the continued leaf fall while the increase from the 34^{th} week was due to the increase in pods dry matter (Fig. 13b).

At Kiboko in the long rains 1989, at flowering time, NPP 670 had an average total dry matter of about 91 g per plant (Fig 14a). This declined slightly to 80 g per plant at the 16^{th} week. It then remained almost the same for the next two weeks and then increased to about 153 g per plant at 18 weeks from planting, then declined to about 146 g per plant at harvest time. The decline at the 16^{th}

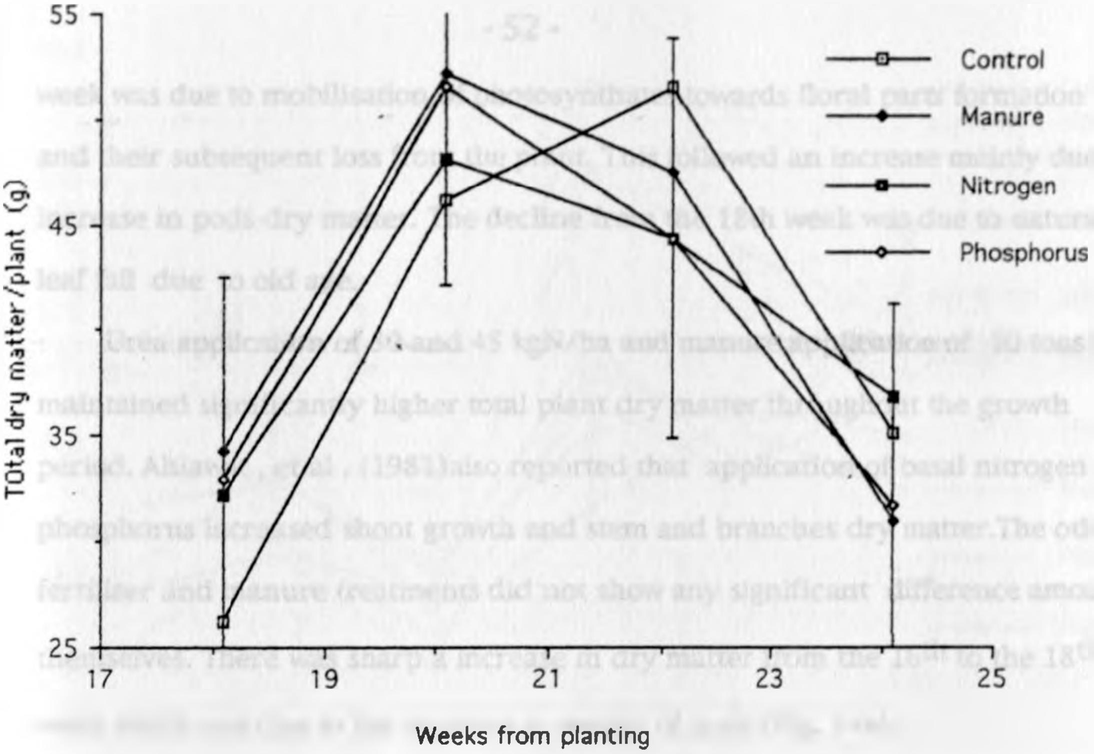

Figure 13a. Effect of type of fertilizer and manure on total dry matter of NPP 670 grown at Thika in the short rains 1989/'90

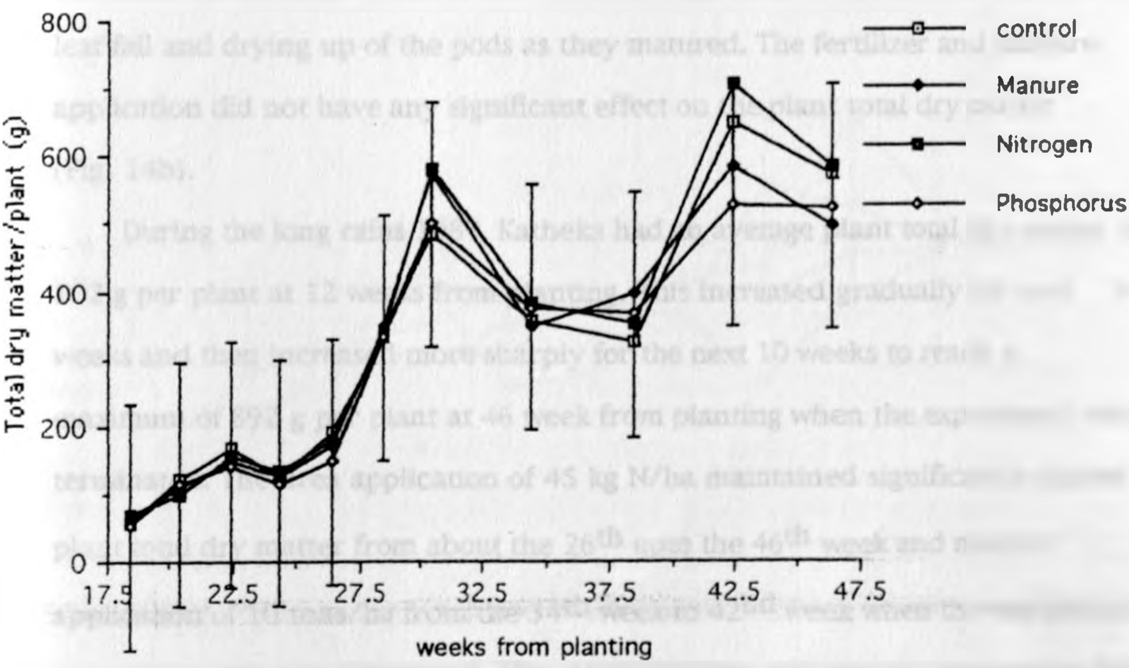

Figure 13b. Effect of type of fertilizer and manure on total dry matter of Katheka grown at Thika in the short rains 1989/'90.

week was due to mobilisation of photosynthates towards floral parts formation and their subsequent loss from the plant. This followed an increase mainly due to increase in pods dry matter. The decline from the 18th week was due to natural leaf fall due to old age.

Urea application of 30 and 45 kgN/ha and manure application of 10 tons/ha maintained significantly higher total plant dry matter throughout the growth period. Ahlawat , et al , (1981)also reported that application of basal nitrogen and phosphorus increased shoot growth and stem and branches dry matter.The other fertilizer and manure treatments did not show any significant difference among themselves. There was sharp a increase in dry matter from the 16^{th} to the 18^{th} week which was due to the increase in weight of pods (Fig. 14a).

In the short rains 1989/90, NPP 670 had a plant total dry matter of 154 g per plant at 17 week from planting. This continued to increase almost linearly to reach a maximum of about 274g per plant, two weeks before harvesting, this then decreased to 264 g per plant at harvest time. This drop in dry matter was due to leaf fall and drying up of the pods as they matured. The fertilizer and manure application did not have any significant effect on the plant total dry matter (Fig. 14b).

During the long rains 1989, Katheka had an average plant total dry matter of 102 g per plant at 12 weeks from planting. This increased gradually for next 14 weeks and then increased more sharply for the next 10 weeks to reach a maximum of 892 g per plant at 46 week from planting when the experiment was terminated. The urea application of 45 kg N/ha maintained significantly higher plant total dry matter from about the 26^{th} upto the 46^{th} week and manure application of 10 tons/ha from the 34^{th} week to 42^{nd} week when the experiment was experiment was terminated. The other fertilizer and manure treatments did not show significant differences among themselves. The sharp increase in total

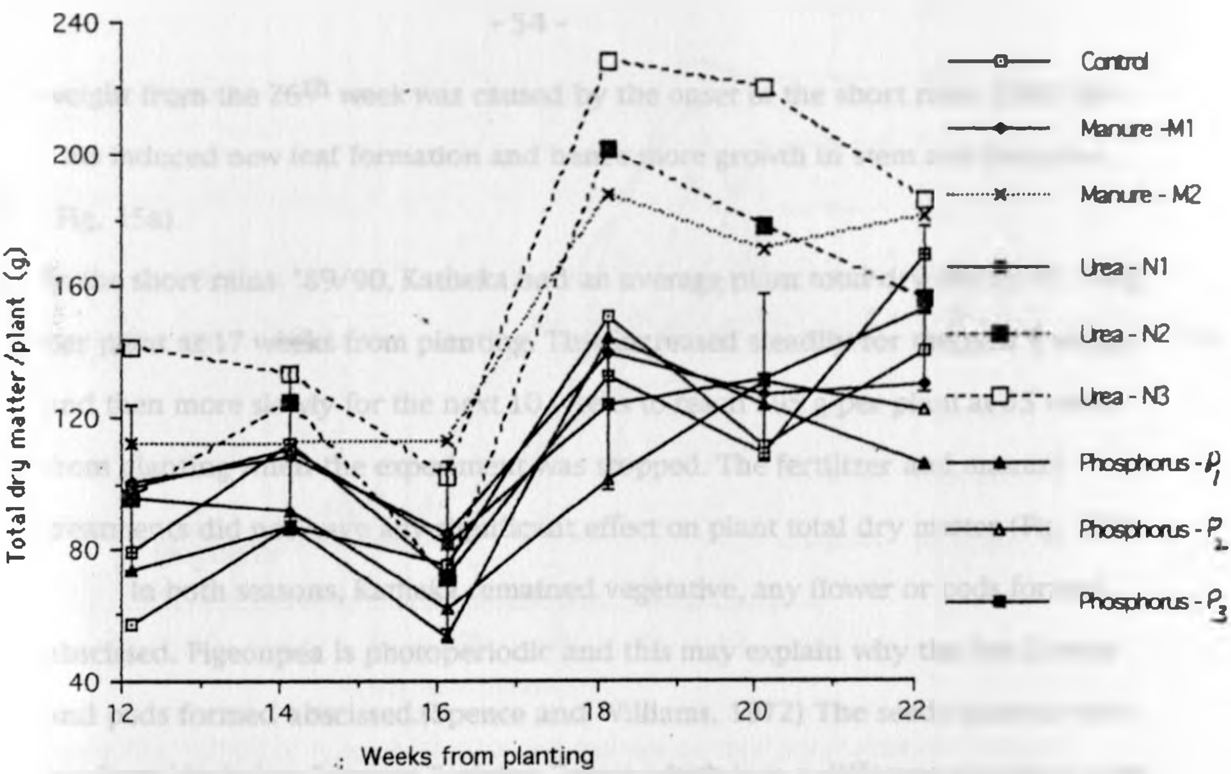

Figure 14a. Effect of type of fertilizer and manure on total dry matter of NPP 670 grown at Kiboko in the long rains 1989.

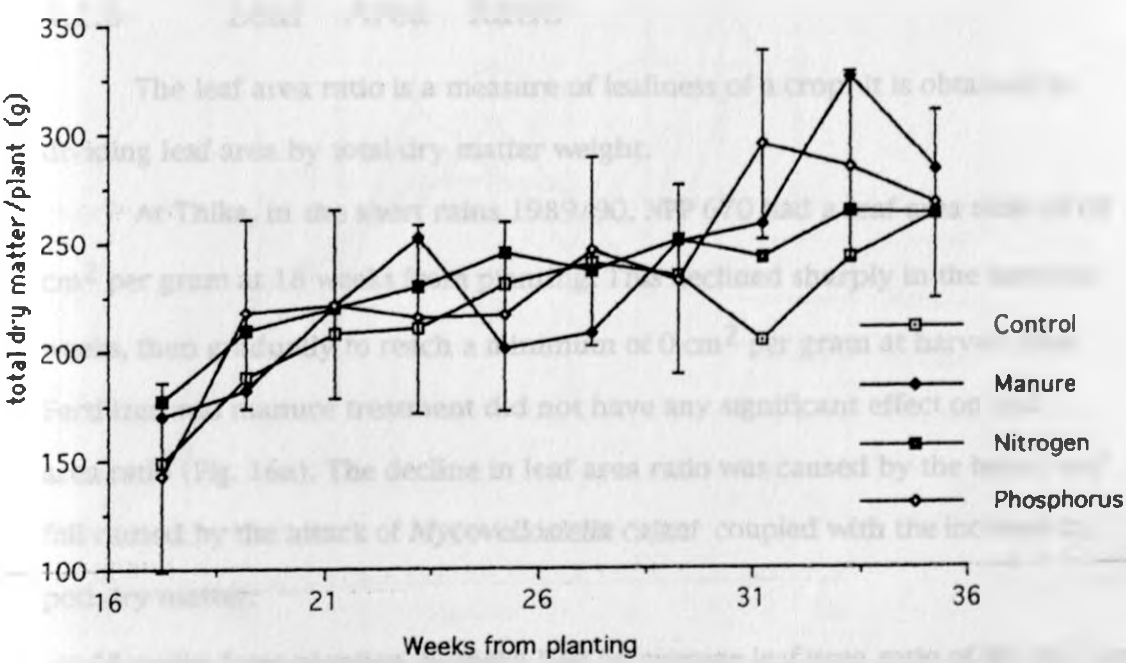

Figure 14b. Effect of type of fertilizer and manure on total dry matter of NPP 670 grown at Kiboko in the short rains 1989/'90.

weight from the 26th week was caused by the onset of the short rains 1989/90. This induced new leaf formation and hence more growth in stem and branches (Fig. 15a).

In the short rains '89/90, Katheka had an average plant total dry matter of 168 g per plant at 17 weeks from planting. This increased steadily for the next 8 weeks and then more slowly for the next 10 weeks to reach 595 g per plant at 35 weeks from planting when the experiment was stopped. The fertilizer and manure treatments did not have any significant effect on plant total dry matter (Fig. 15b).

In both seasons, Katheka remained vegetative, any flower or pods formed abscissed. Pigeonpea is photoperiodic and this may explain why the few flowers and pods formed abscissed.(Spence and Williams, 1972) The seeds planted were got from Machakos Farmers Training Centre which is in a different ecological zone from Kiboko. This means that there is need to have different seed material for different ecological zones.

4.1.6 Leaf Area Ratio

The leaf area ratio is a measure of leafiness of a crop. It is obtained by dividing leaf area by total dry matter weight.

At Thika, in the short rains 1989/90, NPP 670 had a leaf area ratio of 68 cm^2 per gram at 18 weeks from planting. This declined sharply in the next two weeks, then gradually to reach a minimum of 0 cm^2 per gram at harvest time. Fertilizer and manure treatment did not have any significant effect on leaf area ratio (Fig. 16a). The decline in leaf area ratio was caused by the heavy leaf fall caused by the attack of *Mycovellosiella cajani* coupled with the increase in pod dry matter.

At 18 weeks from planting, Katheka had an average leaf area ratio of 88 cm^2 per gram.This declined sharply at first, then gradually to reach a minimum of 5 cm^2

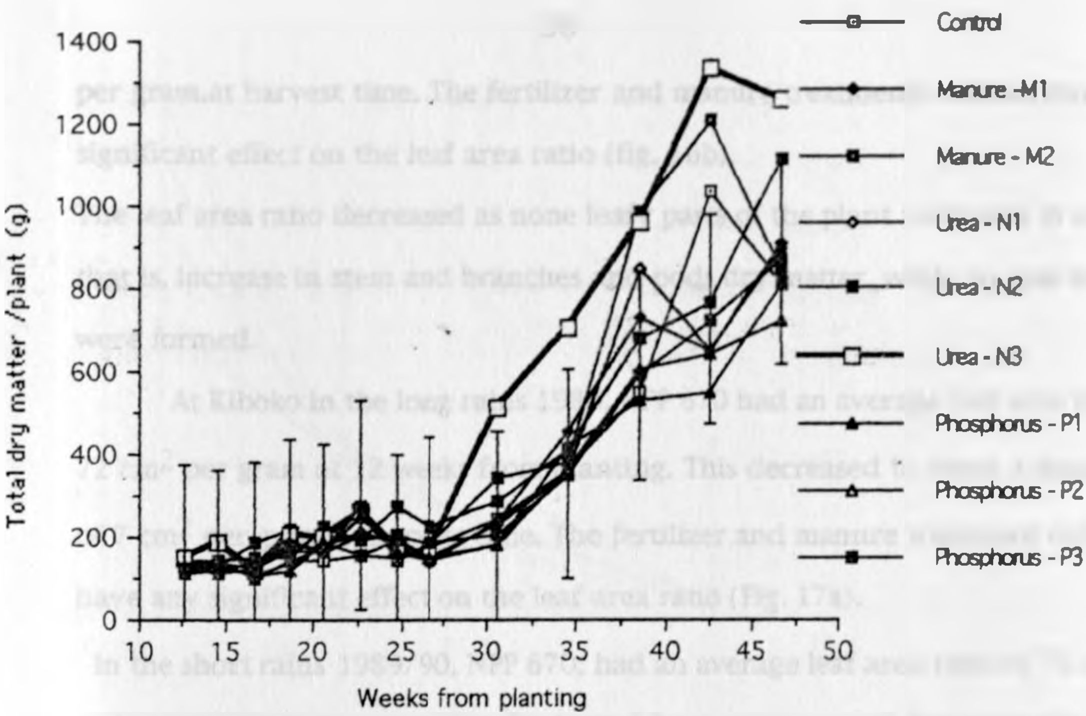

Figure 15a. Effect of type of fertilizer and manure on total dry matter of Katheka grown at Kiboko in the long rains 1989.

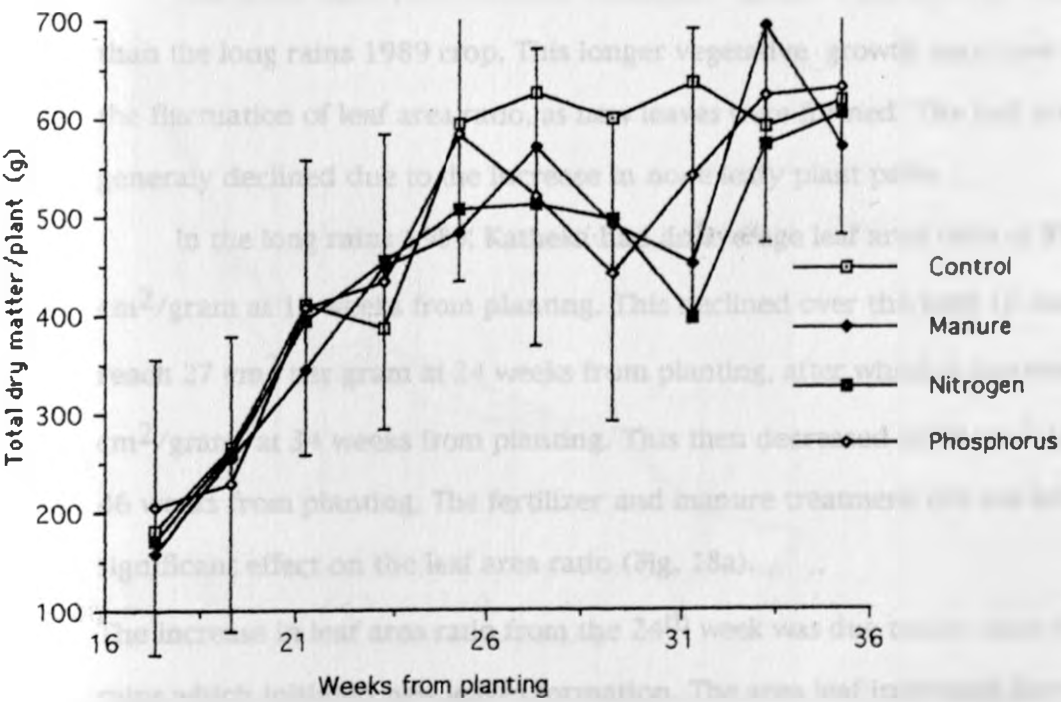

Figure 15b. Effect of type of fertilizer and manure on total dry matter of Katheka grown at Kiboko in the short rains 1989/'90.

per gram.at harvest time. The fertilizer and manure treatments did not have any significant effect on the leaf area ratio (fig. 16b).

The leaf area ratio decreased as none leafy parts of the plant increased in weight, that is, increase in stem and branches and pods dry matter, while no new leaves were formed.

At Kiboko in the long rains 1989, NPP 670 had an average leaf area ratio of 72 cm^2 per gram at 12 weeks from planting. This decreased to reach a minimum of 7 cm^2 per gram at harvest time. The fertilizer and manure treatment did not have any significant effect on the leaf area ratio (Fig. 17a).

In the short rains 1989/90, NPP 670, had an average leaf area ratio of 75 cm^2/g at 17 weeks from planting. This fluctuated from week to week but generally showed a declining trend to reach a minimum of 28 cm^2 /gram at 35 weeks from planting. The fertilizer and manure treatment did not have any significant effect on the leaf area ratio (Fig. 17b).

The short rains 1989/90 crop remained vegetative for about 5 weeks longer than the long rains 1989 crop. This longer vegetative growth may have caused the fluctuation of leaf area ratio, as new leaves were formed. The leaf area ratio generaly declined due to the increase in none leafy plant parts.

In the long rains 1989, Katheka had an average leaf area ratio of 85 cm^2/gram at 12 weeks from planting. This declined over the next 12 weeks to reach 27 cm^2 per gram at 24 weeks from planting, after which it increased to 67 cm^2/gram. at 34 weeks from planting. This then decreased to 28 cm^2 /gram at 46 weeks from planting. The fertilizer and manure treatment did not have any significant effect on the leaf area ratio (Fig. 18a).

The increase in leaf area ratio from the 24^{th} week was due to the onset of the short rains which initiated new leaves formation. The area leaf increased faster than

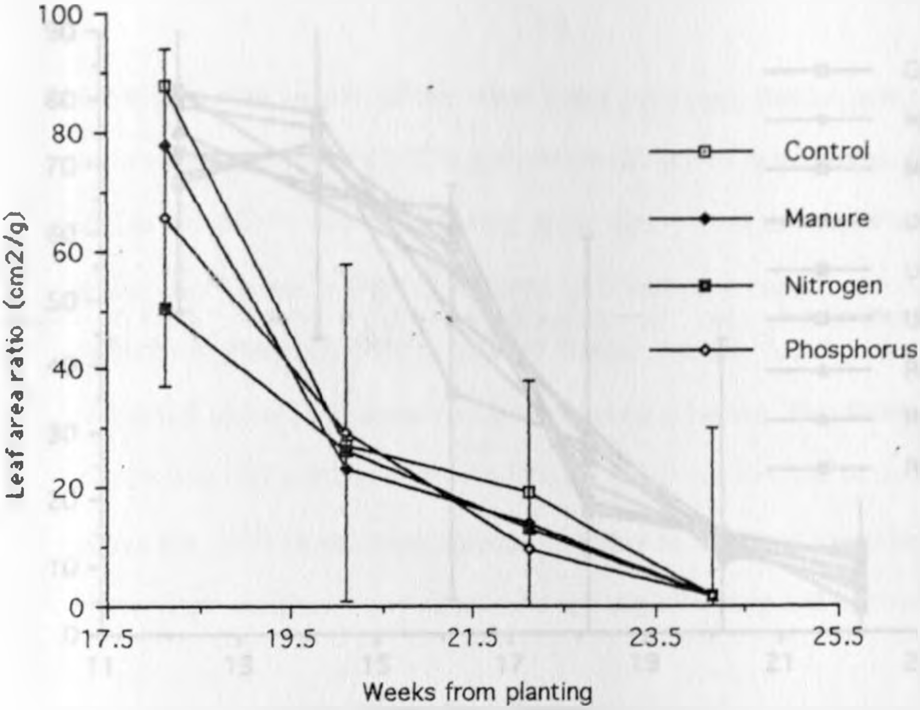

Figure 16a. Effect of type of fertilizer and manure on leaf area ratio of NPP 670 grown at Thika in the short rains 1989/'90.

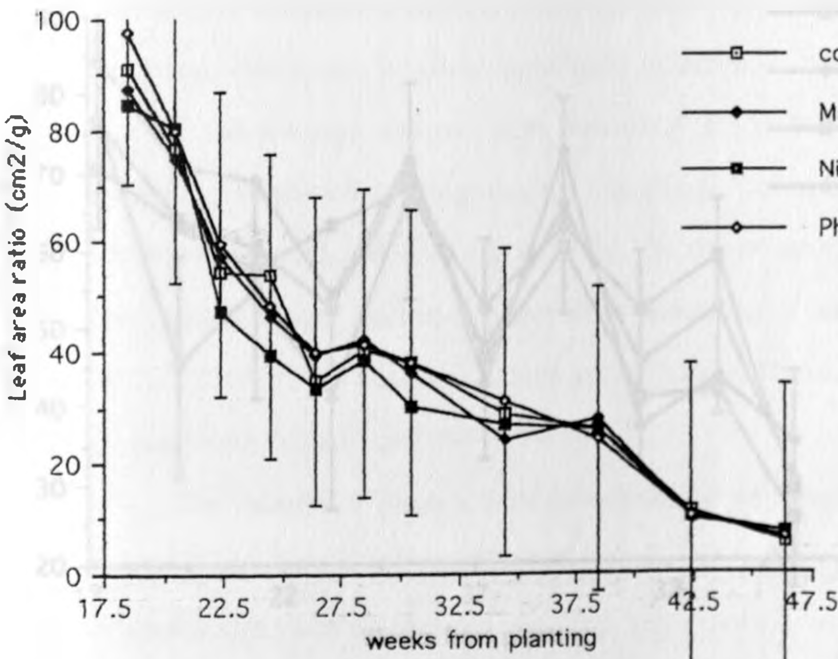

Figure 16b. Effect of type of fertilizer and manure on leaf area ratio of Katheka grown at Thika in the short rains 1989/'90.

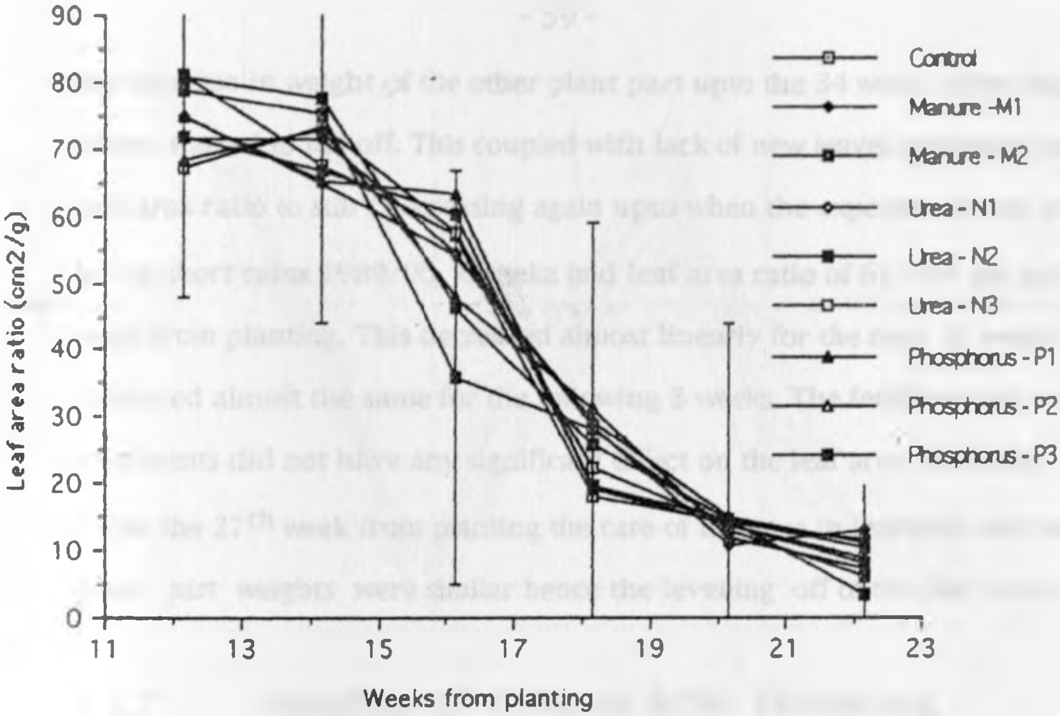

Figure 17a. Effect of type of fertilizer and manure on leaf area ratio of NPP 670 grown at Kiboko in the long rains 1989

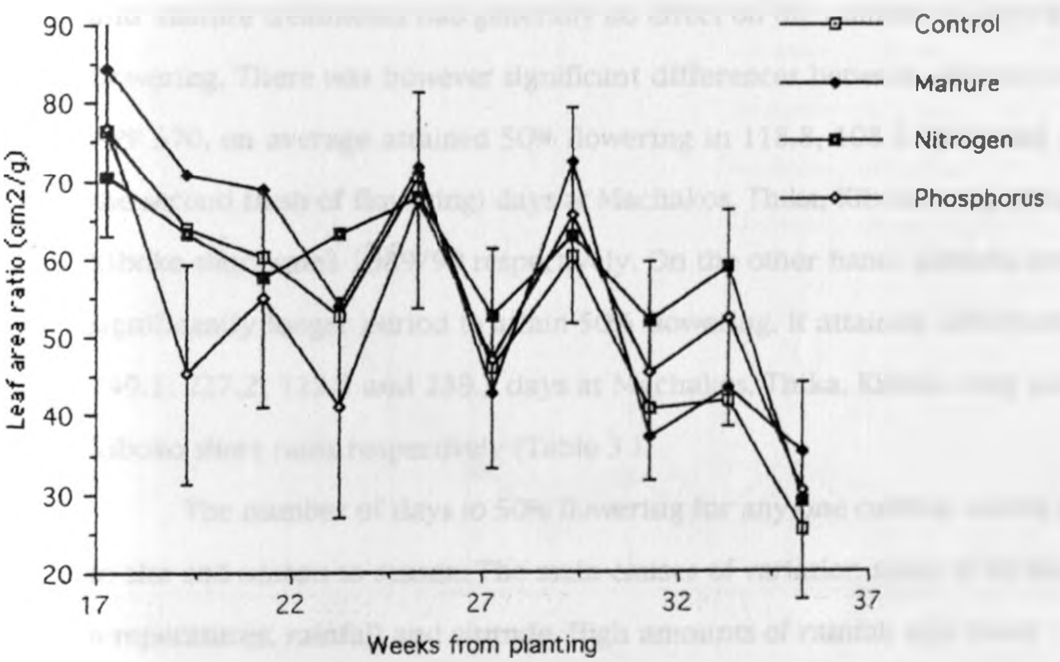

Figure 17b. Effect of type of fertilizer and manure on leaf area ratio of NPP 670 grown at Kiboko in the short rains 1989/'90.

the increase in weight of the other plant part upto the 34 week. After this, the old leaves started to fall off. This coupled with lack of new leaves initiation caused the leaf area ratio to start decreasing again upto when the experiment was stopped. In the short rains 1989/90, Katheka had leaf area ratio of 61 cm^2 per gram at 17 week from planting. This decreased almost linearly for the next 10 weeks and then remained almost the same for the following 8 weeks. The fertilizer and manure treatments did not have any significant effect on the leaf area ratio (Fig.18b). From about the 27th week from planting the rate of increase in leaf area and the other plant part weights were similar hence the levelling off of the leaf area ratio.

4.1.7 Number of Days to 50% Flowering

The number of days to 50% flowering were determined as the number of days from planting to when 50% of the plants in a plot had flowered.

At all the three sites namely Thika. Machakos and Kiboko. all the fertilizer and manure treatments had generally no effect on the number of days to 50% flowering. There was however significant differences between the two cultivars. NPP 670, on average attained 50% flowering in 118.8, 108.3, 86.8 and 169.1 (to the second flush of flowering) days at Machakos, Thika, Kiboko long rains, and Kiboko short rains 1989/90 respectively. On the other hand, Katheka took significantly longer period to attain 50% flowering. It attained 50% flowering in 149.1, 227.2, 122.9 and 239.1 days at Machakos, Thika, Kiboko long rains, and Kiboko short rains respectively (Table 3).

The number of days to 50% flowering for any one cultivar varied from site to site and season to season. The main causes of variation seem to be due to temperatures, rainfall and altitude. High amounts of rainfall and lower temperature seem to increase the number of days to flowering. Wamatu (1989) and Ogombe (1978) reported similar variation depending on the season and site.

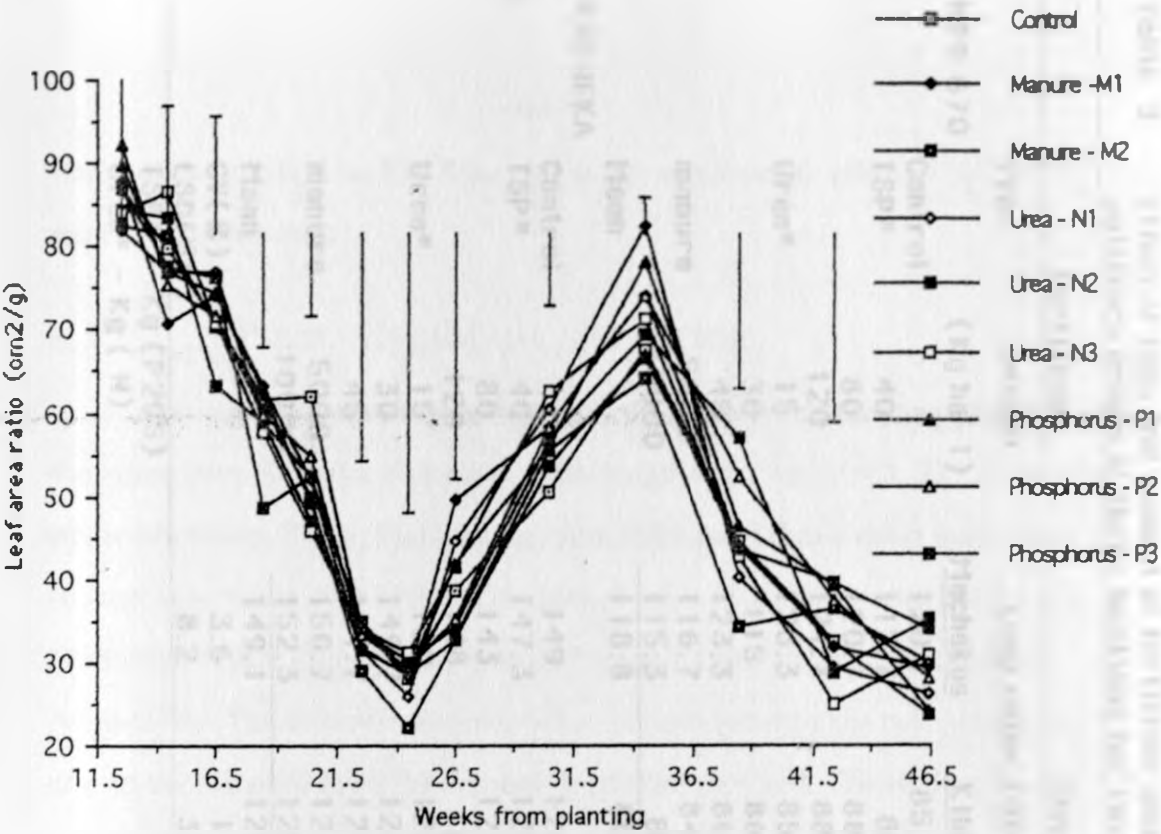

Figure 18a. Effect of type of fertilizer and manure on leaf area ratio of Katheka grown at Kiboko in the long rains 1989.

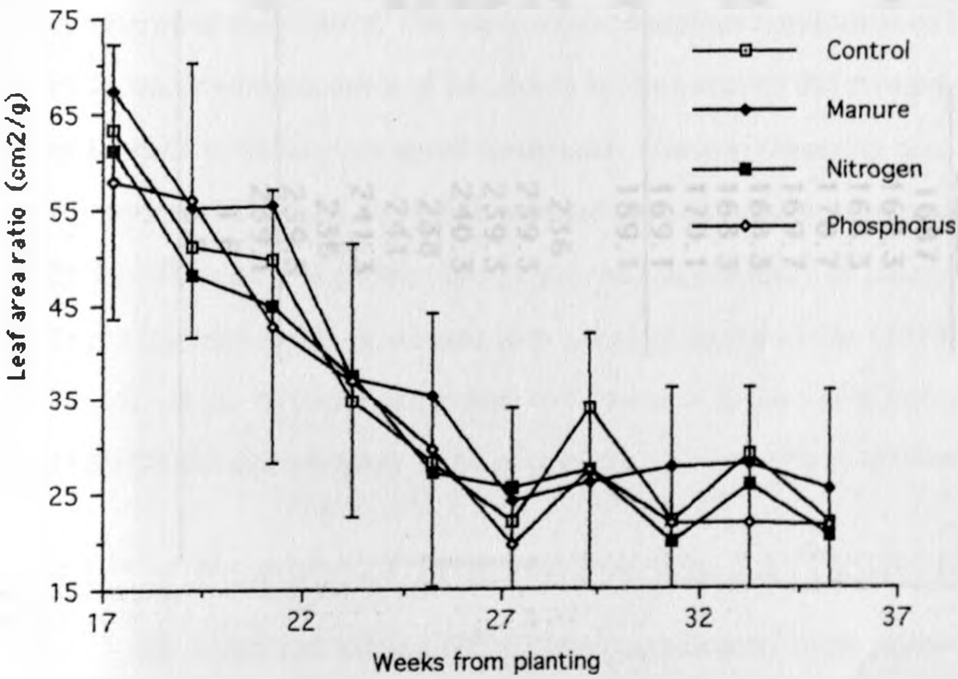

Figure 18b. Effect of type of fertilizer and manure on leaf area ratio of Katheka grown at Kiboko in the short rains 1989/'90.

Table 3. Effect of type and amount of fertiliser and manure on duration to flowering of two pigeonpea cultivars grown at three locations for two seasons

	Fertiliser		Days to flowering			
			Long rains 1989		Short rains 1989/90	
	Type	amount (Kg ha-1)	Machakos	Kiboko	Thika	Kiboko
NPP 670						
	Control		120.7	85.30	109	1687
	TSP*	40	112.7	88	110.3	168.3
		80	120.7	88.3	109	168.3
		120	121.7	88.3	108	170.7
	Urea*	15	123.3	85.3	107	169.7
		30	115	86.3	108.3	168.3
		45	123.3	86.7	108.3	168.3
	manure	5000	116.7	84.7	107	170.1
		10000	115.3	88	108	169.1
	Mean		118.8	86.8	108.3	169.1
KATHEKA						
	Control		149	123.7	227.7	236
	TSP*	40	147.3	123.7	227.3	239.3
		80	143	122.7	226.3	239.3
		120	148	124	227.3	240.3
	Urea*	15	150	123.7	227.6	238
		30	149.7	121.7	227.3	241
		45	151.7	121.3	227	241.3
	manure	5000	150.7	123.7	227	236
		10000	152.3	122.3	227	239.3
	Mean		149.1	122.9	227.2	239.1
	CV(%)		3.6	1.5	1.2	1.6
	LSD(5%)		8.2	3.4	3.3	5.5

TSP* - Kg (P205)
Urea* - Kg (N)

The number of days to 50% flowering is not significantly affected by fertiliser and manutre application.

4.1.8 Plant Height at Flowering

Katheka had significantly taller plants at flowering time than NPP 670 at all the three sites. Katheka had plants with heights of 79.5, 304.2, 211.5 and 366.5 cm at Machakos, Thika, Kiboko long rains 1989 and Kiboko short rains 1989/90, respectively, while NPP 670 had heights of 40.1, 66.5, 106.0 and 124.9 cm at Machakos, Thika, Kiboko long rains 1989 and Kiboko short rains 1989/90, respectively. The differences observed at Kiboko between the two seasons were due to the differences in the amount of rainfall received. The short rains 1989/90 had received more rain and had subsequently tall er plants.

At all sites, fertilizer treatments applied to NPP 670 did not have any significant effect on plant height at flowering time. The urea application of 30 kg N/ha to Katheka at Machakos,resulted in significantly shorter plants at flowering time compared to the control. The triple superphosphate application of 120 kg P_2O_5/ha, urea application of 30 and 45 kgN/ha and all the manure applications to Katheka at Thika gave significantly taller plants at flowering time compared to the control. Singh, et al, (1957) reported that a nitrogen basal application of 25 kg N/ha and 13 kg P/ha (30 kg P_2O_5/ha) significantly increased plant height. These findings are in agreement with those of Ram and Giri (1973)and Ahlawat (1976). All the fertilizer applcatons to Katheka at Kiboko in the short rains 1989/90 did not have any significant effect on plant height at flowering (Table 4).

4.1.9 Number of Primary Branches at Flowering

At Thika and Kiboko, NPP 670 had significantly more primary branches than Katheka. At Machakos NPP 670 had similarly more primary branches than

Table 4. Effect of type and amount of fertiliser and manure on plant height at flowering of two pigeonpea cultivars grown at three locations for two seasons

	Fertiliser		Plant heihgt (cm)			
			Long rains 1989		Short rains 1989/90	
	Type	amount (Kg ha-1)	Machakos	Kiboko	Ihika	Kiboko
NPP 670						
	Control		40.2	106	66.1	127.6
	TSP*	40	43.1	101.3	67.2	122
		80	38.7	101.3	66.3	121.8
		120	38.8	99	67.7	117.4
	Urea*	15	38	111.8	62.9	125.9
		30	42.5	111.5	64.8	127.6
		45	36.1	111.1	71.9	130.3
	manure	5000	41.1	106.1	67.3	127.5
		10000	42.3	106	64.4	123.7
	Mean		40.1	106	66.5	124.9
KATHEKA						
	Control		84.1	205.1	315.4	366.5
	TSP*	40	75.5	205.1	309	370.5
		80	84.5	206.6	309.2	373.1
		120	77.1	200.1	297	361.5
	Urea*	15	77.2	207.7	304.3	364.9
		30	75.3	215	297.7	370.2
		45	83.6	230.5	300.7	351.9
	manure	5000	80.4	214.4	300.78	360.3
		10000	81	218.7	310.3	379.1
	Mean		79.9	211.5	304.2	366.5
	CV(%)		7.1	6.3	4.2	5.3
	LSD(5%)		8.1	12.2	13.1	22

TSP* - Kg (P205)
Urea* - Kg (N)

Katheka but the differences were not significant.

The average number of primary branches for NPP 670 were 6.5, 16.3, 25.3 and 18.5 at Machakos, Thika, Kiboko long rains 1989 and Kiboko short rains 1989/90 respectively, while the average for Katheka were 5.6, 13.0, 21.3 and 14.9 at Machakos, Thika, Kiboko long rains, 1989 and Kiboko short rains 1989/90 respectively.

All the fertilizer and manure applications had no significant effect on the number of primary branches except at Kiboko in long rains 1989, where urea application of 30 and 45 kg N/ha to both cultivars and manure application of 10 tons/ha to Katheka had significantly more number of primary branches than the control (Table 5). Singh et al, (1957) also reported increase in number of branches with the application of fertilisers.

The number of primary branches is an important yield component. Plants with higher number of primary branches would be expected to give higher yields since they have more nodes from which flower buds can be borne.This was observed to be so, since the fertilizer applications that gave higher number of primary branches also gave higher grain yields (Table 14). Therefore the number of primary branches is one of ths yield components positively infuenced by fertiliser application especially by nitrogenous fertiliser, but as Edwards (1981) pointed out the response is not consist.

4.1.10 Number of Days to 50% Maturity

The number of days to 50% maturity were determined as the number of days from planting to when 50% of the pods on the plants in a plot had turned yellowish, a sign of maturity.

NPP 670 showed significant site and seasonal differences in the number of days to reach 50% maturity. It reached 50% maturity in 149.3 days at Kiboko in

Table 5. Effect of type and amount of fertiliser and manure on number of primary branches of two pigeonpea cultivars grown at three locations for two seasons

	Fertiliser		primary branches			
	Type	amount	Long rains 1989		Short rains 1989/90	
NPP 670		(Kg ha-1)	Machakos	Kiboko	Thika	Kiboko
	Control		7	24	16	19
	TSP*	40	5.5	25	17	18.4
		80	5.5	25.3	15.7	21.7
		120	5.8	23.7	17.7	17.3
	Urea*	15	5.8	25.3	15.3	17.7
		30	6	27	15.7	19.5
		45	6.3	27	18.3	17.7
	manure	5000	7.3	25.7	15.3	18.3
		10000	8.3	25	16.7	17.3
	Mean		6.5	25.3	16.3	18.5
KATHEKA						
	Control		5.3	18.3	12.9	15.5
	TSP*	40	5	20	12.7	14.7
		80	5	21	13.1	14.2
		120	5.7	19.7	12.5	14.3
	Urea*	15	5.3	20	13.6	14.1
		30	5.6	23.7	12.8	15.6
		45	7.3	24.7	13.1	13.6
	manure	5000	5.3	20.7	13.3	15.1
		10000	6	23.7	12.9	16.7
	Mean		5.6	21.3	13	14.9
	CV(%)		23.4	7.8	9.9	12
	LSD(5%)		2.6	3.1	2.4	3.4

TSP* - Kg (P_2O_5) [Triple Superphosphate]

Urea* - Kg (N)

the long rains 1989 and 240 in short rains 1989/90 after planting. The difference was due to the prolonged vegetative phase in the short rains1989/90. Note that the short rains crop at Kiboko first flush of flowers aborted, the above figure is for the second flush of flowers.At Thika, Katheka took significantly longer time to reach 50% maturity compared to NPP 670. Katheka took 302 while NPP 670 took 161 days to reach 50% maturity. All the fertilizer applications had no significant effect on the number of days to 50% maturity (Table 6).

The number of days from flowering to maturity, that is grain filling period, for NPP 670 were 53.1, 62.5 and 70.9 at Thika, Kiboko long rains 1989 and Kiboko short rains 1989/90, respectively. For Katheka grown at Thika, the number of days from flowering to maturity were 75 days. The period from flowering to maturity is important in management of pests that attack pods. If this period is short then it means less number of sprays would be required to protect the pods against pest attack, on the other hand if this period is long then, more sprays would be required hence higher expenses. The number of days to 50% maturity was not affected by fertiliser application.

4.1.11 Plant Height at Harvest

NPP 670 showed significant site and seasonal difference in plant height at harvest time. As expected Katheka had significantly taller plants compared to NPP 670 (Table 7).

The fertilizer and manure treatments had no significant effect on the plant height on NPP 670. All the fertilizer and manure treatment gave significantly shorter plants at harvest time compared to the control (Table 7).

The plants height at harvest time were not significantly different from those at flowering time although slightly taller, with the exception of NPP 670 grown at Kiboko in the short rains 1989/90 where the heights continued to increase after

Table 6. Effect of type and amount of fertiliser and manure on days to 50% maturity Of two pigeonpea cultivarsgrown at two locations for two seasons

Fertiliser		Days to 50 percent maturity			
		Long rains 1989	Short rains 1989/90		
		Kiboko	Kiboko	Thika	
Type	amount (Kg ha-1)	NPP 670	NPP 670	NPP 670	KATHEKA
Control	-	148.3	239	161.3	302.7
Urea*	15	149.3	239	162	302.3
	30	149.6	238	161	302
	45	149.3	238.7	161.3	302
TSP*	40	149	238.3	162.3	303.3
	80	149	238.3	161.7	301.7
	120	149.3	239	161	302.3
manure	5000	149	239	161	303
	10000	149.2	239.3	160.7	302
Mean		149.1	238.7	161.4	302.3
CV(%)		0.4		0.3	
LSD(5%)		1.3		1.3	

TSP* - Kg (P205)[Triple superphosphate]

Urea* - Kg (N)

Table 7. Effect of type and amount of fertiliser and manure on plant height at harvest Of two pigeonpea cultivars grown at two locations for two seasons

Fertiliser		plant height at harvest (cm)			
Type	amount	Long rains 1989	Short rains 1989/90		
	(Kg ha-1)	Kiboko	Kiboko	Thika	
		NPP 670	NPP 670	NPP 670	KATHEKA
Control	-	150.8	160	66.9	327.4
TSP*	40	101.9	158.1	65.5	311.7
	80	111.7	156.7	65.9	314
	120	111.1	161.4	72.1	311.1
Urea*	15	101.9	161.9	68.3	305
	30	101.3	156.2	67.7	315
	45	66.1	154.7	69.1	306
manure	5000	107.1	158.2	68.3	305
	10000	106.3	155	65.1	314.7
Mean		106.2	158	67.7	312.2
CV(%)		4.3		3.7	
LSD(5%)		9.6		11.7	

TSP* - Kg (P205)[Triple superphosphate]
Urea* - Kg (N)

flowering. This indicates that the photosynthates manufactured went to the shoot growth. This may have been caused by the high amounts of rainfall received (Appendix 3d).

Otherwise the plant height did not change much from flowering to maturity. This may due to the fact that after flowering, the plant mobilises most of the the photosynthetes towards grain formation.

4.1.12 Dry Matter of Stem and Branches at Harvest Time

Dry matter of stems and branches of NPP 670 differed significantly at the two sites for the two seasons. The average stem and branches dry matter of NPP 670 were 19.0, 52.8 and 184.7g at Thika, Kiboko long rains 1989 and Kiboko short rains '89/90 respectively. Compared to NPP 670, Katheka had significantly heavier stems and branches (310.0g). The difference in dry matter of NPP 670 at Kiboko between the two seasons was due to the differences in the amount of rainfall received. Npp 670 grown at Thika had the lowest dry matter maybe due to the attack of *Mycovellosiella cajani* which stopped further growth of the stems and branches and mobilised the photosynthetes to pods and grain filling.
Urea applications of 30 and 45 kgN/ha and manure application of 10 tons/ha to NPP 670 grown at Kiboko in long rains 1989, gave significantly heavier stems and branches than the control. Similar observation were made by Lenka and Ssatpathy (1976), with the application of 25 kg N/ha.
The stem and branches dry matter of NPP 670 grown at Thika was not significantly affected by the fertilizer and manure treatments. Only urea application 45 N/ha to Katheka grown at Thika gave significantly heavier stems and branches dry matter; all the other fertilizer and manure treatments had no significant effect (Table 9).

The average NPP 670 stems and branches dry matter at harvest time was lowest (19 g) at Thika and highest (184 g) at Kiboko in the short rains 1989/90 season, with the long rains 1989 crop falling in between. The short rains 1989/90 NPP 670 crop had stem and branch dry matter more than three times as heavy as the long rains 1989 season crop. However this higher dry matter which was due to the prolonged vegetative growth, was not beneficial in grain produciton. This is contrary to what Akinola and Whiteman (1975a) report that pigeonpea yields were directly related to plant size. The two seasons had similar average grain yields (Table 14). It should however be noted that fertilizer and manure treatments which had significantly higher stem and branch dry matter had also significantly higher grain yields. Katheka had stems and branches dry matter about six times that of NPP 670 grown at Kiboko in the long rains 1989, yet the grain yields were not significantly different. This shows that NPP 670 has a higher partitioning efficiency compared to Katheka during grain filling. dry matter production thereforeseems to be influenced slightly by fertiliser application but largely by variety, site and the amount of rainfall.

4.1.13 Pod (unthreshed) Weight at Harvest Time

NPP 670 grown at Kiboko in the long rains 1989 had slightly heavier pods weight per plant than in the short rains 1989/90, however the difference was not significant. NPP 670 grown at Thika had significantly higher pods weight per plant compared to that grown at Kiboko in both seasons, but the difference was not significant. At Thika, Katheka had significantly heavier pods weight per plant than NPP 670. Only urea application of 30 and 45 kgN/ha to NPP 670 grown at Kiboko in long rains 1989 gave significantly heavier pods than the control. At Kiboko in short rains 1989/90 urea treatments at 15 and 45 kgN/ha and triple superphosphate of 40 and 80 kg P_2O_5/ha to NPP 670 gave significantly higher pods weight per plant than the control. All the fertilizer applications to NPP 670 at

Table 8. Effect of type and amount of fertiliser and manure on stem and branches dry matter at harvest. Of two pigeonpea cultivars grown at two locations for two seasons

Fertiliser		stem & branches dry matter (g)			
Type	amount	Long rains 1989	Short rains 1989/90		
	(Kg ha-1)	Kiboko	Kiboko	Thika	
		NPP 670	NPP 670	NPP 670	KATHEKA
Control	-	40.6	164	18.4	288
Urea*	15	43.3	200.2	16.1	314.3
	30	72.3	212.3	17.9	339.5
	45	82.6	206.3	23.5	353.5
TSP*	40	36.7	198.6	16.8	279.3
	80	40.4	205.2	16.3	335.8
	120	37.2	153.7	18.7	312.5
manure	5000	54.5	168.8	20	259.9
	10000	67.5	153.7	21.3	307.7
Mean		52.8	184.7	19	310.1
CV(%)		8.6		22	
LSD(5%)		17.2		60	

TSP* - Kg (P205)[Triple superphosphate]
Urea* - Kg (N)

Thika did not have any significant effect on pod weight per plant only urea application at 45 kgN/ha to Katheka gave significantly higher pod weight per plant than the control (Table 9).

4.1.14 Number of Pods per Plant

There was no significant difference in the number of pods per plant of NPP 670 grown at Kiboko in the two seasons. However NPP 670 grown at Thika had significantly fewer pods per plant compared to NPP 670 grown at Kiboko. This maybe taken as an indicator that NPP 670 performs better in warmer places like Kiboko than than in cooler ones.

Urea applications of 30 and 45 kg N/ha to NPP 670 grown at Kiboko in long rains 1989 gave significantly more pods per plant than the control. In the short rains 1989/90, urea application of 45 kg N/ha and Triple superphosphate treatment of 40 kg P_2O_5/ha to NPP 670 gave significantly more pods per plant than the control. Urea application of 45 kg N/ha to Katheka grown at Thika gave significantly more pods per plant than the control. The other fertilizers applications had no significant effect (Table 10).

Applications that gave significantly more pods per plant also had higher yields. This shows that the number of pods per plant is one of the yield components positively affected by fertilizer application. Other researchers have reported that the number of pods per plant is the most sensitive yield component. Ogombe (1978), Khan and Rachie (1973) and Veeraswany, et al, (1972)

4.1.15 Number of Seeds per Pod

There was no significant difference in number of seeds per pod for NPP 670 grown at Kiboko in both reasons. NPP 670 grown at Thika however had significantly fewer seeds per pod compared to that grown at Kiboko. This shows that NPP 670 has higher yield potential at Kiboko than at Thika. Katheka had

Table 9. Effect of type and amount of fertiliser and manure on pods weight at harvest Of two pigeonpea cultivar sgrown at two locations for two seasons

Fertiliser		pods weight/plant (g)			
Type	amount (Kg ha-1)	Long rains 1989	Short rains 1989/90		
		Kiboko	Kiboko	Thika	
		NPP 670	NPP 670	NPP 670	KATHEKA
Control	-	57.1	52	21.7	67.8
Urea*	15	60	100.1	22.1	84.8
	30	126.1	80	19.6	64.7
	45	162.9	101.5	20.3	94.5
TSP*	40	50.6	106.9	17.6	63.5
	80	60.8	103.3	17.3	77.6
	120	60	61.2	19.1	68.4
manure	5000	75.1	90.5	20.3	64.5
	10000	92.8	71.4	18.4	86
Mean		82.8	85.2	19.6	74.7
CV(%)		28		29.1	
LSD(5%)		40		23.1	

TSP* - Kg (P205)[Triple superphosphate]
Urea* - Kg (N)

Table 10. Effect of type and amount of fertiliser and manure on number of pods per plant Of two pigeonpea cultivars grown at two locations for two seasons

Fertiliser		Number of pods/plant			
Type	amount	Long rains 1989	Short rains 1989/90		
	(Kg ha-1)	Kiboko	Kiboko	Thika	
		NPP 670	NPP 670	NPP 670	KATHEKA
Control	-	43.3	44	20.7	44.9
Urea*	15	46.8	69.3	18.1	58.3
	30	94.2	62.6	17.8	42.5
	45	130.9	76.5	21.4	69.8
TSP*	40	39.3	77.1	16.6	45.7
	80	52.1	68.7	18.2	47.2
	120	43.4	43.8	18.3	47
manure	5000	62.1	67.4	19.2	46.6
	10000	72.1	53.7	17.4	54.9
Mean		64.9	62.5	18.6	50.8
CV(%)		29		27.7	
LSD(5%)		31		16.2	

TSP* - Kg (P2O5)[Triple superphosphate]

Urea* - Kg (N)

significantly more seeds per pod than NPP 670 grown at both sites. The amount of vegetitative growth maybe one fact that determines the number of seeds per pod. such that in places why there is better vegetative growth more seeds per pod are initiated. The number of seeds per pod were not significantly affected by any fertilizer treatments in both.seasons and at the two sites (Table 11).

Ogombe (1978) alos reported that the number of seed per pod does not change wth the applcaton of fertlsers. Manjhi, et al. (1973), Ahlawat, et al . (1975) Akinola and Whiteman (1975b) also reported similar observations.

The number of seeds per pod seem to be strongly influenced by the site, being constant for any one site. Sites where the number of seeds per pod is high, have a higher yield potential compared to those with lower number of seeds per pod. This component of yield however seems not have been influenced by fertilizer application. Similar observations were made by Wamatu (1989) that the number of seeds per pod varied from site to site.

4.1.16 Seed Weight

There was no significant difference in 100-seed weight of NPP 670 grown at Kiboko in both seasons. However NPP 670 grown at Thika had a significantly lower 100-seed weight compared to that grown at Kiboko. The low 100-seed weight of NPP 670 grown at Thika may have been caused by the loss of leaves due to attack of *Mycovelosiella cajani*, which then reduced the photosynthetes during grain filling. Katheka grown at Thika had significantly higher 100-seed weight than NPP 670 grown at both sites. This reason for this maybe that since the Katheka grain filling period was long than that of NPP 670, then the grains were able to be filled properly over the longer period.

All the fertilizer applications had no significant effect on the 100-seed weight in both seasons and at the two sites (Table 12). Similar observation were made by

Table 11. Effect of type and amount of fertiliser and manure on number of seeds per pod Of two pigeonpea cultivars grown at two locations for two seasons

Fertiliser		Number of seeds per pod			
Type	amount (Kg ha-1)	Long rains 1989	Short rains 1989/90		
		Kiboko	Kiboko	Thika	
		NPP 670	NPP 670	NPP 670	KATHEKA
Control	-	4.23	4.18	3.80	5.26
Urea*	15	4.45	4.24	3.89	5.12
	30	4.40	4.12	3.91	5.20
	45	4.36	4.25	3.85	5.17
TSP*	40	4.20	4.34	3.80	5.18
	80	4.27	4.28	3.86	5.25
	120	4.18	4.16	3.83	5.08
manure	5000	4.29	4.28	3.89	5.24
	10000	4.41	4.17	3.72	5.20
Mean		4.33	4.22	3.84	5.19
CV(%)		3.20		2.70	
LSD(5%)		0.23		0.20	

TSP* - Kg (P205)[Triple superphosphate]
Urea* - Kg (N)

Table 12. Effect of type and amount of fertiliser and manure on 100- seeds wight
Of two pigeonpea cultivars grown at two locations for two seasons

Fertiliser		100- seeds weight (g)			
Type	amount (Kg ha-1)	Long rains 1989	Short rains 1989/90		
		Kiboko	Kiboko	Thika	
		NPP 670	NPP 670	NPP 670	KATHEKA
Control	-	19.6	18.8	15.6	22.7
Urea*	15	18.4	20	15.9	21.9
	30	18.8	19.4	16.3	22.3
	45	18.4	18.7	14.9	22.8
TSP*	40	18.8	20	15.9	21.9
	80	18.3	20.2	14.5	22.7
	120	18.3	20.2	14.9	22.8
manure	5000	18.5	20	15.4	21.9
	10000	18.5	19.4	15.6	22.6
Mean		18.6	19.6	15.5	22.4
CV(%)		4.5		3.7	
LSD(5%)		1.4		1.2	

TSP* - Kg (P2O5)[Triple superphosphate]

Urea* - Kg (N)

Ahlawat, et al, (1975). Wamatu (1989) also reported the same for various sites in Kenya.

4.1.17 Grain Weight per Plant

There was no significant difference in grain yield per plant of NPP 670 grown at Kiboko in both seasons. However it had significantly higher grain yield per plant compared to that grown at Thika.

Urea application of 30 and 45 kgN/ha to NPP 670 grown at Kiboko in long rains 1989, gave significantly higher grain yield per plant compared to the control.

In the short rains 1989/90, at the same site, urea application of 15 and 45 kgN/ha, triple superphosphate applications of 40 and 80 kg P_2O_5/ha and manure application of 5 tons/ha to NPP 670 gave significantly higher grain yield per plant than the control.This shows a positive response to fertilser and manure application

At Thika all the fertilizer treatments had no significant effect on grain yield per plant for both cultivars (Table 13). Dalal (1974), Lenka and Satpathy (1976), Gondalia, et al, (1988), have reported positive yield response to nitrogen application. while Evans, et al, (1962), Grimes, et al, (1962) and Veerasway, et al, (1972) have reported positive response to manure application; which is supportive of the above observation.

The fertiliser application that gave significantly higher grain yield per plant compared to the control are the same application that had higher 'number of pods per plant'. Meaning that yield depends on this parameter.

4.1.18 Grain Yield per Hectare

There was no significant difference in grain yield per hectare of NPP 670 grown at Kiboko in both seasons. However, NPP 670 grown at Kiboko had significantly higher grain yield compared to that grown at Thika.

Urea applications of 30 and 45 kg N/ha to NPP 670 grown at Kiboko in the long

Table 13. Effect of type and amount of fertiliser and manure on grains weight per plant Of two pigeonpea cultivars grown at two locations for two seasons

Fertiliser		grains weight/plant (g)			
Type	amount (Kg ha-1)	Long rains 1989	Short rains 1989/90		
		Kiboko	Kiboko	Thika	
		NPP 670	NPP 670	NPP 670	KATHEKA
Control	-	36	32.9	12.3	43.8
Urea*	15	37.9	59	11.3	55.5
	30	77.5	50.3	11.3	42.5
	45	104.9	60.8	12.4	54.4
TSP*	40	30.8	66.7	10.1	41.7
	80	40.3	59.4	9.8	51.9
	120	33.8	36.8	10.4	45.1
manure	5000	48.7	57.6	11.8	41.3
	10000	58.7	43.5	10.3	56.5
Mean		52.1	51.9	11.1	48.1
CV(%)		28		32.6	
LSD(5%)		24		16.2	

TSP* - Kg (P205)[Triple superphosphate]

Urea* - Kg (N)

rains 1989 gave significantly higher grain yield per hectare than the control. At the same site in short rains 1989/90 urea treatment at 15 and 45 kg per hectare and triple superphosphate at 40 and 80 kg P_2O_5/ha to NPP 670 gave significantly higher yield than the control.

At Thika all the fertilizer and manure applications had no effect on grain yiled per hectare for both cultivars (Table 14).

For NPP 670, grown at Kiboko in the long rains 1989/90, urea and manure application results, show a trend indicating that there is a positive response to these application and even higher levels than indicated can be applied. The Triple superphosphate does not indicate any such a trend. In the short rains 1989/90, no such trend is observed; the response does not seem to follow any trend. Triple superphosphate application beyond 40 kg P_2O_5/ha does not seem to be beneficial.Probably the prolonged vegetative phase masked any advantage that may have been gained from the fertilizer and manure application which was done at planting time. However, urea application even at lower rates seem to have been beneficial. Ram and Giri (1973), Lenka and Satpathy, et al. (1974) have similarly reported that nitrogen application increases pigeonpea grains yield. NPP 670 grown at Thika did not respond to fertilizer application probably due to the loss of leaves caused by *Mycovellosiella cajani*. Any advantage gained from fertilizer and manure application to Katheka grown at Thika may have been masked by the long vegetative phase characteristic of Katheka which is a late maturing cultivar.

Despite the long vegetative phase of NPP 670 grown at Kiboko in short rains 1989/90, it's grain yields were similar to those of NPP 670 grown at the same site in long rains 1989. This shows that larger plants do not necessary lead to higher grain production. This contradicts earlier report by Akinola and Whiteman (1975a) that pigeonp0ea yields were directly related to plant size. Therefore longer vegetative phase in this case was not beneficial for grain production.

Table 14. Effect of type and amount of fertiliser and manure on grain yield per hectare Of two pigeonpea cultivars grown at two locations for two seasons

Fertiliser Type	amount (Kg ha-1)	grains yield (kg ha-1) Long rains 1989 Kiboko NPP 670	Short rains 1989/90 Kiboko NPP 670	Thika NPP 670	Thika KATHEKA
Control	-	1601	1463.8	545.3	1947.5
Urea*	15	1687.3	2623.3	461.3	2465.7
	30	3446.5	2237.3	500.1	1889.6
	45	4663.8	2702.9	549.5	2418.9
TSP*	40	1369.9	2966.5	449.2	1853.1
	80	1789.2	2639.1	435.7	2308.7
	120	1500.6	1633.6	462.2	2004.1
manure	5000	2163	2559.4	522.9	1837.2
	10000	2607.1	1931.1	518.1	2511.8
Mean		2314.2	2306.3	493.8	2137.4
CV(%)		28		32.6	
LSD(5%)		1084		722	

TSP* - Kg (P205)[Triple superphosphate]

Urea* - Kg (N)

However the higher dry matter was produced which can be used as fierwood.

4.1.19 Harvest Index

The harvest index of NPP 670 grown at the two sites and in both seasons were significantly different from one another (Table 15). Urea applciation of 45 kgN/ha to NPP 670 grown at Kiboko in long rains 1989, gave significantly higher harvest index compared to the control. At Thika the harvest Index of both cultivars were not affected by fertilized and manure treatments.

The harvest index, which was got by dividing the dry grain weight per plant by the total above ground dry matter, excluding fallen material, shows the efficiency of the crop in allocation of photosynthates for grain production. The long rains 1989, NPP 670 grown at Kiboko had the highest Harvest Index (0.38). This shows that it was more efficient in grain production compared to the others. The short rains 1989/90 NPP 670 crop had a Harvest Index of 0.19 which was half of the long rains 1989 crop. This was caused by the long vegetative phase which favoured total dry matter production without a similar effect on grain production. Katheka grown at Thika was least efficient with a harvest index of 0.12. It is a late maturing cultivar and concentrates on dry matter production in the early stages of growth. Sheldrake,et al, (1979) reported a mean Harvest Index of some cultivars of 0.24 excluding fallen material and 0.17 taking fallen material into account. Urea treatment of 45 kgN/ha to NPP 670 grown at Kiboko in long rains 1989 gave significantly higher Harvest Index than the control. This shows that application of urea fertilizer to NPP 670 increases its efficiency in grain production. This also shows that short duration pigeonpea cultivars have better partitioning coefficient which is even enhanced further by fertilisers application.

4.2.0 Pigeonpea Stem Energy Content

The average energy content of pigeonpea stems of the two cultivars grown

Table 15. Effect of type and amount of fertiliser and manure on harvest index Of two pigeonpea cultivars grown at two locations for two seasons

Fertiliser		Harvest index			
Type	amount (Kg ha-1)	Long rains 1989	Short rains 1989/90		
		Kiboko	Kiboko	Thika	
		NPP 670	NPP 670	NPP 670	KATHEKA
Control	-	0.37	0.16	0.30	0.12
Urea*	15	0.37	0.19	0.30	0.14
	30	0.38	0.17	0.30	0.10
	45	0.43	0.20	0.28	0.12
TSP*	40	0.35	0.22	0.29	0.12
	80	0.40	0.19	0.29	0.13
	120	0.35	0.17	0.27	0.12
manure	5000	0.38	0.23	0.29	0.13
	10000	0.36	0.19	0.26	0.14
Mean		0.38	0.19	0.29	0.12
CV(%)		13.30		12.90	
LSD(5%)		0.05		0.05	

TSP* - Kg (P_2O_5)[Triple superphosphate]

Urea* - Kg (N)

at Kiboko and Thika was 4.4 Kca/g. Both cultivars grown at Kiboko had higher energy content than those grown at Thika. Katheka grown at Thika had the biggest plants (average weight per plant, 310g) but had the lowest energy content per gram (Table 16).

At both sites, NPP 670 had higher percent ash than Katheka. Both cultivars grown at Kiboko had a higher percent ash than at Thika. Compared to other energy source for domestic use, pigeonpea is fifth after Lp gas, paraffin, charcoal and Kahawa charcoal (Table 2). It has a higher energy content per unit weight than banboo, crop waste sisal and dung. By comparing the percent ash, it is probable that NPP 670 extract more minerals from the soil than Katheka. Therefore if this is correct and minerals extracted are essential, then NPP 670 is likely to respond to fertilizer application more favourably than Katheka.

Table 16. The energy content and percent ash of two pigeonpea cultivars grown at two locations

Location	Cultivar	Percent DM (105 oC, 24hrs)	Percent ash	Kcal/g	Average stem and branches Weight (g)	Kcal/plant
Kiboko	NPP 670	94.85	3.93	4.6	52.8	242.9
	Katheka	94.97	2.77	4.7	184.7	868.1
Thika	NPP 670	94.55	2.33	4.4	18.9	83.2
	Katheka	94.37	1.63	3.9	310.1	1209.4

4.3. SOIL CHARACTERISTICS AND RESPONSES

4.3.1 Soil pH (H_2O); As measured in a Soil Water ratio of 1:5

The soil pH(H_2O) measured in soil samples taken before and after planting at Kiboko in both seasons and Thika are shown in tables 17 and 18. The fertilizer and manure treatments had no significannt effect on the soil pH(H_2O). The soil pH(H_2O) at both horizons (0-30 and 30-60 cm) did not also differ significantly. The fertilizer and manure treatments did not have any significant influence on soil pH(H_2O). The upper horizon (0-30 cm) had a slightly lower soil pH(H_2O) of 5.3 compared to that of the lower horizon (30-60cm) of 5.5 (Table 18). Soil pH is one of the stable soil characteristics that is not easily changed.

4.3.2 Soil pH($CaCl_2$): As measured in 0.01M $CaCl_2$ solution

The soil pH ($CaCl_2$) measured in samples taken before planting and after planting are shown in Tables 17 and 18. The average soil pH ($CaCl_2$) at harvest time at Kiboko was 6.2. The two depths and the two seasons did not show any significant differences in the soil pH($CaCl_2$). The fertilizer and manure treatments also had no significant effect on the soil pH($CaCl_2$).

At Thika the average soil pH($CaCl_2$) at harvest time was 4.9. The cultivars had no significant effect on the soil pH($CaCl_2$). The soil pH($CaCl_2$) of the two depths were not significantly different. The fertilizer and manure treatment did not show any significant effect on soil pH($CaCl_2$). The soil pH is one of the stable characteristics of a soil which does not change easily. It may fluctuate from season to season as the amount of water in the soil varies but it remains stable. The soil pH measured in $Cacl_2$ solution evens out these seaonal changes (Brady, 1984).

Table 17. Soil pH at Kiboko before and after growing NPP 670 for two seasons

Location	Season	Period	Fertiliser Type	Fertiliser Amount (kg/ha)	pH (water 1:5) 0-30 cm	pH (water 1:5) 30-60 cm	pH (CaCl2) 0-30 cm	pH (CaCl2) 30-60 cm
Kiboko	Long rains 1989	Planting	_	_	6.7	_	6.1	_
		Harvest	Control	0	6.5	6.5	6.2	6.2
			Urea*	15	6.8	6.9	6.4	6.2
				30	6.6	6.9	6.1	6.6
				45	6.6	6.6	6.5	6.4
			TSP*	40	6.5	6.4	6.4	6.2
				80	7.2	7.1	6.7	6.6
				120	6.6	6.8	6.2	6.2
			Manure	5000	6.7	6.5	6.3	6.1
				10000	6.7	6.5	6.1	6.1
			Mean		6.7	6.7	6.3	6.3
	Short rains '89/9	Planting	_	_	6.4	6.4	6.1	6.2
								5.9
		Harvest	Control	0	6.6	6.6	5.9	5.9
			Urea*	15	6.8	7.1	6.2	6.2
				30	6.7	6.9	6.1	5.9
				45	7.2	7.4	6.4	6.3
			TSP*	40	6.7	6.8	6	5.8
				80	7.1	7.1	6.3	6.2
				120	6.8	7.2	6.2	6.6
			Manure	5000	6.8	6.4	6.3	5.7
				10000	7.1	7.2	6.5	6.6
			Mean		6.8	6.9	6.2	6.1

Urea* _ (Kg N)
TSP* _ [(kg P2O5) Triple Superphosphate]

Table 18. Soil pH at Thika before and after growing the two pigeonpea cultivars

Cultivar	Period	Fertiliser Type	Amount (kg/ha)	pH (water 1:5) 0-30 cm	30-60 cm	pH (CaCl2) 0-30 cm	30-60 cm
	Planting	—	—	5.5	5.5	4.8	4.8
NPP 670	Harvest	Control	0	5.1	5.2	4.8	4.9
		Urea*	15	5.2	5.6	4.8	4.9
			30	5.1	5	4.6	4.7
			45	5.4	5.4	4.7	5.1
		TSP*	40	5.1	5.1	4.8	4.8
			80	5	5.2	4.7	4.7
			120	5.3	5.5	4.8	4.8
		Manure	5000	5.3	5.3	4.9	4.9
			10000	5.3	5.4	5	5
		Mean		5.2	5.3	4.8	4.9
KATHEKA	Harvest	Control	0	5.4	5.5	5	4.9
		Urea*	15	5.6	5.8	5	5.1
			30	5.4	5.7	5	5
			45	5.2	5.5	4.8	5
		TSP*	40	5.2	5.7	4.7	4.9
			80	5.1	5.4	4.7	4.8
			120	5.4	5.6	4.7	4.8
		Manure	5000	5.5	5.6	4.9	5
			10000	5.4	5.6	5	4.8
		Mean		5.3	5.6	4.9	4.9

*Urea - (kg N)
*TSP - (Kg P205)[Triple superphosphate]

4.3.3.0 Soil Organic Carbon

The percentage organic carbon at planting and harvest time is shown in Tables 19 and 20. At Kiboko, in the long rains 1989, the average percent organic carbon was 1.07 and 0.71% in upper and lower horizons respectively at harvest time. In the short rains 1989/90, the average percent organic carbon was 0.74 and 0.45% in the upper and lower horizons respectively. In the long rains 1989, soil samples had significantly higher percent organic carbon compared to the short rains 1989/90. The upper horizon (0-30 cm) had significantly higher percent organic carbon than the lower horizon (30-60 cm) in the two seasons.

The urea application of 45 kgN/ha in the long rains 1989 and Triple superphospahte applications of 120 kg P_2O_5/ha in the short rains 1989/90 gave significantly higher percent organic carbon compared to the controls in the two seasons. This effect was only observed in the upper horizon (0-30 cm). The other fertilizer and manure application did not have any significant effect (Table 19). Manure application did not increase the organic carbon level possibly due to the higher rate of oxidisation usually expressed in areas with high temperatures. Compared to before planting all the fertilizer and manure application and also the control in the long rains, 1989 gave higher percent organic carbon. However, only urea applications of 30 and 45 kg N/ha had significantly higher percent organic carbon than at planting. This effect was only observed the upper horizon (0-39 cm). In the short rains 1989/90, the fertilizer and manure applications and also the control had lower percent organic carbon with the exception of triple superphosphate treatments of 120 kg P_2O_5/ha and manure applicaton of 5 tons/ha whose percent organic carbon was higher than that at planting. However only triple superphosphate treatment of 120 kg P_2O_5/ha showed significantly higher organic carbon (Table 19).

Table 19. Soil Percent organic carbon, total nitrogen, and carbon:nitrogen ratio at Kiboko before and after growing NPP 670 for two seasons

Season	Period	Fertiliser Type	Fertiliser Amount (kg/ha)	Percent Organic Carbon 0-30 cm	Percent Organic Carbon 30-60 cm	Percent - Total Nitrogen 0-30 cm	Percent - Total Nitrogen 30-60 cm	Carbon:Nitrogen ratio 0-30 cm	Carbon:Nitrogen ratio 30-60 cm
Long rains 1989	Planting	_	_	0.90	_	0.104	_	8.7	_
	Harvest	Control	0	0.95	0.71	0.084	0.083	11.4	8.6
		Urea*	15	0.93	0.62	0.101	0.081	9.2	7.8
			30	1.51	0.87	0.114	0.111	13.3	8
			45	1.17	0.79	0.102	0.101	11.4	7.8
		TSP*	40	1.06	0.72	0.103	0.079	10.3	9.2
			80	1.08	0.76	0.114	0.091	9.5	8.4
			120	0.87	0.67	0.119	0.084	7.3	7.9
		Manure	5000	1.04	0.63	0.096	0.08	10.8	8.1
			10000	1.02	0.61	0.114	0.08	9	7.7
		Mean		1.07	0.71	0.105	0.088	10.2	8.2
Short rains '89/9	Planting	_	_	0.81	0.54	0.091	0.07	8.9	7.7
	Harvest	Control	0	0.69	0.40	0.089	0.059	7.8	6.8
		Urea*	15	0.62	0.46	0.084	0.059	7.3	7.8
			30	0.65	0.43	0.101	0.067	6.5	6.4
			45	0.77	0.46	0.103	0.071	7.4	6.6
		TSP*	40	0.65	0.50	0.095	0.069	6.9	7.3
			80	0.79	0.44	0.114	0.065	7	6.9
			120	0.92	0.45	0.116	0.07	8	6.4
		Manure	5000	0.83	0.43	0.104	0.066	7.9	6.5
			10000	0.73	0.52	0.095	0.067	7.7	7.8
		Mean		0.74	0.45	0.10	0.066	7.4	6.9

Urea* _ (Kg N)
TSP* _ [(kg P205) Triple Superphosphate]

The increase in organic carbon in the long rains 1989, may have been due to increase in organic matter from the fallen leaves and dead roots of the pigeonpea. The fertilizer and manure applications that produced the highest dry matter also had higher organic carbon in the soil.

Legumes are considered to be soil recuperative crops and are generally grown without fertiliser (Kalyan and Rajendra, 1976). In addition to their ability to fix nitrogen, the deep root system especially that of pigeonpeas, enables the crop to absorb nutrient from the sub-soil for their growth and finally deposit them on the top through fallen leaves and decayed stems and roots, (Pietri, et al, 1971).

The short rains 1989/90 received almost twice the amount of rainfall received in the long rains of 1989. This means the short rains 1989/90 season was wetter and hence higher rate of continued microbial activity leading to the oxidisation of the organic carbon. This explains the low levels of organic carbon in the soil got in the short rains 1989/90.

At Thika in the short rains 1989/90, soil samples got from plots under Katheka had significantly higher percent organic carbon than those under NPP 670. The upper horizon had significantly higher average percent organic carbon at 1.74 compared to that of the lower horizon (30-60 cm) of 1.10 percent. The fertiliser and manure treatments did not have any significant effect on the percent organic carbon (Table 20).

The high organic carbon got under Katheka as compared to NPP 670 may have been caused by their difference in the amount of dry matter produced, where Katheka had higher dry matter produced hence higher amounts of fallen materials and dead roots. It has been reported (Brady, 1984) that the mass of crops root residues remaining in the soil after harvest commonly vary from 15 to 40 % of the above ground crop. By this added root residue a satifactory supply of organic matter in arable soil can be maintained. This supportive of the above observation

Table 20. Percent organic carbon, Total nitrogen, and Carbon:Nitrogen at Thika before and after growing the two pigeonpea cultivars

Cultivar	Period	Fertiliser Type	Fertiliser Amount (kg/ha)	Percent Organic Carbon 0-30 cm	Percent Organic Carbon 30-60 cm	Percent Total Nitrogen 0-30 cm	Percent Total Nitrogen 30-60 cm	Carbon: Nitrogen ratio 0-30 cm	Carbon: Nitrogen ratio 30-60 cm
	Planting	_	_	1.57	1.34	0.163	0.132	9.6	10.2
NPP 670	Harvest	Control	0	1.62	0.9	0.145	0.093	11.2	9.6
		Urea*	15	1.54	0.83	0.145	0.1	10.6	8.3
			30	1.68	0.99	0.152	0.096	11	10.4
			45	1.8	0.94	0.149	0.091	12.1	10.3
		TSP*	40	1.5	0.96	0.144	0.105	10.5	9.2
			80	1.3	0.84	0.154	0.089	8.5	9.4
			120	1.34	1.31	0.166	0.102	8.2	12.8
		Manure	5000	1.79	1.03	0.152	0.105	11.8	9.8
			10000	2.05	1.04	0.178	0.111	11.5	9.4
		Mean		1.62	0.98	0.154	0.099	10.6	9.9
KATHEKA	Harvest	Control	0	1.89	1.04	0.152	0.1	12.4	10.5
		Urea*	15	1.83	1.03	0.15	0.113	12.3	9.1
			30	1.87	1.11	0.167	0.109	11.2	10.2
			45	1.94	1.13	0.187	0.112	10.4	10.1
		TSP*	40	1.93	1.37	0.172	0.127	11.2	10.8
			80	1.95	1.35	0.174	0.123	11.2	11
			120	1.78	1.51	0.167	0.13	10.7	11.6
		Manure	5000	1.76	1.37	0.173	0.133	10.2	10.3
			10000	1.7	1.01	0.173	0.111	9.9	9.1
		Mean		1.85	1.21	0.168	0.118	11.1	10.3

*Urea -(kg N)

*TSP - (Kg P205)[Triple superphosphate]

that Katheka which had higher above ground matter than the NPP 670 also had higher organic carbon level in the soil.

4.3.3.1. Response to Manure Application

At Thika application of manure to both cultivars did not significantly affect any of the plant parameters measured except Katheka's plant height at flowering and harvest time which were significantly depressed by manure application.

At Kiboko in the long rains 1989, manure application of 10 tons/ha to NPP 670 significantly increased leaf area, and plant dry matter. For Katheka, only plant height at flowering and number of primary branches were significantly increased by manure application of 10 tons/ha. The manure application of 5 and 10 tons/ha to NPP 670 increased grain yield by 35.1 and 62.8 percent respectively.

In the short rains 1989/90 season at Kiboko, manure application to Katheka did not affect any of the plant parameters measured. However, manure application of 5 tons/ha to NPP 670, significantly increased pods dry matter, grain yield and Harvest Index; whereas the application of 10 tons/ha did not have any significant effect. Comparing this observation with the long rains 1989 response to manure application it is concluded that pigeonpea response to fertilizer and manure is erratic and difficult to explain. Dalal, (1980), Rachie, et al, (1974) reported similar findings.

The favourable response got from application of manure, maybe due to its availing nutrients to plants after mineralization or/and due to its influence on soil physical properties that favour plant growth. Organic matter increases the moisture retention of soils and more importantly it improves soil structure and in turn soil porosity. This allows better root growth and hence better nutrient uptake. Favourable response to manure application have also be reported by Veerasway (1972), Evans, et al, (1962) and Grimes, et al, (1962).

4.3.3.2. Effect of Manure Application on the Soil

Manure application of 10 tons/ha to NPP 670 at Thika significantly increased soil organic matter and percent total nitrogen in the upper (0-30 cm) horizon. The cation exchange capacity was also slightly increased but not significanlty. Manure application to Katheka also increased soil total nitrogen.

At Kiboko in the long rains 1989, manure application to NPP 670 of 10 tons/ha significantly increased soil cation exchange capacity (CEC) in the upper horizon.This is supportive of Brady's (1984) report that organic matter increases CEC The increase in organic matter may have been caused by lack of complete mineralization of the applied manure or from plant tissue produced. The increase in total nitrogen may have arisen from the mineralisation of the applied manure or from plant tissue decomposed in the soil or from the fixation of free nitrogen from the atmosphere. Increase in organic matter also leads to increase in nitrogen because of the C:N ratio maintenance.

4.3.4.0 Soil Total Nitrogen

The percent total nitrogen before planting and at harvest time are shown in Tables 19 and 20. At harvest time at Kiboko, in long rains 1989, the soil samples had significantly higher total percent nitrogen of 0.104 and 0.085 in the upper and lower horizon respectively, compared to short rains 1989/90 when the percent total nitrogen were 0.100 and 0.066 in the upper and lower horizon respectively. The upper horizon had significantly higher percent total nitrogen of 0.102 compared to that of the lower horizon of 0.075 percent. The manure application of 10 tons/ha, urea application of 30 kgN/ha and all the triple superphosphate levels gave significantly higher levels of percent total Nitrogen compared to control, in the upper horizon in the long rains, 1989. These application also increased the organic matter which contains some nitrogen hence the increased levels noted.

In the lower horizon (30-60 cm) only urea treatment of 30 kgN/ha gave significantly higher percent total nitrogen than the control. In the short rains 1989/90, only Triple Superphosphate treatments of 80 and 120 kg P205/ha gave significantly higher levels of percent total nitrogen. This effect was only in the upper horizon (0-30 cm) (Table 19). Again this was due to the increase in organic matter and hence subsequent increase in total nitrogen.

At Thika, soil under Katheka had significantly higher percent total nitrogen of 0.168 and 0.118 in the upper and lower horizon than that under NPP 670 which was 0.154 and 0.099 percent total nitrogen in the upper and lower horizon respectively. The upper horizon had significantly higher percent total nitrogen of 0.161 compared to that of the lower horizon of 0.108 percent. Under NPP 670 only manure application of 10 tons/ha had soil with significantly higher percent total nitrogen compared to the control. This effect was only in the upper horizon. Under Katheka, urea applicaton of 45 kgN/ha, Triple Superphosphate at 80 kg P_2O_5/ha and manure applcaton of 5 tons/ha gave significantly higher total nitrogen in the upper horizon (0-30 cm) compared to the control (Table 20).

Compared to before planting, the average percent total nitrogen under both cultivars at harvest time were not significantly different; except under NPP 670 in the lower horizon (30-60 cm) where the average percent total nitrogen at harvest time was significantly lower than before planting. This may have been caused by absorption by deep roots of pigeonpea. The lack of increase in nitrogen in the lower horizon (30-60 cm) shows that there was not much leaching of the element into the sub-soil.

4.3.4.1 Response to Nitrogen Application

Nitrogen was applied in form of urea. At Thika there was generally no

response to nitrogen application to either of the two cultivars. Katheka's plant height at flowering was significantly depressed by the urea application of 30 and 45 kgN/ha. This is contrary to Singh, et al , (1976) report that nitrogen application increased plant height. Urea application of 45 kgN/ha to Katheka significantly increased the stem and branches dry matter, pods weight per plant and number of pods per plant. This is in agreement with Ram and Giri (1973) and Ahlawat (1976) report. However the grain yields were not significantly increased by any of the urea application. The increase in grain yields might have been masked by the effect of *Mycovellosiella cajani* disease attack.The lack of response of grain yield to nitrogen application may have been due to the fact that pigeonpea is a deep rooted crop with an extensive root system and therefore capable of extracting nutrients from a high volume of soil, such that its growth is not often limited by nutrient availability, except in soils with relatively low levels of these nutrients, (Pietri, et al, 1971) Pigeonpea being a legume is also capable of fixing atmospheric nitrogen to meet its nitrogen requirements. Sen (1958) reported that pigeonpea can fix about 125 kg N/ha under favourable conditions. Soils at Thika compared to those at Kiboko had higher levels of total nitrogen. This may explain why there was response to nitrogen application at Kiboko and non at Thika. The urea application of 15, 30, and 45 kgN/ha to NPP670 at Kiboko in the long rains 1989, increased yields by 5.4, 115.3 and 191.3 percent respectively.
However in the short rains 1989/90 the response to urea application was inconsistent. The urea applications of 15, 30, and 45 kgN/ha increased yields by 79.2, 52.8 and 84.6 percent, respectively. This supports earlier observation that pigeonpea response to fertilizers application is difficult to get and is erratic, (Rachie, et al, 1974; Dalal , 1980)

The short rains 1989/90 inconsistent response may have been caused by the prolonged of vegetative growth, which masked any benefits gained by the urea application. The high amounts of rainfall received in this season (Appendix 3d) may have increased the absorption of nutrients from the soil hence minimising benefits from applied nutrients. Ogombe (1978) made similar observation due to differences in the amount of rainfall received.

The leaf area, leaf, stem, and branches total dry matter were all significantly increased by urea application of 30 and 45 kg N/ha to both cultivars grown at Kiboko in the long rains 1989. The number of primary branches pod weight per plant, grain weight per plant, grain yield per hectare and Harvest Index were also significantly increased by the same urea treatments in the same season. The leaf area ratio, number of days to 50 percent flowering, plant height at flowering and harvest time, days to 50 percent maturity, number of seeds per pod and seed weight were not significantly affected by the nitrogen application.

The urea applications especially of 30 and 45 kgN/ha at Kiboko in the long rains 1989, produced plants that grew more vigorously, and gave significantly higher grain yields than the control. The partitioning efficiency of photosynthates was also enhanced as reflected by the high harvest index of 0.43 got from application of 45 kg N/ha. The control had a Harvest Index of 0.37 (Table 15). The trend of response to urea application shows that even higher levels of nitrogen can be applied. Similar positive responses of pigeonpea to nitrogen application have been reported by Dalal (1974), Lenka and Satpathy (1976) and Gondalia, et al. (1988).

The soils at Kiboko are low in nitrogen and this may be the main reason why the pigeonpea responded positively to nitrogen application. Siderius and Muchana (1977) described the Kiboko soils as deficient in nitrogen.
The urea application at Machakos did not have any significant effect on number of days to 50 percent flowering, plant height at flowering and number of primary branches. Like the Thika soil, Machakos soil had also relatively high nitrogen level

and this may explain the lack of response.

From these observations it can be concluded that response to nitrogen application will be beneficial to early maturing pigoenpea cultivars in soils with low nitrogen levels. Cultivars that have long vegetative phase or where the early maturing cultivars have long vegetative phase due to environmental factors, response to nitrogen application may not be obviously detected. There is therefore need to know the soil nitrogen status before applying nitrorogenous fertilizers. Singh, et al, (1972) reported that improved cultivars benefit more from fertilisers application than unimproved cultivars.

4.3.4.2. Effect of Urea Application on the Soil

At Thika the application of urea to both cultivars did not change any of the soil characteristics measured. Urea application of 45 kgN/ha to Katheka, however significantly increased the percent total nitrogen. The carbon: Nitrogen ratio was subsequently reduced (Table 20). The increase in nitrogen maybe due to high dry matter produced and /or nitrogen fixation (Sen, 1958).

At Kiboko, in the long rains 1989, urea application to NPP 670 of 30 kg N/ha significantly increased the nitrogen level in both soil horizons. Percent organic carbon was significantly increased by application of urea of 30 and 45 kg N/ha to NPP 670 in the long rains 1989. This was probably due to the high levels of dry matter produced by these applications. The other soil characteristics measured were not affected by urea application. In the shot rains 1989/90, the urea application did not affect any of the soil characteristics measured.

4.3.5 Carbon: Nitrogen Ratio

The Carbon-Nitrogen ratio at planting and harvest time are shown in Table 19 and 20. At Kiboko, at harvest time in long rains 1989, the soil had significantly higher Carbon-Nitrogen ratio of 10.2 than the short rains 1989/90 with the Carbon-Nitrogen ratio of 7.4. This effect was only observed in the upper horizon. In the lower horizon (30-60cm) in both seasons the Carbon-Nitrogen ratios were not significantly different. Urea application of 15 kgN/ha,Triple superphosphate of 120 kg P_2O_5/ha and manure of 10 tons/ha had significantly lower Carbon: Nitrogen ratio than the control. These fertiliser application increased the organic matter which has a lower Carbon:Nitrogen ratio and hence this observation. This effect was observed only in the upper horizon. The other fertilizer applications in both seasons and in the two horizons had no significant effect on the Carbon-Nitrogen ratio (Table 19).

At Thika the Carbon:Nitrogen ratio did not differ under the two cultivars and for both horizons. Under Katheka urea application of 45 kg N/ha, Triple superphosphate treatment of 120 kg P_2O_5/ha and the two manure applications had significantly lower Carbon:Nitrogen ratio compared to the control. This effect was observed only in the upper horizon. The fertilizer treatments did not have any significant effect on the Carbon:Nitrogen ratio (Table 20). The carbon:nitrogen ratio is an important soil parameter as it influences the availability of nitrogen (Brady, 1984).

4.3.6.0 `Available' Phosphorus

The levels of `available' phosphorus at planting and harvest time are shown in Tables 21 and 22. At Kiboko, at harvest time in the long rains 1989, the average phosphorus level were 62.5 and 20.8 ppm in the upper and lower horizon respectively while in the short rains 1989/90 they were 37.0 and 15.3 ppm in the upper and lower horizon respectively. The upper horizon had significantly higher level of phosphorus of 49.8 ppm compared to that of the lower horizon of 18 ppm.

In the long rains 1989, Triple superphosphate treatments of 80 and 120 kg

Table 21. Soil phosphorus and CEC at Kiboko before and after growing NPP 670 for two seasons

Season	Period	Fertiliser		Phosphorus (ppm)		CEC (Meq/100 g soil)	
		Type	Amount (kg/ha)	0-30 cm	30-60 cm	0-30 cm	30-60 cm
Long rains 1989	Planting	—	—	42	—	16.5	—
	Harvest	Control	0	39.3	14	11.8	10.8
		Urea*	15	50	12.5	16.8	15.1
			30	47	21.5	17.1	18.1
			45	46	19	12.9	16.5
		TSP*	40	67.5	29.8	16.2	10.9
			80	107.5	30.5	12.6	15.4
			120	116.9	36	13.5	16.6
		Manure	5000	44.3	11.8	9.2	18.4
			10000	43.5	11.8	16.4	16.3
		Mean		62.5	20.8	14.1	15.3
Short rains '89/9	Planting	—	—	35	21.1	10.1	19.9
	Harvest	Control	0	35.5	13	10.7	11.1
		Urea*	15	27	13	14.7	7.7
			30	28	12.5	13.4	19.5
			45	31	14.5	14.1	15.6
		TSP*	40	21	11.3	16.2	9.3
			80	46.9	18	17.7	15.5
			120	67.5	18	17.9	11.8
		Manure	5000	31.8	11.3	17.7	14.2
			10000	44.5	26.5	23.8	11.5
		Mean		37	15.3	16.20	12.9

Urea* _ (Kg N)
TSP* _ [(kg P205) Triple Superphosphate]

Table 22. Soil Phosphorus and CEC at Thika before and after growing the two pigeonpea cultivars

Cultivar	Period	Fertiliser		Phosphorus (ppm)		CEC (Meq/100 g soil)	
		Type	Amount (kg/ha)	0-30 cm	30-60 cm	0-30 cm	30-60 cm
	Planting	–	–	16	4	15.4	11.3
NPP 670	Harvest	Control	0	7	1	19.9	17
		Urea*	15	9.3	1.2	21.3	11.9
			30	14.8	1.9	29	18
			45	9.7	1	15.9	11
		TSP*	40	5.4	2.2	22.1	9.3
			80	26.8	4.3	20.2	18.6
			120	32.3	8.3	22.6	18
		Manure	5000	9.3	1.6	24.9	16.7
			10000	7.8	1.2	22.3	19.5
		Mean		13.6	2.5	22	15.6
KATHEKA	Harvest	Control	0	8.7	2.1	16.5	16.3
		Urea*	15	12.8	2.5	19.6	14.8
			30	13	1.8	22.2	15.9
			45	11	2	22.5	13.2
		TSP*	40	7.	1.9	18.1	12.1
			80	18	2.6	16.1	14.9
			120	21.5	3.3	18	16.8
		Manure	5000	4.8	2.5	22.2	13.2
			10000	11	1.8	16.1	15.7
		Mean		11.9	2.3	19	14.8

*Urea -(kg N)
*TSP - (Kg P205)[Triple superphosphate]

P_2O_5/ha gave significantly higher levels of phosphorus compared to the control. This effect was observed in the upper horizon only. This increase was due the residual phosphorus left in the soil . In the short rains 1989/90, Triple superphosphate application of 120 kg P_2O_5/ha gave significantly higher phosphorus level compared to the control. This effect was observed only in the upper horizon.

At Thika under NPP 670, the average phosphorus levels were 13.6 and 2.5 ppm in the upper and lower horizons respectively, while under Katheka the phosphorus level were 11.9 and 2.3 in the upper and lower horizons respectively.

The upper horizon had an average phosphorus level of 12.8 ppm which was significantly higher than that of the lower horizon of 2.4 ppm. Under the two cultivars only the Triple superphosphate treatments of 80 and 120 kg P_2O_5/ha gave significantly higher levels of phosphorus than the other fertilizer application. This effect was observed only in the upper horizon. This is due to residual effect of the applied phosphorus, since phosphorus is not easily lost from the soil. All the other fertilizer applications did not have any significant effect on the phosphorus levels (Table 22).

4.3.6.1 Response to Phosphate Application

Phosphorus was applied as triple superphosphate. At Thika the application of phosphate to both cultivars had no significant effect on any of the parameters measured. However, Katheka plant height at harvest time wa significantly depressed by the phosphate application (Table 22).

At Machakos none of the three parameters measured, namely number of days to 50 percent flowering, plant height at flowering and number of primary branches, were significantly affected by the phosphate application.

Similarly at Kiboko, in the long rains 1989, phosphate application to both cultivars had no significant effect on any of the parameters measured. In the short rains 1989/90, however phosphate application of 40 and 80 kg P_2O_5/ha to NPP 670 significalty increased stems and branches dry matter, pod dry matter, number of pods per plant, grain weight per plant, grain yield and Harvest Index. The application of 40 kg P_2O_5/ha had a higher positive effect than the 80 kg P_2O_5/ha application on the above parameters while the treatment at 120kg P_2O_5/ha did not differ significantly from the control. The phosphate application of 40, 80 and 120 kg P_2O_5/ha increased grain yield by 102.7, 80.3 and 11.6 percent respectively. From the observation of the short rains 1989/90 it appears that application of phosphate beyond 40kg P_2O_5/ha is not beneficial. Results from Thika, Machakos and Kiboko in the long rains 1989; show that there is no need of applying thephosphate fertilizer at all. For it did not have any positive significant effect on any of the parameters measured. Maybe the soils had sufficient quantities required for growth.

Ae et al, (1990) reported that the root exudates of pigeonpea contain substances which solubilize phosphorus from iron bound form, thus allowing the crop to grow well in soils where available phosphorus maybe low. This explains the lack of response to phosphate application at Thika despite the low 'available' phosphourus level. In the short rains 1989/90, at Kiboko phosphate application of 40 and 80 kg P_2O_5/ha significantly increased stem and branch dry matter, pod (whole) weight, grain weight per plant and grain yield per hectare, whereas only phosphate application of 40 kg P_2O_5/ha significantly increased number of pods per plant and Harvest Index. However, in the long rains 1989 there was no response at all. This further supports Dalal, (1980), Rachie, et al, (1974) conclusion that pigeonpea response fertilizer is difficult to get and is erratic.

Olsen et al, (1961) showed that phosphorus uptake by maize seedlings was directly proportional to moisture content of the soil. When moisture was constant, uptake depended on the level of phosphorus in the soil solution. This may explain the response to phosphate in the short rains 1989/90 which received about twice as much rainfall during the growth period compared to the long rains 1989.

Ahiamet et al, (1981),reported that application of phosphorus improved plant growth. However the increase in phosphorus from 17 to 34 kg P/ha did not bring about any improvement in growth. In this experiment, phosphate application of 40 kg P_2O_5/ha significantly increased grain yield and application of 80 kg P_2O_5/ha to a lesser extent also increased grain yield. The higher level application of 120 kg P_2O_5/ha had no effect. Similar observation were reported by Singh, et al (1972) and Ram and Giri, (1973).

4.3.6.2 Effect of Phosphate Application on Soil Characterisitcs

Compared to control, phosphate application of 80 and 120 kg P_2O_5/ha at the two sites, to both cultivars and in the two seasons, significantly increased available phosphorus in the upper horizon (0-30 cm) of the soil (Table 21 and 22). With exception of phosphate application of 40 kg P_2O_5/ha at Kiboko in the short rains 1989/90, all the phosphate application at Kiboko in both seasons significantly increased nitrogen level in the upper horizon (0-30 cm). Also all the phosphate application to Katheka at Thika significantly increased nitrogen level in the lower (30-60 cm) horizon. This is probably through the effect of increasing dry matter.

Phosphate application of 120 kg P_2O_5/ha at Kiboko in the short rains 1989/90 significantly increased the organic carbon level in the upper horizon. The same rate of application at Thika to Katheka significantly increased organic carbon in the lower soil horizon.

Phosphorus enhances root growth. This increases organic matter in the soil. Nitrogen fixation is also done in the roots. This may explain the increases in both organic carbon and total nitrogen in the soil due to phosphate application. Phosphate fertilizer application normally increases the phosphorus level in the soil since phosphate gets fixed in the soil and is not easily lost through leaching (Brady, 1984) and the crops takes only small quantities (Lenka and Satpathy, '76).

4.3.7 Soil Cation Exchange Capacity (CEC)

The soil CEC at planting and after harvesting are shown in Tables 21 and 22. At harvest time, at Kiboko in long rain 1989 the average cation exchange capacity were 14.1 and 15.3 meq./100g of soil in the upper and lower horizon respectively. In the short rains 1989/90 the CEC were 16.2 and 12.9 meq/100g of soil in the upper and lower horizon respectively.

There was no significant difference in CEC for the two seasons and also between the two horizons. Only manure applcation of 10 tons/ha in short rains 1989/90 gave significantly higher CEC than the control. All the other fertilizer applicatons in both seasons of both horizons had no significant effect on the soil CEC (Table 21).

At Thika under NPP 670, the average CEC were 22.0 and15.6 meq/100g of soil in the upper (0-30 cm) and lower (30-60 cm) horizons respectively; which were slightly higher than those under Katheka of 19.0 and 14.8 meq/100g of soil in the upper and lower horizon respectively. Under the two cultivars the upper horizon had slightly higher CEC than the lower horizon.

All the fertilizer treatments did not have any significant effect on the cation exchange capacity (Table 22).

5.0 CONCLUSION AND RECOMMENDATIONS

Pigeonpea usually has slow initial growth rate and develop a deep extensive root system. This avails a very large volume of soil from which it gets its nutrient requirements for growth. It is therefore only in soils with very low levels of nutrient concentrations that its growth maybe limited by nutrient availability. This is supported by the observation at both Thika and Kiboko, where at Thika there was no response at all to fertilizer applications while at Kiboko there was some response. Application of nitrogenous fertilizers upto about 45 kgN/ha or more at planting time significantly enhanced plant growth and yields. Manure application also upto 10 tons/ha or more had similar effect of enhancing growth and hence yields. Phosphorus application beyond 40 kgP_2O_5/ha did not seem to be beneficial. However, if the vegetative phase is prolonged as was observed at Kiboko in the second season these advantages get masked.

Improved early maturing cultivars, such as NPP 670 planted in soils with low nutrients are likely to show positive response to fertilizers than the unimproved late maturing cultivars.

Environmental factors such as temperature and rainfall strongly influence pigeonpea growth and hence the response to fertilizers. Because of the interaction between environmental factors and soil factors it is not possible to give a general guide on fertilizer application rates to pigeonpea.

From these results, it can be recommended that application of starter nitrogen fertiliser is beneficial . However, the amount to be applied will depend on soil nutrient status and environmental factors. In Kiboko and places with similar conditions, applications of 45 kgN/ha or more, manure of 10 tons/ha or more and not more than 40 kg P_2O_5/ha would be recommended. These recommendations are only for early maturing cultivars.

Application of manure significantly increased leaf area, plant dry matter number of primary branches, Number of pods per plant, grain yield, harvest index and to a less extent plant height. The number of days to flowering and maturity, number of seeds per pod and seed weight were not signifcantly affected by the manure application. · However these effects were not consist in all the sites and among the cultivars.Urea application significantly increased leaf area, plant dry matter, number of primary branches, pods weight per plant, number of pods per plant grain yield and harvest index.The number of seeds per pod,seedweight, plant height number of days to flowering and maturity were not significantly affected by the urea application. The response of these yield component however varied from sites to sites and among the cultivars. NPP 670 was more responsive to the nitrogen application.

Phosphate application increased stem and branches dry matter, pods dry matter, number of pods per plant, grain yield and harvest index. The other yield components were not significantly affected by phosphate applications.

Manure application increased soil nitrogen, organic carbon and to a less extent CEC with the application of 10 tons/ha.

Urea application increased soil total nitrogen and organic carbon,while the application of triple superphosphate at the higher rates increased availble phophrus, soil total nitrogen and organic carbon level.

5.1 Suggestions for further work

Further work needs to done to determine the optimum amounts of nitrogen and manure required. In this case, the results show that more than what was added can be added with positive response expected. Some studies, to determine the optimum amount water and its distribution is also needed. The continous rains received at Kiboko in the short rains 1989/90 only prolonged the vegetative growth without any added benefits in terms of grain yield. Importance of pigeonpea in restoring fertility in a rotation is evident from these results. More work needs to be done on this aspect.The results from soil analysis show that pigeonpea increased the organic matter and nitrogen in the soil . Studies ought be done on ecological zones bases so as to come up with specific recommendations for each zone, since each ecological zone seem to give different results.

Some work on planting dates and seasons maybe also essential. Studies ought to be done to categorise the pigeonpea cultivars according to ecological zones. This would avoid the problem like was expressed at Kiboko with Katheka, where no pods were formed but in Thika it performed well.

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Appendix 1a. Rainfall (mm) of thika field over the last 7 years (1983- 1989)

Year	1983	1984	1985	1986	1987	1988	1989	Average
January	1	5.3	4.5	15.9	5.7	48.60	165.6	35.2
February	126.3	1.2	103.8	0	3.6	19.1	34.1	41.2
March	124.3	23.5	145.6	123	6.3	174.7	116.8	102
April	243.5	67.4	392.1	345.9	159.9	271.3	314.9	256.4
May	14.1	0.9	58.5	125.2	102.5	118.9	78.9	71.3
June	29.9	0.9	10.9	12.1	137.5	46.4	7.4	35
July	0	29.5	2	1.2	18.6	13.1	30.3	12.5
August	9.5	2.7	0	1.1	33.9	8.6	23	11.3
September	0.4	76	5.2	1.5	0	35.2	49.6	24
October	167.5	158.4	56.4	44.5	2.8	56.6	109.4	85.1
November	77.6	124.4	105.7	227.3	161.9	136.4	145.2	139.8
December	170.2	81.6	21.5	73.1	18.6	189.8	127.7	97.5
Total	964.3	571.8	906.2	970.8	651.3	1118.7	1203	911.3

Source -National Horticultural Research Centre Met. Section -THIKA.

Appendix 1b. Maximum temperature (oC) of Thika field over the last 7 years (1983- 1989)

Year	1983	1984	1985	1986	1987	1988	1989	Average
January	26.2	27.2	26.5	27.5	26.2	27.50	24.9	26.6
February	27.5	27.6	27.3	29.3	28.1	28.7	25.9	27.8
March	28.6	28.1	27.2	27.8	29.8	28.1	27.3	28.1
April	26.5	27.5	24.8	25.1	26.8	25.6	24.3	25.8
May	25.2	26.6	23.5	23.8	25.3	24.4	24.8	24.8
June	24.2	25.4	22.9	22.2	23.6	23.5	23.3	23.6
July	23.7	22.3	23.9	22.4	23.5	22.8	22	22.9
August	24.9	22.4	22.4	24.5	23.8	23.1	21.8	23.3
September	25.7	26.3	25.8	25.1	27.3	24.7	25	25.7
October	26.4	24.7	25.9	27	28.5	26.8	25.1	26.3
November	25.7	23.5	25.8	24.5	25.7	23.9	24	24.7
December	25.5	24.4	25.1	24.3	26.8	23.8	24.9	24.9
Average	25.8	25.5	25.1	25.3	26.3	25.2	24.4	25.4

Source -National Horticultural Research Centre, Met. Section -THIKA.

Appendix 1c. Minimum temperature (oC) of Thika field over the last 7 years (1983-1989)

Year	1983	1984	1985	1986	1987	1988	1989	Average
January	14	11.8	12.7	12.9	13.4	14.1	14	13.3
February	14.2	11	14.6	12.5	13.1	13.4	12.1	13
March	15.4	14.3	14.1	14.6	13.8	15.6	14.3	14.6
April	16.5	16	15.7	15.8	15	16.3	15.2	15.8
May	15.9	14.4	15.3	15.3	14.4	15.4	14.9	15.1
June	14.3	12.3	12.8	13.4	14	14	13.2	13.4
July	13.6	13.5	12.8	11.4	12.6	13.2	12.6	12.8
August	12.9	12.6	12.2	11.1	12.9	13.6	12.7	12.6
September	12.5	12.8	13.4	12.6	13.7	13.4	13.3	13.1
October	14.6	14.5	14	14.9	14.8	13.5	14.6	14.4
November	13.9	15.1	15	15.3	15.4	14.6	15	14.9
December	14.2	13.6	13.8	14.6	13.2	13.7	15.5	14.1
Average	14.3	13.5	13.8	13.7	13.9	14.2	13.9	13.9

Source -National Horticultural Research Centre Met. Section - THIKA.

Appendix 1d. Rainfall, Maximum and Minimum temperature (oC) during cropping period at Thika.

Month		Rainfall (mm)	Max. temp. (oC)	Min. temp. (oC)
November	1989	145.2	24	15
December	1989	127.7	24.9	15.5
January	1990	68.1	25.2	13.5
February	1990	78.4	27.1	14.7
March	1990	318.5	25.5	15.7
April	1990	268.9	25.1	15.8
May	1990	97.3	25.1	15.2
June	1990	3.6	22.7	11.5
July	1990	3.3	22.8	12.7
August	1990	3.1	23.3	12.6
September	1990	61.4	25.5	11.7

*planting date 1/11/'90

Source -National Horticultural Centre, Met. Section - THIKA.

Appendix 2a. Rainfall [mm] of Machakos field

Year	1984	1985	1986
January	34.1	12	70
February	12.3	113.5	0.3
March	14.3	111.7	69.1
April	59.7	321.7	162.1
May	0.5	104	73.3
June	0.5	0.5	7.3
July	11.9	1.3	0.8
August	4.6	0.8	1
September	10.4	1.5	0
October	145.3	85.1	9.6
November	235.4	91.8	239.2
December	54.5	134.1	144.6
Total	583.5	978	777.3

Source -ICRAF FIELD STATION MACHAKOS.

over the last 7 years (1984- 1990)

1987	1988	1989	1990	Average
27.3	149.10	132.8	73.3	71.2
0	26	11.5	12.6	25.2
27.5	120.1	94.1	245.6	97.5
89.8	272.1	176.1	283.6	183.7
34.3	14.3	63.4	91.8	50.4
70.5	17.1	2.8	9.3	14.5
5.5	3.1	7.3	1.6	4.6
12.3	7.8	19.8	4	8.2
0	26.6	0.8	2.8	5.5
0.8	34	138.3	39	56.9
87.8	151.4	131.3	198.3	151.4
19.8	211.6	98.3	69.3	111.1
375.6	375.6	876.5	1031.2	807.9

Appendix 2b. Maximum temperature (oC) of Machakos field over the last 7 years (1984- 1990)

Year	1984	1985	1986	1987	1988	1989	1990	Average
January	27.8	26.8	26.9	25.6	27.20	25.6	25.7	26.5
February	29.6	27	30.1	28.4	28.9	26.4	28.4	28.4
March	29.5	27.5	28.7	30.1	28.6	27.9	26.1	28.3
April	28.7	25.5	26.7	27.3	25.9	24.6	25.7	26.3
May	27.3	24.5	23.8	27	25.3	25.4	25.6	25.6
June	24.1	23.5	23.4	24.5	24.2	23.8	24.1	23.9
July	22.8	23.1	23.2	24.8	24.1	22.6	23.6	23.5
August	22.8	22.9	25.5	25	24.3	22.7	22.8	23.7
September	26.8	26.4	26.3	28.3	25.8	26.5	26.7	26.7
October	25.8	26.6	28.4	29.3	28.4	26.8	27.8	27.6
November	25.3	25.2	25.3	27.3	25	25	25	25.4
December	25.1	25.5	24.5	27.3	24	25.4	24.7	25.2
Average	26.3	25.4	26.1	27.1	26	25.2	25.5	25.9

Source -ICRAF FIELD STATION MACHAKOS.

Appendix 2c. Minimum temperature (oC) of Machakos field over the last 7 years (1984- 1990)

Year	1984	1985	1986	1987	1988	1989	1990	Average
January	20.4	20	20.2	19.1	20.7	18.9	18.9	19.7
February	21.2	20.2	21.7	20.5	21.5	19.4	20.4	20.7
March	21.5	20.6	21.1	21.9	21.3	20.4	19.6	20.9
April	21.3	19.5	20.3	20.6	20.3	18.4	19.2	19.9
May	20.1	18.5	18.2	19.6	19.1	18.4	18.8	18.9
June	17.7	16.9	16.9	17.5	17.8	17.1	16.8	17.2
July	16.6	16.4	16	17.3	17.5	16.2	16	16.6
August	16.4	16.7	16.9	17.7	17.7	16.3	16.4	16.9
September	18.5	18.7	18.3	19.5	18.2	18.5	18.2	18.6
October	19.2	19.5	20.3	20.9	20.3	19.3	19.9	19.9
November	19	20.3	19.4	20.2	18.8	18.9	19	19.4
December	19.1	20.5	18.6	20.6	18.2	19.1	18.7	19.3
Average	19.2	19	19	19.6	19.3	18.4	18.5	19

Source -ICRAF FIELD STATION MACHAKOS.

Appendix 2d. Rainfall, Maximum and Minimum temperature (oC) during cropping period at Machakos.

Month		Rainfall (mm)	Max. temp. (oC)	Min. temp. (oC)
March	1989	94.1	27.9	20.4
April	1989	176.1	24.6	18.4
May	1989	63.4	25.4	18.4
June	1989	2.8	23.8	17.1
July	1989	7.3	22.6	16.2
August	1989	19.8	22.7	16.3
September	1989	0.8	26.5	18.5
October	1989	138.3	26.8	19.3

Planting date 8/4/'89

Source -ICRAF FIELD STATION MACHAKOS.

Appendix 3a. Rainfall [mm] of Kiboko field over the last 7 years (1983- 1989)

Year	1983	1984	1985	1986	1987	1988	1989	Average
January	0	17.5	14.2	20.3	17	41.30	191.5	43.1
February	36.9	0	129.6	0	0	9.3	0	25.1
March	6.9	35	12	46.3	29.8	201.2	37.6	52.7
April	47.3	72.9	35	99.2	69.5	83.6	169.4	82.4
May	17.3	0	29.7	12.5	40.7	5	73.9	25.6
June	0	0	0	6.1	13.4	9.5	2.2	4.5
July	0	0	0.7	0	0.9	0	0	0.2
August	0	0	0	0	4.8	2.1	0	1
September	0	0	5.6	0	0	2.5	1.5	1.4
October	0	75.6	55.4	5.4	0	0	113.5	35.7
November	31.8	245.6	102.6	120.2	100.4	117.5	170.1	126.9
December	137.6	113.6	103.4	51.1	17.9	130.2	206.1	108.6
Total	277.8	560.2	488.2	361.1	294.4	602.2	965.8	507.2

Source -Range Dryland Research Station Met. Section -KIBOKO.

Appendix 3b. Maximum temperature (oC) of Kiboko field over the last 7 years (1983- 1989)

Year	1983	1984	1985	1986	1987	1988	1989	Average
January	28.8	30.7	28.1	31	28.9	31.70	28.2	29.6
February	31.5	32.4	30.6	33.4	32.1	33	30.3	31.9
March	32	32.1	31.6	32.3	33.8	32.9	32.3	32.4
April	30.8	30.7	30.9	30.6	31.1	29.1	28	30.2
May	29.7	29.7	29.1	27.7	29.5	29.1	27.9	29
June	28.9	28.1	27.8	27.5	28.5	28.3	27.5	28.1
July	28	26.7	27.9	27.3	28.4	27.9	27	27.6
August	29.3	26.4	27.9	28.4	29.7	27.9	26.9	28.1
September	29.5	29.8	30.2	29.6	30.9	29.4	29.6	29.9
October	30.6.	29.2	30.5	31.4	32.3	32.1	30.6	31
November	29.8	26.5	28.8	28.8	30.4	29	27.8	28.7
December	29.1	27.9	27.8	27.1	32	27.9	27.5	28.5
Average	29.8	29.2	29.3	29.6	30.6	29.9	28.6	29.6

Source -Range Dryland Research Station Met. Section -KIBOKO.

- 128 -

Appendix 3c. Minimum temperature (oC) of Kiboko field over the last 7 years (1983- 1989)

Year	1983	1984	1985	1986	1987	1988	1989	Average
January	17.1	16.9	17.4	17.3	16.7	19.3	17.5	17.5
February	18.7	18.4	18.3	17.6	16.9	19.4	16.9	18
March	19.8	18.1	17.6	18.8	18.7	19.7	18.5	18.7
April	19.9	18.8	17.7	19	17.8	19.4	18	18.7
May	18.4	17.1	16.8	17.7	16.7	16.9	16.6	17.2
June	16.9	14.7	14.3	14.6	15.4	16.3	14.3	15.2
July	16.3	14.7	13.7	13.6	14.3	15.4	13.6	14.5
August	16.6	15.4	13.9	13.4	13.8	15.4	14.5	14.2
September	16.9	17.3	15.5	15	16	16	16.2	16.1
October	17.7	18.6	17.4	18.3	17.5	18	16.6	17.7
November	18	19.1	18.3	18.2	18.5	18.4	18.1	18.4
December	18.6	18.6	18.3	17.4	19	18.1	18.2	18.3
Average	17.9	17.3	16.6	16.7	16.8	17.9	16.6	17.1

Source -Range Dryland Research Station Met. Section - KIBOKO.

Appendix 3d. Rainfall, Maximum and Minimum temperature (oC) during cropping period at kiboko.

Month		Rainfall·(mm)	Max. temp. (oC)	Min. temp. (oC)
March	1989	37.6	32.3	18.5
April	1989	169.4	28	18
May	1989	73.9	27.9	16.6
June	1989	2.2	27.5	14.3
July	1989	0	27	13.6
August	1989	0	26.9	14.5
September	1989	1.5	29.6	16.2
October	1989	113.5	30.6	16.6
November	1989	170.1	27.8	18.1
December	1989	206.1	27.5	18.2
January	1990	85.6	28.2	16.6
February	1990	100.4	31.1	18.3
March	1990	165.4	29.1	18.8
April	1990	120.8	28.6	18.7
May	1990	25.2	28.7	17
June	1990	0.2	27.9	13.7
July	1990	0	27.1	13.2

	Long rains 1989/'90	Short rains 1989/'90
*planting date	9/4/'89	31/10/'89
Harvesting date (cultivar NPP 670)	16/9/'89	10/7/'90

Source -Range Dryland Research Station Met. Section - KIBOKO.

Appendix 4: SOIL ANALYSIS.

Materials

Reagent used in determination of soil pH, Total soil nitrogen, "available phosphorus, organic carbon and cation exchange capacity.

A Soil pH

(1) 0.01M Calcium chloride solution ; made by dissolving 1.11 grams of calcium chloride in 1 litre of distilled water.

B Total soil nitrogen:

(1) Concentrated sulphuric acid (36 N), analytical grade.
(2) Mixed catalyst; prepared by mixing 160.0 g potassium sulphate (K_2SO_4), 10.0 g copper sulphate ($CuSO_4$) and 3.0 g of selenium powder.

10.0 g copper sulphate ($CuSO_4$) and 3.0 g of selenium powder.

(3) Sodium hydroxide solution approximately 10N prepared by dissolving 420 g sodium hydroxide pellets in 1 litre of carbon dioxide free distilled water.
(4) Boric acid 20.0 g boric acid (H_3BO_3) per litre.
(5) Indicator solution, A mixed indicator was prepared by dissiving 0.12 g Methyl red and 0.8 g methylene blue in 100ml of 95% methanol.
(6) 0.01 N sulphuric acid. Made by dissolving 5 ml of 10N concentrated sulphuric acid into a five litre volumetric flask.

C 'Available' phosphorus:

(1) Double acid. (0.05 N HCl in 0.025N H_2SO_4). This was prepared by pouring about 15 litres of distilled water into a 20 litre bottle and shaking adding 14 ml of concentrated (H_2SO_4) sulphuric acid (AR) and 83 ml of fonc. HCl. The volume was made to 20 litres and thoroughly mixed.
(2) Reagent A:
   (i) Dissolved 12g of ammonium molybdate in 250 ml distilled water.
   (ii) Dissolved 0.2908 g of potassium atimony tartarate in 100 ml of distilled water.
   (iii) Prepared 5N sulphuric acid by diluting approximately 1000 ml of distilled water.
   (iv) mixed i, ii, and iii together in a 2 litre volumetric flask and made up to volume with distilled water.

(3) Reagent B:
Made by dissiving 1.056 g of ascorbic acid to every 200 ml of reagent A.
(4) Standard P stock solution- Made by weighing 0.4393 g of KH_2PO_4 into a one litre volumetric flask, adding 500 ml of distiilled water and shaking to dissolve the salt and then made to volume. 5 drops of Toluene were added to diminish microbal activity.

(5) 5 ml of the solution got from (4) were pipetted into a 100-ml volumetric flask and made up to volume with distilled water.

E <u>Organic Carbon:</u>

(1) 1 N potassium dichromate ($K_2Cr_2O_7$) made by dissolving 49.04 g analytical grade dichromate (dried at 105 ^oC) in distilled water and made upto 1000 ml.
(2) Concentrated (36 N) suphuric acid.
(3) Concentrated orthophosphoric acid.
(4) Barium diphenylamine.
(5) 0.5 N ferrous sulphate. Made by dissolving 140 g of analytical grade $FeSO_4.7H_2O$ in distilled water adding 5 ml of concentrated sulphuric acid , cooled and made upto 1000 ml.

F <u>Cation Exchange Capacity (CEC)</u>

(1) Ammonium acetate with pH adjusted to exactly 7.0
(2) Methyl alcohol 95 % concentrated.
(3) 2 percent boric acid made by dissolving 20 grams of boric acid in 1000 ml volumetric flask.
(4) Mixed indicator . Prepared by dissolving 0.12 g methyl red and 0.08 g methylene blue in 100ml of 95 % percent methanol.
(5) Magnessium oxide.
(6) 0.1 hydrochloric acid.

Appendix 5a. Mean squares for leaf area of two pigeonpea cultivars grown at Kiboko in long rains 1989 from the 12th week after planting to harvest time

Source	df	Mean squares of leaf area					
		week 12	week 14	week 16	week 18	week 20	week 22
				X10,000			
Replicate	2	18	10.5	71.8	16.7	23	24.1
Cultivar (A)	1	563.2	367.1	1647.1*	3057.4**	5172.5*	3072.3*
Error	2	42.7	102.4	19.9	9.1	80.3	60.8
Fertiliser(B)	2	44.8	234.3**	64.1	89.6	5.3	22.9
AB	2	1.4	34.1	11.6	13.7	1.5	51.5
Error	8	23.9	25.1	79.1	46.4	19.1	42.7
Fertiliser levels(C)	2	280.1**	243.2**	52.8	50.6	26.9	58.7
AC	2	31.6	6.1	24.6	8.4	0.3	27.3
BC	4	33.8	56.3	56.3	97.3	17.9	30.8
ABC	4	1.4	61.6	56.8	91.8	17.7	30.5
Error	24	31.4	22.8	32.2	27.5	28.1	17.8

*- Shows significance at 5 %
** Shows significance at 1%

Appendix 5b. Mean squares of leaf dry matter of two pigeonpea cultivars grown at Kiboko in long rains 1989 from the 12th week after planting to harvest time

Source	df	Mean squares of leaf dry matter					
		week 12	week 14	week 16	week 18	week 20	week 22
Replicate	2	154.5	102.4	50.1	20.7	24.3	192.2
Cultivar (A)	1	4.7	173.2	3369.1 *	6436.2	165110.3*	18414.9*
Error	2	127.2	192.1	69.3	353.5	204.3	527.5
Fertiliser(B)	2	361.9	929.2*	229.3	683.3*	89.7	194.2
AB	2	37.8	72.9	22.1	201.1	43.8	203.9
Error	8	86.6	136.5	97.1	107.1	117.3	383.6
Fertiliser levels(C)	2	1378.1**	636.9**	447.5*	247.9*	174.5	142.4
AC	2	208.1	35.1	74.1	5.7	32.4	33.5
BC	4	200	166.8	153.5	580.7	87.6	295.1
ABC	4	18.2	198.5	120.6	204.3	53.1	209.5
Error	24	96.3	84.9	94.6	64.9	106.1	132.8

*- Shows significance at 5 %

** Shows significance at 1%

Appendix 5c. Mean squares of stem & branches dry matter of two pigeonpea cultivars grown at Kiboko in long rains 1989 from the 12th week after planting to harvest time

Source	df	Mean squares of stem & branches dry matter					
		week 12	week 14	week 16	week 18	week 20	week 22
Replicate	2	283.6	258.4	176.7	334.2	297	665.1
Cultivar (A)	1	1702.4**	2618.1*	13681.6*	29503.7*	40953.1**	82096.5
Error	2	10.1	109.7	199.3	477.7	6.9	4444.3
Fertiliser(B)	2	422.9	1008.5	434.4	1889.7	806.7	1178.7
AB	2	75.8	201.8	32.8	321.3	5.8	2754.3
Error	8	165.4	238.9	279.7	442.2	389.3	2661.6
Fertiliser levels(C)	2	1336.4**	335.2	968.7	1187.8**	1603.7	3992.3*
AC	2	204.4	6.7	458.1	77.8	118.6	862.4
BC	4	172.6	122.1	682.5	1556	669.1	522.8
ABC	4	48.1	261.2	571.9	625	550.4	889.6
Error	24	107.1	136.8	252.1	170.6	339.2	831.3

*- Shows significance at 5 %

** Shows significance at 1%

Appendix 5d. Mean squares of pods dry matter of two pigeonpea cultivars grown at Kiboko in long rains 1989 from the 12th week after planting to harvest time

Source	df	Mean squares of pods dry matter				
		week 14	week 16	week 18	week 20	week 22
Replicate	2	8.8	281.2	231.7	49.5	228.3
Cultivar (A)	1	57.6	6502.7*	84634.7**	75052.7**	73208.4*
Error	2	8.8	281.2	231.7	518.8	1193
Fertiliser(B)	2	3.9**	143.1*	801.9	929.1	2026.8
AB	2	3.9	143.1	801.9	944.4	307.4
Error	8	0.4	40.9	277.6	402.9	1069
Fertiliser levels(C)	2	9.7	114.3	541.1	2142.8	1657.2
AC	2	9.7	114.3	541.1	1682.8	401.4
BC	4	2.6	23.9	549.4	361	79.5
ABC	4	2.6	23.9	549.4	562.6	268.1
Error	24	4.2	136.6	173.3	228.5	972.1

*- Shows significance at 5 %

** Shows significance at 1%

(Note. No pods were formed by the 12th week)

Appendix 5e. Mean squares for total dry matter of two pigeonpea cultivars grown at Kiboko in long rains 1989 from the 12th week after planting to harvest time

Source	df	Mean squares of total dry matter					
		week 12	week 14	week 16	week 18	week 20	week 22
Replicate	2	843.6	713.9	1329.4	215.8	123.7	1107.6
Cultivar (A)	1	1528.3	924.3	8906.1	1515.3	3236.8	22999.9
Error	2	192.8	659.7	1487.9	2553.2	231	14319.3
Fertiliser(B)	2	1549.3	3630.4*	1829.4	9291.5	4551.5	4205.9
AB	2	217.7	447.1	425.9	2711.5	519.9	4996.1
Error	8	452.6	712.1	807.6	1926.5	1775.8	8262.8
Fertiliser levels(C)	2	5408.5**	2004.5*	3552.2	4820.1	9533.7	10890.6
AC	2	795.7	119.9	1355.2	451.3	845.4	483.6
BC	4	730.2	598.2	1191.2	6908.6	2634.1	1699.4
ABC	4	94.8	866.5	1488.1	1227.6	1518.5	3517.9
Error	24	388.2	391.3	1080.7	625.8	1026.1	3262

*- Shows significance at 5 %

** Shows significance at 1%

Appendix 5f. Mean squares for leaf area ratio of two pigeonpea cultivars grown at Kiboko in long rains 1989 from the 12th week after planting to harvest time

Source	df	Mean squares of leaf area ratio					
		week 12	week 14	week 16	week 18	week 20	week 22
Replicate	2	243	131.1	47.6	329.6	48.5	41
Cultivar (A)	1	2016.7*	976.2	5086.7	16282.9**	19918.1*	7831.3
Error	2	63.7	168.1	763.6	135.4	201.4	12.1
Fertiliser(B)	2	169.6	44.7	25.1	25.1	66.4	4.8
AB	2	91.6	49.9	164.3	53.9	31.5	33.8
Error	8	56.9	152.1	491.6	108.3	13.4	46.9
Fertiliser levels(C)	2	5.4	209	213.1	42.3	40.6	15.6
AC	2	67.9	12	158.1	88.5	29.3	21.3
BC	4	13.4	46.1	70.7	66.2	29.9	12.1
ABC	4	44.8	54.4	172.9	92.7	38.2	24.3
Error	24	70.8	132.6	190	53.2	62.4	27.9

*- Shows significance at 5 %

** Shows significance at 1%

Appendix 6a. Mean squares of leaf area of two pigeonpea cultivars grown at Kiboko in short rains 1989/'90from the 17th week after planting to harvest time

Source	df	Mean squares of leaf area									
		week 17	week 19	week 21	week 23	week 25	week 27	week 29	week 31	week 33	week 35
						X10,000					
Replicate	2	155.3	533.5	1519	264.7	758.7	122.4	81.3	673.4	1862.6	798.8
Cultivar (A)	1	261.9	105.4	2568	2182	60.2	138	408.3	8.5	72.7	3763.2
Error	2	15.6	215.3	231.1	66.1	543.2	71.8	1842.3	21.7	1229.4	594.5
Fertiliser(B)	2	27.9	184.5	1987	478.1	6.1	125.2	186.5	111.2	185.8	16.6
AB	2	102.6	133.5	8.3	278.6	187.3	366.8	37.8	946.4	1322.8	7.6
Error	8	108.2	161.5	183	194.2	261.3	160.3	155.3	302.7	525.4	211.6
Fertiliser levels(C)	2	140.1	21.1	96.5	39.6	36.7	73.6	343.9	58.8	30.1	205.6
AC	2	27.2	188.9	100.8	45	72.9	21.6	705.1	447.4	775.4	244.1
BC	4	94.6	123.2	130.4	99.1	64	7.5	43.1	22.5	380.2	615.6
ABC	4	97	41.1	48.7	130.3	189.2	108.5	365.6	124.4	256.4	258.1
Error	24	92.8	92.6	57.8	135.3	231.2	96.1	208.9	447.3	452	373.2

*- Shows significance at 5 %

** Shows significance at 1%

Appendix 6b. Mean squares Of leaf dry matter of two pigeonpea cultivars grown at Kiboko in sl rains 1989/'90 from the 17th week after planting to harvest time

Source	df	Mean squares of leaf dry matter									
		week 17	week 19	week 21	week 23	week 25	week 27	week 29	week 31	week 33	week 35
Replicate	2	50.6	857.4	37.6	175.4	817.1	553.4	1220.4	3447.4	1730	422.1
Cultivar (A)	1	902.2	871.4	3832	12324*	14449	3989.9	198.8	445.3	1084	4686.8
Error	2	248.1	79.9	308.7	155.1	463.9	115.1	1658.9	605.3	676.1	637.3
Fertiliser(B)	2	35.6	30.6	1.8	206.7	89.4	160.4	256.3	480.9	270.6	6.6
AB	2	463.3	371.7	9.1	99.6	176.1	396.5	26.9	1501.1	260.8	43.9
Error	8	674.4	215.8	250.8	309.9	330.3	300	369.8	674.5	609.6	174.9
Fertiliser levels(C)	2	553.6	4.4	301.8	108.5	50.6	19.2	867.8	238.3	5.9	220.6
AC	2	108.2	429	19.6	93.1	139.4	60.8	1228.2	453.8	860.8	66.4
BC	4	2023	301.1	414.5	587.8	608.1	162.6	140.6	185.7	684.1	499.9
ABC	4	95.2	219.2	204.9	463.4	609.6	124.5	375.7	441.8	345.5	14608
Error	24	287.3	261.4	214.4	429.1	364.4	223.1	396.8	799.4	376.9	284.9

*- Shows significance at 5 %

**- Shows significance at 1%

Appendix 6c. Mean squares of stem & branches dry matter of two pigeonpea cultivars grown at Kiboko in sho rains 1989/'90 from the 17th week after planting to harvest time

Source	df	an squares of stem & branches dry matter									
		week 17	week 19	week 21	week 23	week 25	week 27	week 29	week 31	week 33	week 35
Replicate	2	1266	66630	11237.3	3449.8	41557.4	1515.8	11823.1	32761.3	25413	70713.8
Cultivar (A)	1	6844	31406.6*	293631.2*	415094.6*	1020297	1098681**	939573.8*	723712.9*	1628566.1**	1803800*
Error	2	1175	754.5	13117.2	7572.2	56742.4	29.9	35155.5	22138.7	4510	49589.9
Fertiliser(B)	2	357	866.1	2377.8	965.4	4709.9	4036.4	2238.5	33279.2	4224	3381.1
AB	2	3283	2333.3	1827.4	1161.7	11119.9	10728.8	634.6	12984.8	2563	2469.8
Error	8	3042	1197.5	1410.9	2610.3	12645.7	8267.9	7475.3	43227.3	34128	28554.8
Fertiliser levels(C)	2	2038	8.6	7326**	3682.1	2470.4	12632.2	25728.3**	58006.9	3026	23673.4
AC	2	123	3473.4	3916.7*	404.9	5278.8	17243.7	17752.1	47929.6	84.8	10669.5
BC	4	418	1763	1437.5	2486.5	7509.1	2967.9	2909.4	8298.6	23728	19936.2
ABC	4	652	356.3	1282.1	1852.6	4558.4	1138.6	2112.1	7935.3	21750	15437.5
Error	24	967	1276.6	1062.1	4070.1	4437.9	7224.4	4976.7	19456.2	18195	18985.6

*- Shows significance at 5 %

** Shows significance at 1%

Appendix 6d. Mean squares of pods dry matter of two pigeonpea cultivars grown at Kiboko in short rains 1989/'9 from the 17th week after planting to harvest time

Source	df	Mean squares of pods dry matter				
		week 27	week 29	week 31	week 33	week 35
Replicate	2	9.2	21.4	2447.8	4288.3	15915.4
Cultivar (A)	1	48.4	127.5	4241.3	9172.6	36532.1
Error	2	9.2	21.4	2447.8	8899.8	18131.5
Fertiliser(B)	2	0.3	8	219	2301.3	425.9
AB	2	0.3	8	219	85.1	328.6
Error	8	1.4	18.9	150.8	1664.3	227.8
Fertiliser levels(C)	2	1.1	7.8	4	1295.8	389.8
AC	2	1.1	7.8	4	156.9	470.5
BC	4	2.8	5.6	125.9	3417.8	1576.4
ABC	4	2.8	5.6	125.9	274.1	1431.8
Error	24	1.7	12.2	124.9	1728.4	1090.4

*- Shows significance at 5 %

** Shows significance at 1%

(Note. Pods Formation only by 27th week)

Appendix 6e. Mean squares Of total dry matter of two pigeonpea cultivars grown at Kiboko in : rains 1989/'90 from the 17th week after planting to harvest time

Source	df	Mean squares of total dry matter									
		week 17	week 19	week 21	week 23	week 25	week 27	week 29	week 31	week 33	week 35
Replicate	2	1813	12221	10103.9	5148.5	50653	2818.4	19919	33850.8	10528	151944.1
Cultivar (A)	1	2776	21815.7*	364547.2*	570466	1277585*	1219672.4**	945024	650747.3*	1472114.1**	1489335*
Error	2	2500	1148.1	16577.1	5688.4	65766	323.4	47900	34117.5	14677	21548.7
Fertiliser(B)	2	606.1	1028	2508.2	1437.1	5325.8	4278.7	2575.9	44352.8	16660	1603.1
AB	2	6185	4488.9	1588.3	1532	12665	13909.1	864.3	17707.6	3193	3212.4
Error	8	6394	2042.9	2687.4	4236.5	16105	11020.8	11105	54474.4	46327	31102.6
Fertiliser levels(C)	2	4612	25.2	9786.4**	4916.4	3110.1	13359.4	36259	65394.4	2099	30649.9
AC	2	423.9	6118.1	4490	834.4	6885.2	19626.6	25286	57442.6	1215	8047.8
BC	4	892.6	3472.8	2723.2	4800.8	10212	2963.9	4112.1	11144.2	46071	27270.9
ABC	4	1152	943.8	2254.2	3520.9	6578.3	1347.8	3096.2	10003.7	23308	14889.6
Error	24	2082	2479.1	1990.6	6725.1	6619.8	8463.7	6226.1	26605.8	21744	24490.8

*- Shows significance at 5 %

**- Shows significance at 1%

Appendix 6f. Mean squares of leaf area ratio of two pigeonpea cultivars grown at Kiboko in short rains 1989/'90 from the 17th week after planting to harvest time

Source	df	Mean squares of leaf area ratio									
		week 17	week 19	week 21	week 23	week 25	week 27	week 29	week 31	week 33	week 35
Replicate	2	81.6	304.8	3142	126.4	482.8	48.4	39.3	114.9	1252.9	436.8
Cultivar (A)	1	2800.8*	509.1	2035	3197.8	19183.6**	8298.4**	19056	7276	8993.8	868
Error	2	58.7	635.5	240.8	213.4	105.3	26.6	457.9	52.8	627.8	385.1
Fertiliser(B)	2	325.6	500.4	606.7	578.9	68.1	179.6	53.2	47.7	233.7	49.7
AB	2	101.3	977.8*	0.1	534.2	0.6	71.1	18.9	349.6	461.5	1
Error	8	241.4	175.6	173.8	53.8	123.2	191.5	72.3	120.3	128.2	67.7
Fertiliser levels(C)	2	48.4	49.6	80.3	9.5	0.5	41.7	0.5	70.8	183.2	70.4
AC	2	414.2	3.8	23.2	16.1	118.6	92.8	290.7	12.9	679.8	136.9
BC	4	459.1	81.4	48.7	27.7	49.2	15.2	52.3	81.6	116.9	205.8
ABC	4	557.9	19.9	4.8	49.6	71.2	73.6	150.7	92.6	137.4	290.8
Error	24	181	60.5	48	30.1	83.8	69.8	104.3	208.8	324.1	93.3

*- Shows significance at 5 %

** Shows significance at 1%

Appendix 7a. Mean squares for leaf area of Katheka grown at Kiboko in long rains 1989 from the 24th week after planting to 46th week when the experiment was terminated

Source	df	Mean squares of leaf area						
		week 24	week 26	week 30	week 34	week 38	week 42	week 46
					X10,000			
Replicate	2	28.2	76.4	311.4	250.3	2507.2	1672.4	2190
Fertiliser(A)	2	55.6	29.2	1076.1	73.4	2240.6	1346.2	2905.7
Error	4	8.5	31.8	288.3	1137.7	913.6	947.6	29572.2
Fertiliser levels(B)	2	102.8**	15.6	605.8	218.9	745.1	2835.9	2442.1
AB	4	14.7	17.7	108.3	452.1	407.7	705.9	465.9
Error	12	12.4	36.1	183.7	441.7	1667.6	253.3	891.5

* Shows significance at 5 %

** Shows significance at 1%

Appendix 7b. Mean squares for leaf dry matter of Katheka grown at Kiboko in long rains 1989 from the 24th week after planting to 46th week when the experiment was terminated

Source	df	Mean squares of leaf dry matter						
		week 24	week 26	week 30	week 34	week 38	week 42	week 46
Replicate	2	174.5	317.4	402.9	1210.6	10092.1	3668.7	8826.4
Fertiliser(A)	2	343.5	170.8	5336.8	641.8	7758.6	1989.9	4205.1
Error	4	52.5	134.1	897.4	5702.5	3208.8	2547.4	927
Fertiliser levels(B)	2	634.8**	124.7	2628.5	252.3	6335	11880.6**	7413.1
AB	4	90.8	123.4	576.5	2884.1	3297.7	2369.5	1388.8
Error	12	76.5	143.3	732.6	1194.9	6149.1	541.6	3479

*- Shows significance at 5 %
**'Shows significance at 1%

Appendix 7c. Mean squares for stem & branches dry matter of Katheka grown at Kiboko in long rains 1989 from the 24th week after planting to 46th week when the experiment was terminated

Source	df	Mean squares of stem & branches dry matter						
		week 24	week 26	week 30	week 34	week 38	week 42	week 46
Replicate	2	32530.4	1312.4	19130.9	4375.1	85795.2	103710	62136.6
Fertiliser(A)	2	36820.8	461.4	8549.8	25703.8	98732	253547	162326.2
Error	4	38607.1	334.2	58038.8	6481.7	14956.1	71655.3	49020.5
Fertiliser levels(B)	2	23771.1	678.1	36405.5	29216.7*	61483.4	300263	20956.7
AB	4	36577.5	2584	55339.6	27402.8	30015.9	93995.6	27102.7
Error	12	40404.2	1656.2	33757.2	4507.4	54046.1	32048.1	45105.6

*- Shows significance at 5 %

** Shows significance at 1%

Appendix 7d. Mean squares for total dry matter of Katheka grown at Kiboko in long rains 1989 from the 24th week after planting to 46th week when the experiment was terminated

Source	df	Mean squares of total dry matter						
		week 24	week 26	week 30	week 34	week 38	week 42	week 46
Replicate	2	26275.4	2643.7	4375.1	8779.7	154723	146388	114183.9
Fertiliser(A)	2	37897.3	794.4	25703.8	32422.9	151970	281036	218537.6
Error	4	38563.4	746.6	6481.7	24288.7	26838.9	96992.1	55814.3
Fertiliser levels(B)	2	23108.7	880.6	29216.7*	24045.6	107282	430651.6**	52826.8
AB	4	33015.7	3722.7	27402.8	46909.6	50135.4	123279	36317.3
Error	12	43420.6	2630.7	4507.4	9347.2	86795.9	36908.1	69967.8

Appendix 7e. Mean squares for leaf area ratio of Katheka grown at Kiboko in long rains 1989 from the 24th week after planting to 46th week when the experiment was terminated

Source	df	Mean squares of leaf area ratio						
		week 24	week 26	week 30	week 34	week 38	week 42	week 46
Replicate	2	16.4	280.6	250.3	123.6	7.1	58.7	85
Fertiliser(A)	2	76.1	253.1	83.9	173.4	115.7	280.8*	24.1
Error	4	33.8	192	480.3	101.1	99.4	19.6	63.7
Fertiliser levels(B)	2	36	258.4	121.6	878.8**	279.7	2.5	130.1
AB	4	17.4	524.1	399.5	310.8	63.1	18.3	20.7
Error	12	51.1	243.4	335.4	85.7	165.6	59.1	33.6

Appendix 8a. Mean squares for leaf area of two pigeonpea cultivars grown at Thika in short rains 1989/'90 from the 17th week after planting to 23rd week when NPP 670 was harvested

Source	df	Mean squares of leaf area			
		week 17	week 19	week 21	week 23
			X10,000		
Replicate	2	14.7	278	22.7	6.1
Cultivar (A)	1	527.5**	4657	6005**	314**
Error	2	1.7	430.5	1.7	6
Fertiliser(B)	2	8.6	47.5	29.4	5.5
AB	2	24.7	45.1	21.7	5.5
Error	8	4.1	52.9	19.6	8.9
Fertiliser levels(C)	2	2.4	24.4	4.9	0.9
AC	2	8.2	7.7	30.5	0.9
BC	4	13.5	14.9	13.8	12.7
ABC	4	9.6	13	21.3	12.7
Error	24	7.5	16.4	13.1	7.5

*- Shows significance at 5 %
**- Shows significance at 1%

Appendix 8b. Mean squares for leaf dry matter of two pigeonpea cultivars grown at Thika in short rains 1989/'90 from the 17th week after plantin(to 23rd week when NPP 670 was harvested

Source	df	Mean squares of leaf dry matter			
		week 17	week 19	week 21	week 23
Replicate	2	46.4	504.9	297.7	37.7
Cultivar (A)	1	141.7	8965.7	23400.9**	11006.7**
Error	2	17.1	689.4	49.2	37.7
Fertiliser(B)	2	31.2	168.2	62.9	20.6
AB	2	59.6*	107.1	25.8	20.6
Error	8	12.7	76.5	125.8	37.8
Fertiliser levels(C)	2	19.6	71.6	14.8	7.6
AC	2	24.4	13.4	86.9	7.6
BC	4	34	32.5	50.1	42
ABC	4	52.5	19.3	72.9	42
Error	24	30.7	45.9	43.4	26

*- Shows significance at 5 %
**- Shows significance at 1%

Appendix 8c. Mean squares for stem & branches dry matter of two pigeonpea cultivar grown at Thika in the short rains 1989/'90 from the 17th week after planting to 23th week when NPP 670 was harvasted

Source	df	Mean squares of stem &branches dry matter			
		week 17	week 19	week 21	week 23
Replicate	2	18	10.5	71.8	16.7
Cultivar (A)	1	563.2	367.1	1647.1*	3057.4**
Error	2	42.7	102.4	19.9	9.1
Fertiliser(B)	2	44.8	234.3**	64.1	89.6
AB	2	1.4	34.1	11.6	13.7
Error	8	23.9	25.1	79.1	46.4
Fertiliser levels(C)	2	280.1**	243.2**	52.8	50.6
AC	2	31.6	6.1	24.6	8.4
BC	4	33.8	56.3	56.3	97.3
ABC	4	1.4	61.6	56.8	91.8
Error	24	31.4	22.8	32.2	27.5

*- Shows significance at 5 %
** Shows significance at 1%

Appendix 8d. Mean squares for pods dry matter of two pigeonpea cultivars grown at Thika in the short rains 1989/'90 from the 17th week after planting to 23th week when NPP 670 was harvasted

Source	df	Mean squares of pods dry matter			
		week 17	week 19	week 21	week 23
Replicate	2	18	10.5	71.8	16.7
Cultivar (A)	1	563.2	367.1	1647.1*	3057.4**
Error	2	42.7	102.4	19.9	9.1
Fertiliser(B)	2	44.8	234.3**	64.1	89.6
AB	2	1.4	34.1	11.6	13.7
Error	8	23.9	25.1	79.1	46.4
Fertiliser levels(C)	2	280.1**	243.2**	52.8	50.6
AC	2	31.6	6.1	24.6	8.4
BC	4	33.8	56.3	56.3	97.3
ABC	4	1.4	61.6	56.8	91.8
Error	24	31.4	22.8	32.2	27.5

*- Shows significance at 5 %
** Shows significance at 1%

Appendix 8e. Mean squares for total dry matter of two pigeonpea cultivars grown at Thika in short rains 1989/'90 from the 17th week after planting to to 23rd when NPP 670 was harvested

Source	df	Mean squares of total dry matter			
		week 17	week 19	week 21	week 23
Replicate	2	18	10.5	71.8	16.7
Cultivar (A)	1	563.2	367.1	1647.1*	3057.4**
Error	2	42.7	102.4	19.9	9.1
Fertiliser(B)	2	44.8	234.3**	64.1	89.6
AB	2	1.4	34.1	11.6	13.7
Error	8	23.9	25.1	79.1	46.4
Fertiliser levels(C)	2	280.1**	243.2**	52.8	50.6
AC	2	31.6	6.1	24.6	8.4
BC	4	33.8	56.3	56.3	97.3
ABC	4	1.4	61.6	56.8	91.8
Error	24	31.4	22.8	32.2	27.5

*- Shows significance at 5 %
**-Shows significance at 1%

Appendix 8f. Mean squares for leaf area ratio of two pigeonpea cultivars grown at Thika in short rains 1989/'90 from the 17th week after planting to to 23rd when NPP 670 was harvested

Source	df	Mean squares of leaf area ratio			
		week 17	week 19	week 21	week 23
Replicate	2	18	10.5	71.8	16.7
Cultivar (A)	1	563.2	367.1	1647.1*	3057.4**
Error	2	42.7	102.4	19.9	9.1
Fertiliser(B)	2	44.8	234.3**	64.1	89.6
AB	2	1.4	34.1	11.6	13.7
Error	8	23.9	25.1	79.1	46.4
Fertiliser levels(C)	2	280.1**	243.2**	52.8	50.6
AC	2	31.6	6.1	24.6	8.4
BC	4	33.8	56.3	56.3	97.3
ABC	4	1.4	61.6	56.8	91.8
Error	24	31.4	22.8	32.2	27.5

*- Shows significance at 5 %
**- Shows significance at 1%

Appendix 9a. Mean squares for leaf area of Katheka grown at Thika in short rains 1989/'90 from the 25th week after planting to harvest time (45th week)

Source	df	Mean squares of leaf area						
		week 25	week 27	week 29	week 33	week 37	week 41	week 45
					X10,000			
Replicate	2	231.3	61.6	230.1	22.4	544.6	114.2	34.1
Fertiliser(A)	2	13.1	29.7	132.2	129.1	46.8	38.6	25.6
Error	4	144.9	10.2	403.1	228.9	265.6	71.3	10.4
Fertiliser levels(B)	2	6.9	81.7	78	128.4	8.5	3.7	14.5
AB	4	34.4	15.3	72	57.5	56.9	25.9	13.7
Error	12	52.9	13.3	159.2	108.2	29.7	30.9	12.9

*- Shows significance at 5 %

** Shows significance at 1%

Appendix 9b. Mean squares for leaf dry matter of Katheka grown at Thika in short rains 1989/'90 from the 25th week after planting to harvest time (45th week)

Source	df	Mean squares of leaf dry matter						
		week 25	week 27	week 29	week 33	week 37	week 41	week 45
Replicate	2	1017.7	87.2	223.1	64.6	999.2	438	164.3
Fertiliser(A)	2	67.9	97.1	115.1	296.1	262.4	568.7	60
Error	4	438.8	7.8	1033.3	596.4	1313.5	669.3	27.8
Fertiliser levels(B)	2	21.2	233.7	239.7	529.2	24.2	44.4	10
AB	4	111.6	34.7	324.2	350.2	215.1	60.9	40.4
Error	12	177.8	40.3	565.6	244.9	99.6	171	40.2

*- Shows significance at 5 %

** Shows significance at 1%

Appendix 9c. Mean squares for stem &branches dry matter of Katheka grown at Thika in short rains 1989/'90 from the 25th week after planting to harvest time (45th week)

Source	df	Mean squares of stem & Branches dry matter						
		week 25	week 27	week 29	week 33	week 37	week 41	week 45
Replicate	2	19987.3	2250.6	2325.2	982.3	12943.9	7734	31823.7
Fertiliser(A)	2	1987.1	546.7	13191.7	1299.9	536.7	38211.1	3426.7
Error	4	2253.4	1079.1	2165.6	657.1	16788.5	13155.6	17205
Fertiliser levels(B)	2	1235.2	2091.7	11244.3	2539.1	4285.9	617.4	8005.8
AB	4	735.2	174.3	4489.8	513.1	10431.7	3241	17646.4
Error	12	2610.1	654.3	7950.4	1467.4	3963.2	17037	13759.2

Appendix 9d. Mean squares for pods dry matter of Katheka grown at Thika in short rains 1989/'90 from the 25th week after planting to harvest time (45th week)

Source	df	Mean squares of pods dry matter		
		week 37	week 41	week 45
Replicate	2	145.3	13589.1	24.6
Fertiliser(A)	2	40.1	3152.8	2274.2
Error	4	165.2	10288.2	2935
Fertiliser levels(B)	2	69.3	2012.9	1141.9
AB	4	284.3	347.1	2099.3
Error	12	84.5	3183.8	2561

Appendix 9e. Mean squares for total dry matter of Katheka grown at Thika in short rains 1989/'90 from the 25th week after planting to harvest time (45th week)

Source	df	Mean squares of total dry matter						
		week 25	week 27	week 29	week 33	week 37	week 41	week 45
Replicate	2	29895.3	1840.9	2907.3	771.3	15824.7	44524.3	35074.5
Fertiliser(A)	2	2715.1	184.4	14276.1	2622.9	464.6	74368.8	11814.8
Error	4	4604.3	1203	3713.8	1642.6	20257.8	50526.6	27991.9
Fertiliser levels(B)	2	1514.6	3720.1*	14472.2	4893.8	4999.2	2655.8	12262.2
AB	4	1375.4	311.9	7019.5	1302.2	14015.6	3874.4	31815.5
Error	12	3976.9	778.8	10679.9	2050.6	4870.3	29746.3	26833.5

Appendix 9f. Mean squares for leaf area ratio of Katheka grown at Thika in short rains 1989/'90 from the 25th week after planting to harvest time (45th week)

Source	df	Mean squares of leaf area ratio						
		week 25	week 27	week 29	week 33	week 37	week 41	week 45
Replicate	2	102.2	119.2	85.6	5.1	156.6	26.1	2.9
Fertiliser(A)	2	101.4	28.8	154.6	66.8	22.7	0.1	3.2
Error	4	84.6	12.8	60.6	124.9	73.4	2.1	2.9
Fertiliser levels(B)	2	21.2	3.1	8.9	39.3	23.6	0.8	1
AB	4	21.1	3.4	5.6	26.9	49.8	4.7	2.8
Error	12	21.2	15.3	27.1	73.1	33.6	3.3	3.4

*- Shows significance at 5 %
** -Shows significance at 1%

Appendix 10. Mean squares of some parameters of two pigeonpea cultivars grown at Machakos in the long rains 1989

Source	df	Mean squares		
		Days to 50% flowering	plant height at flowering	No. of primary branches
Replicate	2	7.1	56.4	5
Cultivars (A)	1	12360.9**	20994.7**	10.7**
Error	2	16.1	28.2	0.7
Fertiliser(B)	2	48.7*	51.6	4
AB	2	32.4	5.2	5
Error	8	9.9	23.5	1.9
Fertiliser levels(C)	2	34.9	0	1.9
AC	2	0.5	14.9	1.5
BC	4	24.7	18.5	0.2
ABC	4	57.3	94.3	1.5
Error	24	23.7	17.8	2

*- Shows significance at 5 %

**- Shows significance at 1%

Appendix 11. Mean squares growth and harvest parameters of NPP 670 grown at Kiboko for two seasons (long rains 1989 and short rains 1989/'90)

Source	df	Mean squares							
		Days to 50% flowering	plant height at flowering	No. of primary branches	Days to 50% maturity	Plant height at harvest	stems DM at harvest	Pods weight per plant	No. of pods perplant
Replicate	2	22.3	48.5	1.7	0.7	40.6	3023.7	2050.5	1193.3
Season (A)	1	92421.4**	4641.8**	613.4**	107914.7**	36858.4**	234814.9**	79.4	76.1
Error	2	37.6	113.3	4.2	1.1	46.3	1923.7	2806.6	1606.9
Fertiliser(B)	2	16.3	429.5**	3.6	0.4	126.9*	4171.7**	5995.3**	3641.1**
AB	2	18.4	32.8	7.4	0.6	80.5	2002.9	3627.3	1763.1
Error	8	30.8	36.1	3.8	1.2	27.1	463.6	592.1	393.4
Fertiliser levels(C)	2	7.9	14.2	15.8	1	8.4	670.9**	2255.3*	1499.7*
AC	2	6.7	2.3	4.6	0.4	25.1	1886.7**	3764.4	2226.8
BC	4	7.9	9	3.3	0.7	27.7	862.8	2092.6	1480.8
ABC	4	9.1	16.8	3.2	0.5	6.5	103.8	1237.1	439.5
Error	24	4.1	52.5	4.3	0.6	32.2	104.6	549.7	345.5

*- Shows significance at 5 %

**- Shows significance at 1%

Appendix 11, (Cont.). Mean squares growth and harvest parameters of NPP 670 grown at Kiboko for two seasons (long rains 1989 and short rains 189/'90)

Source	df	Mean squares				
		No. of seeds per pod	Grain weight per plant	100 seed weight	Grain yield (Kg/ha)	Harvest Index
Replicate	2	0.03	857.9	0.4	1694630.2	0.016
Season (A)	1	.14*	0.4	10.9**	840.9	0.464**
Error	2	0.02	1041.8	0.4	2057696.5	0.009
Fertiliser(B)	2	0.01	2336.3**	0.7	4614333.1**	0.001
AB	2	0.04	1495.5	2.5	2953776.1	0.001
Error	8	0.01	230	0.5	454409.1	0.001
Fertiliser levels(C)	2	0	880.1*	0.4	1738404.1*	0.001
AC	2	0.02	1519.7*	1.1	3001791.6	0
BC	4	0.01	960.8	0.4	1898111.1	0.003
ABC	4	0.03	410.8	2.1	811279.9	0.002
Error	24	0.02	209.4	0.7	413739.7	0.001

*- Shows significance at 5 %

**- Shows significance at 1%

Appendix 12. Mean squares of growth and harvest parameters of two pigeonpea cultivars grown at Thika in the short rains 1989/'90

Source	df	Mean squares							
		Days to 50% flowering	plant height at flowering	No. of primary branches	Days to 50% maturity	Plant height at harvest	stems DM at harvest	Pods weight per plant	No. of pods perplant
Replicate	2	17.9	359.5	40.9	2.3	188.8	85.6	502.8	127.9
Cultivars (A)	1	190341.4**	762268.3**	148**	268252.5**	809651.6**	1144509.2**	40939.9**	13949.1**
Error	2	28.7	171	4	5.9	228.5	108.9	1098.5	466.8
Fertiliser(B)	2	1.9	62.3	1.2	0.3	23.2	2785.2	232.4	162.1
AB	2	3.1	93.3	2.1	1.2	67.4	3001.1	106.8	107.4
Error	8	2.9	135.5	6.3	1	86.3	4719.8	976.5	251.6
Fertiliser levels(C)	2	6.4	19.4	2.4	3.2*	6.5	1335.2	238	180.2
AC	2	1.7	65	4.2	0.1	40.1	844	258.4	142.3
BC	4	0.3	64.4	1.1	0.8	121	797.6	182.9	102.4
ABC	4	0.8	85	1.9	0.7	146.4	810	201.6	72.5
Error	24	3.9	60.5	2.1	0.6	48.4	1280.6	187.8	92.3

*- Shows significance at 5 %

**- Shows significance at 1%

Appendix 12 (Cont.). Mean squares of growth and harvest parameters of two pigeonpea cultivars grown at Thika in the short rains 1989/'90

Source	df	Mean squares				
		No. of seeds per pod	Grain weight per plant	100 seed weight	Grain yield (Kg/ha)	Harvest Index
Replicate	2	0.02	164.6	2.1	320662.3	0
Cultivars (A)	1	24.6**	18508.2**	630.1**	36466388.3**	0.359**
Error	2	0.07	385.5	1.1	767585.8	0.003
Fertiliser(B)	2	0	42.6	0.3	74572.2	0
AB	2	0.03	15.6	0.9	42989	0.001
Error	8	0.03	301.5	2	594889.2	0.001
Fertiliser levels(C)	2	0.03	55.5	0.4	1288109	0.001
AC	2	0	55.2	2	91121.8	0.001
BC	4	0	72.7	0.8	145621.6	0
ABC	4	0.01	92.3	1.6	178687.4	0.001
Error	24	0.01	92.9	0.5	183790.9	0.001

*- Shows significance at 5 %

**- Shows significance at 1%

Appendix 13. Mean squares of soil characteristics of soil samples taken at Kiboko

Source	df	Mean squares			
		Organic carbon (percent)	Carbon:Nitrogen (ratio)	Available phosphorus (ppm)	CEC (Meq./100 g soil)
Replicate	1	0.019	2.7	0.9	47.4
Season (A)	1	1.555**	74.2**	4309.8**	0
Depth (B)	1	1.879**	28**	18134	6
AB	1	0.029	11.9	1820.5	122.7
Fertiliser (C)	2	0.022	1.1	3356.8**	8.9
AC	2	0.069	1.3	1784.7	16.7
BC	2	0.002	2.8	1097	11.2
ABC	2	0.025	3.7	289.3	29.8
Fertiliser levels (D)	2	0.055**	1.3	839.1	99.9**
AD	2	0.046	3.9	78.6	11.6
BD	2	0.03	1.3	261.2	45.8
ABD	2	0.007	1.3	13.9	14.8
CD	4	0.021	0.9	413	21.3
ACD	4	0.04	3.3	25	6.6
BCD	4	0.003	1.4	331	34.6
ABCD	4	0.022	1.1	44.3	17.6
Error	35	0.007	0.9	6.2	17.4

*- Shows significance at 5%
**- Shows significance at 1%

Appendix 14. Mean squares of soil characteristics of soil samples taken at Thika

Source	df	Mean squares: Organic carbon (percent)	Carbon:Nitrogen (ratio)	Available phosphorus (ppm)	CEC (Meq./100 g soil)
Replicate	1	0.038	2.7	2.9	31.3
Cultivar (A)	1	0.907**	1.1	15.3**	67.8
Depth (B)	1	7.605**	7.7*	1938.6**	105.3*
AB	1	0	0.1	8.5	0.9
Fertiliser (C)	2	0.022	0.2	245.3**	8
AC	2	0.229	5.6	47.3	18.8
BC	2	0.259	10.1	105.1	21.4
ABC	2	0.042	3.9	6.1	37.6
Fertiliser levels (D)	2	0.067	0.9	113.2**	48.7
AD	2	0.071	2.1	38.4	18.8
BD	2	0.026	4.3	68.5	80.4
ABD	2	0.011	0.3	30	21.4
CD	4	0.036	1.9	96.4	28.9
ACD	4	0.028	0.6	7	17.5
BCD	4	0.063	3.6	57.7	65
ABCD	4	0.019	1.7	5.1	26.6
Error	35	0.022	1.9	0.5	20.9

*- Shows significance at 5%

**- Shows significance at 1%