# COWPEA GROWTH IN RELATION TO NUTRIENT ACCUMULATION AND DISTRIBUTION

BY

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# DECLARATION

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

10-12-87

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DATE

This thesis has been submitted for examination with my approval as a University supervisor.

18/12/87

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Professor Kimani Waithaka
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Date

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# TABLE OF CONTENTS

# LIST OF TABLES

# LIST OF FIGURES

# COWPEA GROWTH IN RELATION TO NUTRIENT ACCUMULATION AND DISTRIBUTION

## ABSTRACT

The effect of different sampling dates on dry matter production grain yield and mineral distribution and accumulation in two cowpea varieties, 'Katuli 107' and 'MM4' were studied in a deep sandy loam soil of Murinduko, sub-station of Embu Agricultural Research Station.

Results from this study indicated that there were varietal differences in dry matter production and grain yield. Katuli maintained superiority in these two parameters over 'MM4'. Grain yield in Katuli was attributed to the high number of pods per plant and higher number of seeds per pod. High dry matter production in 'Katuli '107' was mainly attributed to the leaves which accounted for over 60% of the total dry matter in most of the sampling periods.

The concentration of N, P, K, Ca, Mg and S showed significant changes in the various sampling times in the two varieties. Except for P, the period of active accumulation of these mineral nutrients occurred between flowering and mid-pod fill (5-8 weeks after emergence). Phosphorus active accumulation occurred between seedling and flowering. 'Katuli 107' accumulated more of these nutrients than 'MM4' except for sulphur.

The results also indicated that the leaves accumulated the highest amount of the mineral nutrients. At mid pod fill the leaves contained 60-70%, stems contained 20-25% and roots contained 7-12% of the total nutrient content in the plant in both varieties. This high nutrient content in the leaves decreased for most nutrients after mid pod fill. This decrease suggested a mobilization phenomenon of nutrients from the leaves to the developing seeds. The results also showed that cowpea varieties which have ability to accumulate more nutrients produce higher dry matter and grain yields.

# INTRODUCTION

Cowpea (*Vigna unguiculata* (L) Walp) commonly known as Kunde, Southern pea, Catjang etc. belongs to the Leguminosae family. It is one of the ancient cultivated beans used as a food source. The origin of the crop has long been disputed upon because of the occurrence of the different cultivated species in different regions of the world i.e. sub-species *unguiculata* in Africa, *susquipedalis* in South East Asia and *cylindrica* in India. However, all the three species can be found in one region. There is also lack of archaeological data to support the origin of cowpeas but due to its widespread in Africa and the occurrence of its wild types, it is now believed by many scientists that cowpea originated in Africa (Summerfield *et al.*, 1974).

Cowpea is widely distributed in the tropics and sub-tropics and it is the third important legume in Africa south of Sahara (Daisy Kay, 1979). It is a hot weather crop adopted to arid and semi-arid regions and preferring daily temperatures between 20 and 30$^{o}$C (Minchin *et. al.*, 1981). It grows fairly well in warm to hot areas where most of the other legumes like soyabean *(Glycine max)* and kidney bean *(Phaseolus vulgaris)* do not.

Africa produces about 75% of the world's cowpea with Nigeria, Upper Volta, Niger and Uganda being the most important producing countries. Nigeria alone produces more than 60% of the world's cowpeas (Rachie, *et al.*, 1974).

In Kenya, it is estimated that the area under cowpea production is about 1800 ha but this figure excludes cowpeas grown in home gardens for domestic use (Muruli, *et al.,* 1980). Cowpea is commonly intercropped with other crops like sorghum, maize and pigeon peas. About 85% of the total area under cowpea cultivation in Kenya is in marginal areas of Eastern Province, while the remaining 15% is distributed in Nyanza and Western Provinces (Muruli *et al.,*1980).

Cowpea contains about 24% protein and 57% carbohydrate (Summerfield *et al.,* 1974). It therefore offers a cheap and inexpensive source of protein to the rural population which cannot afford animal proteins. Different communities in different parts of the world utilise different parts of the cowpea as a source of food. In some parts of Nigeria, they prefer to use the young tender pods, while in East Africa most people utilise the tender green leaves as a vegetable but by and large the majority of cowpeas are consumed as seeds.

Over 75% of Kenya is either arid or semi-arid and therefore the introduction of well adopted cultivars of cowpeas in these areas would go along way in alleviating recurrent food shortage in the country. The Sessional Paper No. 4 (1980) on Food Policy expresses the importance of identifying such crop cultivars like cowpea and pigeon peas that would do well in the semi-arid and arid areas. This would allow the country to be self sufficient in its food requirements and also to cope up with the high population growth rate.

Very little research work has been done on cowpeas in Kenya and the existing research projects are still in their early stages of development. Bearing in mind that cowpea is the second most important grain legume in Kenya and ranks second in production area to beans *(Phaseolus vulgaris)*, this study wa conducted to investigate the relationship between cowpea growth and nutrient accumulation and distribution in a semi-arid area.

# LITERATURE REVIEW

## Historical Background

Cowpea (*Vigna unguiculata* (L) Walp) has been cultivated or gathered in tropical Africa since pre-historic times and must have reached Egypt, Arabia and India very early since these were recorded in Sanskritic times (Purseglove, 1968). The early Greeks and Romans also knew of cowpea as they were introduced by Spaniards into West Indies in the sixteenth century. They were not introduced to the new world until late seventeenth century (Sellschop; 1962). At present the crop is grown universally in the tropical and sub-tropical zones of the world and provides food for both human and livestock.

There has been a great deal of discussion on the origin of the crop. Much of the confusion surrounding the origin of cowpeas results from the occurrence of many different cultivated species in different regions i.e. *unguiculata* in Africa, *cylindrica* in Asia and *Sesquipedalis* in South Asia but all three can be found in any region (Westphal, 1974). One of the strongest lines of evidence favouring Africa as the origin of the crop is the widespread distribution of the wild cowpea (Decandole, 1959).

## Botany

Cowpea is a member of the family *Papilionaceae*. the largest of the three division of *Leguminosae* (F' 1963).

Cultivated cowpea is usually a glabrous annual herb showing great variation according to cultivar, climatic and soil conditions. Trailing, climbing bush and erect forms of cowpeas exist. Most cultivars are indeterminate i.e. produce flowers and seeds over a long period but some arre determinate producing flowers and seeds within a very short period (Daisy, 1979). The tap root is well developed with numerous spreading laterals near the soil surface. The root nodules are smooth and spherical, about 5mm in diameter and are numerous on the tap root and its main branches but sparse on the smaller roots.(Summerfield and Huxley, 1973).

The leaves are alternate, trifoliate with a petiole measuring 5 - 25 cm in length. The leaves are usually dark green and ovate acute in shape. The first pair of leaves above the cotyledonary node is simple and opposite but exhibit considerable variation in size and shape. The trifoliate leaves arise alternately and the terminal leaf is frequently longer and of great area than the asymmetrical laterals (Faris, 1965).

There is a range of leaf shapes and sizes from linear, lanceolate to orate. The leaf orientation is usually planophile in cultivated varieties, becoming more erectophile in the wild types (Summerfield and Huxley, 1973).

The inflorescence is an unbranched auxillay raceme with a long peduncle. The flowers are borne in alternate pairs and although numerous pairs may occur per inflorescence frequently only the first two will set fruit. The flowers which are conspicuous and self pollinated are borne on short pedicel and may be white, dirty yellow, pale blue, pink or violet. They commonly open early in the day and close around mid-day. After opening once, the flower wilt and collapses (Daisy, 1979).

The pods can vary greatly in size, shape colour and texture. They may be linear, crescent shaped or coiled and are normally 15 - 45 cm long. They are indehiscent, usually yellow when ripe and normally contains 8 - 20 seeds (Daisy Kay, 1959).

The seeds also vary considerably in size, shape and colour but on the overall they are 2 - 12 mm long and weigh 5 - 30 g per 100 seeds. The seeds are normally white, creamy white or black while the testa may be smooth, wrinkled, red, brown, black and variously speckled. The seeds are also non-endospermous and germination is epigeal (Summerfield and Huxley, 1973).

## Dry Matter Accumulation

Karlem *et al.* (1980) working on dry matter accumulation in winter wheat found that there was a steady accumulation of dry matter after plant emergence both in the crown and aerial portion of the plant. They noted that dry matter accumulation followed a sigmoid pattern from germination to maturity. It increased most rapidly at flowering and later declined because of senescence. There was an increase in dry matter in the stem fraction of the wheat until physiological maturity and then declined because of dessication. They further noted that the head accounted for approximately 46% of the total dry matter of physiological maturity.

Littleton *et al.* (1979) in their study of growth and development of cowpeas indicated that the increases in dry matter was proportional to the intercepted radiation. They also found that the period of rapid increase in pod weight was quite short (about 20 days). The dry weights of the roots increased slightly from the date of emergence, and almost levelled off up to 65 days after emergence. They further noted that the dry matter of the stem and petiole increased steadily up to 50 days after emergence and then started to decrease. The leaf dry matter was found to increase rapidly after the 30th day after emergence, then levelled off between 43 and 53 days and then declined sharply. The pod dry weight increased very sharply from 35th day after emergence to the 55th day and thereafter decreased. The results from this study indicated that the major requirement for higher yield is a large plant weight. They also observed that most of the increase in dry matter occurred before or during pod filling stage.

Steel (1972) concluded that the highest cowpea yields are obtained when young leaves are continuously being produced during and after pod filling stage. This is because photosynthetic activity declines with age and also young leaves act as a temporary sink of N later used in the pods.

Eaglesham *et al.* (1977) found that the highest dry matter accumulation was in the effectively nodulating cowpea. They also noted that even after applying very high rates of N to the non-nodulating cowpea, the total dry matter was highest in the effectively nodulating cowpea.

Henry *et al.* (1978) working on three indeterminated bean (*Phaseolus vulgaris*) cultivars noted that the erect beans accumulated dry matter faster and more sharply than vining and indeterminate types. On the 60th day after emergence the erect bean had accumulated 94% of the dry weight compared to 79% of vining cultivars, but there was no difference in total dry matter.

Egli and Legget (1973) found that determinate and indeterminate soyabean cultivars had reached 84 and 64% of their stem height but only 67 and 30% of the stem dry weight, respectively by initial flowering. They also observed that there was no difference in dry matter portioning pattern between determinate and indeterminate soyabean cultivars. It therefore means that indeterminancy does not directly influence yield potential if other factors like maturity dates and spacing are equal.

Afolabi (1980) working with two cowpea varieties (Local Brown and Ife Brown) reported that the total dry weight production was highest in the Local Brown but Ife Brown produced higher seed yield. He concluded that under conditions of higher productivity and also the ability to fill those pods.

Jacques *et al.* (1975) found that the first 20 to 30 days after emergence of grain sorghum, plants grew slowly, then growth and dry matter production proceeded rapidly and nearly linearly until physiological maturity (maximum dry matter production). The sorghum plant consisted almost entirely of blades and sheaths until 30 - 40 days after emergence. This was the same period when the culms started to elongate and gained weight rapidly. Maximum vegetative weights in the sorghum plant were reached as soon as the culms ceased gaining weights. Growth after that was entirely on grain production. They also noted that during grain formation and development culms lost dry weight but it increased again just before physiological maturity. This loss in weight was thought to be due to a translocation of material out of the culms into developed grain which was still gaining weight rapidly.

In pigeon peas it was reported by Dalal (1980) that the grain represented about 30% of the total dry matter produced. He also observed that the proportion of the total dry matter accumulated after three months (flowering stage) did not exceed 50% and therefore most of dry matter was accumulated in the last month of growth (This pigeon pea took only 4 months to mature).

In capsicum, leaves contributed most of the dry weight through 42 days after transplanting, then decreased at 56 days and thereafter represented only 25% of the total dry matter produced by the plant (Miller *et al.*, 1979). They further noted that the proportion of the dry matter contributed by stems was minimal near the time of commercial harvest. They also found an increase in dry matter after 84 days and this was attributed to the renewal of vegetative growth following fruit removal.

In sunflower, Olumbe (1974) noted that dry matter apportioned to various parts of the plant increased with plant growth and reached a maximum some weeks before harvesting and then begun to drop. He further observed that the losses in dry matter at harvest time were greatest in petioles and leaves and the roots. These losses (especially with regard to leaves and petioles) were largely due to physiological loss of the plant parts concerned. One important factor he noted was that the loss of dry matter in the stem occurred at a period when the seed had reached their maximum dry weights and therefore rules out a hypothesis of material transfer from the stem to the rapidly developing seeds as postulated by Van Eijnatten (1971).

Van Eijnatten (1971) reported that the sunflower seeds increased in dry matter from the 14th to the 20th week. Thereafter the seed dry matter began to decrease until harvest time and this loss was mainly attributed to birds damage. Olumbe (1974) also found that increasing levels of N in sunflower depressed seed dry matter while phosphorus had the opposite effect. The depressing effect N had on seed yield resulted largely from the increasing incidence of empty heads in the centre as N rates were increased.

Work carried out by Halbrooks and Wilcox (1980) in tomatoes showed that the whole dry matter weight accumulation was relatively slow in the initial stages of plant growth but from 56 - 70 days interval there was a rapid accumulation of dry weight primarily due to vegetative development. During the period of marked fruit expansion the increase in the whole plant weight was attributed to dry matter accumulation in the fruit. They further observed that in the final stage of development (fruit maturation) there was a significant weight gain in the fruit but not in the vegetative portions. The whole plant dry weight accumulation was found to be nearly constant from 56 to 165 days interval and averaged 5 - 6 gm per day per plant.

Eaglesham *et al.* (1977) observed that the major part of dry matter accumulation occurred after flowering in cowpeas. During this productive period they noted that the plant accumulated three times more dry matter than during vegetative growth. By the final harvest mature fruit represented 63% of the post flowering dry weight increament. On the whole they found that the total leaf dry weight appeared to remain almost static after mid pod fill. It was further interesting to note that the nodule weight per plant increased less rapidly throughout the vegetative growth than during early fruit development but declined sharply after mid pod fill as nodule senesced. As the fruit matured there was a small net decrease (7%) in total vegetative dry weight of the pre-flowering stems plus branches.

## NUTRIENT ACCUMULATION AND DISTRIBUTION

### Nitrogen (N)

#### Forms absorbed

Nitrogen is absorbed by plants mostly in form of nitrates ($NO_3^-$). Small quantities are however absorbed as ammonium ions ($NH_4^+$). Paddy rice absorbs the Nitrogen mostly as ammonium ions (Agarwala and Sharma, 1976).

#### Functions

Nitrogen is a major structural constituent of the cell. It is also an essential part of chlorophyll molecule and therefore useful in harvesting light energy. It is also used in the synthesis of nucleic acid which transfers genetic information during protein synthesis (Tisdale and Nelson, 1975).

#### Accumulation and Distribution

Hanway and Webber (1971) noted that total N accumulation in the soyabean during the growing season followed a pattern similar to that of dry matter accumulation in the plants. Accumulation was slow early in the season and increased at an increased rate up to 50 days after emergence. In the leaves they observed that N accumulated steadily until the period of seed development when its accumulation started to go down.

Reichman *et al.* (1959) found that the nitrogen percentages in maize leaves sampled at pollination were highly correlated with yields and with total nutrient uptake values at harvest.

Eaglesham *et al.* (1977) reported that the nitrogen source of cowpea plant was mainly through symbiotic fixation and contributed 83% of the plants N. The very high N content in cowpea nodules (93-96%) at all stages of growth lead them to conclude that nodules largely satisfied their own nitrogen requirement once fixation was initiated. They finally observed that the nitrogen accumulation per plant was similar to dry matter accumulation and hence the maximum rate of nitrogen assimilation occurred after flowering.

Obigbessan and Agboola (1978) reported that N constituted the main nutrient element absorbed by the leaves in yams. Nitrogen concentration was found to increase steadily attaining a peak in mid July and decreased thereafter. The concentration of Nitrogen in the tuber ranked second after phosphorus.

The nitrogen concentration in tomatoes was higher in the leaf tissue than in fruit or branch tissues. The branch leaf nitrogen was found to decrease slightly as the season progressed (Halbrooks and Wilcox, 1980). They also noticed that the nitrogen accumulation in the whole plant increased sharply due to increased branch and leaf development. After 70 days from transplanting the tomatoes, nitrogen accumulation was primarily in the fruit.

Agarwala *et al.*, (1976) reported that wheat plants almost complete their N accumulation by anthesis and concluded that most of the N was remobilized from the stem and leaves to the inflorescence and there was little N uptake by the plant after flowering. Studies by Gregory *et al.* (1977) showed that in the developing cereal plant over 90% of the total N accumulated when the dry weight was only 25% of the final weight. He also concluded that uptake of nitrogen ceased when the plant entered the reproductive phase.

Spiers (1982) observed that nitrogen accumulation in blue berry was highest in the early sampling dates in the leaves then decreased throughout the growing season. He noted that nitrogen content of the leaf followed a cubic regression curve.

Karlem *et al.* (1980) found that the nitrogen content in the leaf samples of winter wheat decreased linearly as the plant matured. In the grain, the concentration of N was relatively constant from the end of flowering to physiological maturity.

Work carried out by Miller *et al.* (1979) in pepers showed that the total nitrogen uptake increased throughout the growing season except the last sampling dates presumably because of the abscised leaves. In the leaf petiole and stem the N concentration increased from 0 to 42 days interval then decreased for the remainder of sampling period. The fruit N was reported to have the highest in the young fruits, 42 days after transplanting. This declined sharply by the next sample then remained relatively constant.

Phosphorus (P)

Forms Absorbed

It is generally considered that plant absorb most of their phosphorus as the primary orthophosphate ion $H_2PO-_4$. Small amounts of the secondary orthophosphate ion $(H_2PO-_4$. Small amounts of the secondary orthophosphate ion $(H_2PO_4{}^{2}-)$ are also absorbed. The relative amount of these two ions which will be absorbed by the plants are affected by the pH of the medium surrounding the roots. Lower pH values will increase the absorption of $H_2PO-_4$ whereas higher pH values will increase the absorption of $HPO_4{}^{2-}$ (Tisdale and Nelson, 1975).

Functions

Phosphorus is a structural component of the membrane system of the cell, the chloroplasts and the mitochondria. It is a constituent of sugar phosphates, nucleic acids, nucleoproteins, purines, pyrimidine nucleotide and several co-enzymes e.g. N.A.D.P.thiamine pyrophosphate etc. (Agarwala and Sharma, 1976). An adequate supply of phosphorus early in the life of the plant is important in laying down the primordia for its reproductive parts (Nathan X.J., 1963). It has been observed that P deficiency results in an increased accumulation of free reducing sugars, suggesting an involvement of phosphorus in carbohydrate metabolism (Abrol *et al.*, 1977).

## Accumulation and Distribution

Miller et. al. (1979) found that accumulation of P in Bell peppers was continuous throughout the experimental period. After 28 days they noted that the leaves and petioles contained 82% while the stem contained 18% of the total P. At 84 days after transplanting, 30% of the total P was in leaves and petioles, 12% in stem and 58% in fruit.

In tomatoes, the P concentration of the leaf and branch tissues was nearly equal at all sampling dates. There was a general decrease in P concentrations in the vegetative portion during the later season (Halbrooks and Wilcox, 1980). The P concentration in fruit was reported to be generally higher at all growth stages than the vegetative P. Karlem and Whitney (1980) reported that the P content in the leaves of winter wheat decreased linearly as the plant matured, whereas the concentration of P in the grain was relatively constant from the end of flowering to physiological maturity. They further observed that the concentration of P in the whole plant decreased slowly at the early stages of growth. The concentration of P in the stem was found to decrease at flowering and tended to stay relatively constant until physiological maturity.

In a study on nutrient flux in cowpeas, Adeptu (1979) found that P accumulation was greatest when the plant was 5 days old, decreased rapidly with the age of the plant to about 28 days old, increased again and remained relatively high between 40 and 50 days. He concluded that the availability of P to cowpea was critical at early stages of growth (about 10 days after emergence and during flowering stage. He however noted that P availability during the early flowering stage was more critical than the early stages of growth.

Work carried out by Spiers (1982) on blue berry showed that P concentration on the leaves was highest in the early growing season and then decreased rapidly until harvest. The P concentration levelled off during the harvest season and then increased slightly through the remainder of the growing season.

Potassium (K)

Forms Absorbed

Potassium is absorbed as the potassium ion ($K^+$) and is found in the soil in varying amounts but the fraction of the total potassium in the exchangeable complex or the available form is usually small (Abrol *et al.*, 1977).

## Functions

Potassium plays an important role in the maintenance of cellular organisation by regulating the cellular membranes and keeping the protoplasm in proper degree of dehydration by stabilizing the emulsions of highly colloidal particles (Agarwala and Sharma, 1976). Apart from organizational and electrochemical role, potassium plays a catalytic role by activating a number of enzymes by catalysing the incorporation of amino acids in protein and the synthesis of peptide bonds. Potassium is also known to increase the resistance to moisture stress, heat and diseases in plants. However, the direct role of K in major metabolic processes in plants is not known. K is also reported to control stomatal movement (Abrol *et al.*, 1977).

## Accumulation and Distribution

Halbrook and Wilcox (1980) reported that K concentration of vegetative portions of tomato plant was higher in branches than in leaf tissues. The fruit K concentration was about 4.5% and was nearly constant as fruit development progressed to maturity. There was an accumulation of K up to 56 days in the vegetative tissues and after 70 days the accumulation was largely in the fruit. Whole plant accumulation of K persisted at a higher rate throughout the growing season.

Concentration of K in the leave in blue berry was high at the start of the growing season, and decreased to a low concentration during harvest. The changes in K leaf content fitted a cubic regression (Spiers, 1982).

Obigbessan and Agboola (1978) found that K was the most abundant mineral nutrient in yam tubers but was found in smaller concentration in leaves.

In Bell pepper Miller *et al.* (1979) noted that the concentration increased with time. At 28 days after transplanting, 80% of the K was contained in the leaves and petioles and 20% in the stem. At 84 days after transplanting they found that 34, 15 and 51% of the total K was contained in leaves and petioles, stems and fruit respectively. The highest K uptake occurred between 56 and 70 days after transplanting.

In soyabean, Hanway and Weber (1971) reported that the total plant accumulation of K was slow early in the season but later increased rapidly up to 50 days of growth. In the leaves K was found to increase steadily until the period of seed development when its accumulation started to go down.

The concentration of K in wheat leaves decreased linearly as the wheat plant matured while that of the whole plant decreased slowly at early stages of growth and rapidly at later stages of growth. The concentration of K in the wheat stem was relatively constant (Karlem and Whitney, 1980).

In cowpea, K accumulation followed similar pattern to that of P. K accumulation was greatest in the early stages of growth and decreased rapidly with the age of the plant (Adeptu, 1979). He further noted that the K concentration increased slowly after 28 days and remained relatively higher between 40 and 50 days after planting.

Calcium ($Ca^{++}$)

Forms Absorbed

Calcium is absorbed as calcium ions ($Ca^{+2}$). It is found in abundant quantities in the leaves of the plant that in some plant species it is precipitated as calcium oxalate (Jackson and Evans, 1962).

Functions

Specific physiological functions of calcium are not clearly defined. It is however necessary for cell elongation and development of meristematic tissues (Agarwala and Sharma, 1976). It is important in neutralising the charges on acidic molecules of phosphoric acid and those of organic acids e.g. citric, malic and oxalic acid which may become injurious to plant (Agarwala and Sharma, 1976). The role of $Ca^{++}$ in the formation of middle lamella has been disputed because even under severe $Ca^{++}$ deficiency the middle lamella still remains intact. Furthermore no calcium could be recovered after the hydrolysis of middle lamella (Jackson and Evans, 1962).

## Accumulation and Distribution

In sorghum, calcium concentration was much lower in the head than any other plant part and then in the blades calcium concentration increased after maximum blade dry weight was reached (Jacques *et al.*, 1975). During grain development, Ca concentrations were again higher in the blade than any other plant parts (Jacques *et al.*, 1975). They suggested that need for calcium in calcium pectate formation of mature leaf cell may have been responsible for the increased concentration in blades and culms. At physiological maturity they noted that an average of 40% of the total calcium taken up was in the blades.

In cowpeas the rate of absorption of calcium was higher during the first 40 days of growth and the highest concentration was in the leaves (Summerfield *et al.*, 1974). They further noted the nutrition effect of added calcium was often difficult to separate from its liming effect, which neutralized toxic elements or increased the availability of certain other elements in the soil.

Jacquinot (1967) showed that the balance between K, and Mg cations depended principally upon the age of the plant, the relative proportions remaining almost constant in the roots and stem but changing markedly in the leaves, primarily due to loss of K and progressive accumulation of calcium.

In the yams, the concentration of calcium ranked third after nitrogen but in one of yam species the concentration of calcium was highest in the leaves suggesting that the species was more efficient in recycling the nutrients (Obigbessan and Agboola, 1978).

Karlem and Whitney (1980) observed that concentration of calcium in the wheat leaves was similar to that of potassium and phosphorus. Calcium concentration in the leaves decreased linearly as the whole plant matured. They also noted that the concentration of calcium in the grain were relatively constant from the end of flowering to physiological maturity whereas the whole plant calcium concentration decreased slowly at early stages of growth and rapidly at later stages of growth.

In Bell peppers, Miller *et al.* (1979) reported that after 28 days after transplanting, 88% and 12% of Ca was contained in the leaves and stems, respectively. The highest Ca uptake was measured between 84 and 98 days, respectively.

### Magnesium (Mg)

#### Forms Absorbed

Magnesium is absorbed by plants in form of divalent ($Mg^{2+}$) ions. Minerals containing magnesium are biotite, chlorite, dolomite olivine etc. The mineral is mobile hence deficiency symptoms show in older leaves (Abrol *et al.*, 1977).

## Functions

Magnesium is a mineral constituent of the chlorophyll molecule. It is known to play a catalytic role as an activator of a number of enzymes most of which are involved in carbohydrate metabolism, phosphate transfer and decarboxylation. Magnesium is also important in citric acid cycle which is important in cell respiration (Nathan X.J., 1963). It has recently been shown to be an essential constituent of polyribosomes the key organelle involved in protein synthesis. Magnesium is a constituent part of the chromosome which are bearers of hereditary characters (Agarwala and Sharma, 1976).

## Accumulation and Distribution

In sorghum the magnesium concentration was higher in the culms and sheaths and remained highest in sheaths throughout the growing season. The greater percentage of the total amount of magnesium were in vegetative parts (Jacques *et al.*, 1975). It was also observed that magnesium concentrations were lower in the head than in any other plant part. In the grains, the magnesium concentration was found to decrease as the plant neared physiological maturity.

In tomatoes, Halbrooks and Wilcox (1980) reported that the magnesium concentration was higher in the leaves than in the branches. Branch magnesium concentration was relatively constant at 0.6% whereas the concentration in the leaf tissue increased from 0.8 in early development to 1.1% at maturity. Magnesium accumulation in the whole plant followed that of dry matter with most of the magnesium in the leaves. At maturity, 20% of the total magnesium was found to be in the fruit.

At 28 days, 80% of the magnesium was contained in the leaves and petioles and 20% in stems in bell peppers (Miller *et al.*,1979). The highest magnesium uptake rate of 0.63 kg/ha/day were measured between 56 and 70 days after transplanting. They concluded that growth processes were therefore at a very high level by 28 days after transplanting and continued so for at least six weeks.

In blue berry, the seasonal changes in magnesium content in the leaves were small with an overall variation of 0.046%. Magnesium content was lowest during harvest and tended to increase late in the growing season. The leaf magnesium followed a quadratic regression (Spiers, 1982).

Jacquinot (1967) in his study of four cowpeas varieties noted that the rate of magnesium uptak increased during the growth of a range of tropical cow a cultivars and was greater in the latest third of :he growing season. He further observed that the foliar magnesium concentration were higher in the more productive type but the final concentration in the different organs showed no significant overall variation. He noted that specific responses to magnesium application in terms of vegetative growth or seed yield are not known to have been reported in cowpeas.

In wheat magnesium concentration in the whole plant and in the leaves remained relatively constant throughout the growing season (Karlem and Whitney, 1980). Obigbessan and Agboola (1978) reported that magnesium was found in relatively small quantities both in leaves and tubers of yam plant.

### Sulphur (S)

#### Forms Absorbed

Plant roots almost exclusively absorb sulphur as the sulphate ion ($SO_4^{2-}$). However, some of the sulphur is taken in form of sulphur dioxide ($SO_2$) through the plant leaves (Jackson and Evans, 1962).

#### Functions

Sulphur is involved in the activation of a number of enzymes participating in the dark reactions of photosynthesis. it is required for the synthesis of the sulphur containing amino acids such as cysteine, cysteine and methionine (Tisdale and Nelson, 1975). The precise role of sulphur in nitrogen metabolism is not well understood but experimental evidence obtained recently suggested that sulphur may be involved in both the synthesis and breakdown of proteins (Agarwala and Sharma, 1976). Sulphur has been shown to be required in nitrogen fixation by leguminous plants. Recent work has shown that sulphur is also involved in the development of tissues e.g. collenchyma fibres and xylem are reported to thicken making the stem hardy and woody with provision of adequate sulphur (Agarwala and Sharma, 1976).

## Accumulation and Distribution

Although cowpea require only small quantities of sulphur, this nutriet is known to be deficient in many parts of tropical Africa (Kang *et. al.*, 1977). In pot experiment they found that to attain maximum yield of cowpea, sulphur fertilization will be required especially in the high rainfall areas.

Karlem and Whitney (1980) found that in winter wheat the sulphur concentration in the whole plant samples remained extremely variable and showed no significant statistical trends. In the leaves the sulphur concentration decreased from approximately 0.4 to 0.1% with the decrease being most rapid during the early stages of growth. They also noted that sulphur concentration in the stems decreased from 0.15 to 0.05% as the season progressed.

When soils have adequate amount of sulphur, then about 30% of the plant sulphur was found in the grain of cowpeas while in moderately deficient soils about 50% of the total sulphur was in the grain (Fox *et al.*, 1977). Although sulphur is an important mineral nutrient, Jacquinot (1967) observed that cowpea generally absorbed only small quantities of sulphur (0.4 kg/100 kg of seeds).

# MATERIALS AND METHODS

## Site:

Experiments to study plant growth, nutrient accumulation and distribution of two cowpea varieties was conducted at Murinduko, in Kirinyaga district. This is a sub-station of Embu Agricultural Research Station and it is approximately 10 kilometres South of Embu town.

Murinduko sub-station is located at $32^{o}$ 7′ due East and 0.30′ due South with an altitude of 1450 m. It has an average annual rainfall of 800 mm (averaged over 10 years).

The soils are deep sandy loam, derived from Mt. Kenya volcanic ash (Mt. Kenya phonolite) classified (FAO/UNESCO) as Ferrasol (Siderius and Muchena, 1977). Soil analysis was done before the study was commenced (Appendix I). The soil analysis report indicated that the site had strongly acid top soil, sufficient in Calcium, sufficient in phosphorus and moderately supplied with organic carbon and hence nitrogen. The soil had a high exchangeable acidity (pH). Appendix IV shows the deficiency and sufficiency ranges for soil nutrients.

The prevailing weather conditions during the study period are shown in Appendix I. The sub-station receives a bimodal rainfall, the long rains (March – May) normally accounting for up to 65% of the total annual rainfall while the short rains (October – November)

4.1a: Soil analysis report (Murinduko)

| | Top soil | | Sub soil | |
|---|---|---|---|---|
| Parameter | Range | Mean | Range | Mean |
| pH | 4.9-5.2 | 5.05 | 5.0-5.4 | 5.2 |
| Na M.e% | 0.6-0.08 | 0.07 | 0.07-0.08 | 0.075 |
| K M.e% | 0.35-0.68 | 0.52 | 0.35-0.50 | 0.43 |
| Ca M.e% | 2.5-2.7 | 2.6 | 2.3-2.5 | 2.4 |
| Mg M.e% | 3.6-3.9 | 3.75 | 2.8-3.4 | 3.1 |
| Mn M.e% | 1.0-1.26 | 1.17 | 0.98-1.04 | 1.01 |
| P ppM (Metric analysis) | 22.28 | 25 | 22-28 | 25 |
| N% | 0.12-0.16 | 0.14 | - | - |
| C% | 0.89-1.35 | 0.112 | - | - |
| HP M.e% | 0.4-0.8 | 0.6 | 0.2-0.7 | 0.5 |
| $SO_4$ (Acetate) soluble) ppm (olson) | 5-12 | 9.5 | 4-6 | 5 |

accounts for about 20%. The remaining 10 - 15% comes in form of isolated showers.

The experimental site in Murinduko is gently sloping and was under maize from 1978 to 1980 long rains. Compound fertilizer 20:20:0 was used to plant the maize. A sorghum trial was planted thereafter using the same fertilizer until long rains 1982 when this cowpea trial was initiated.

Plant Material:

Two cowpea varieties used in the study were Katuli 107 and MM 4. Katuli 107 is an erect determinate cowpea and matures in about 80 - 90 days after planting. It has a strap (narrow leaves) which are dark in colour and has purple flowers. The seeds are smooth and brown with a white eye. The variety is predominantly a prolific seed producer. MM 4 on the other hand is also an erect determinate variety and matures within 105 - 110 days. It has light green globose (broad) leaves and cream white flowers. The seeds are smooth and cream in colour with a cream white eye. The young tender leaves of this variety are used as vegetable. The variety in contrast to Katuli 107 produces less seeds and a lot of leaves. Both varieties are photoperiodically neutral with average seed weight of 12 - 14 gm/100 seeds.

Plant Culture:

The seeds dressed with 40% aldrin were planted in furrows at a depth of 3 cm in a firm weed-free seedbed. Two seeds per hill were planted and later thinned to one plant. No inoculation was done and the cowpeas were expected to utilise the indigenous rhizobin to nodulate. Also no fertilizer was applied at the planting time or in subsequent stages of growth.

Strict cultural practices were followed. These included handweeding two and six weeks after planting commencing 35 days after planting. "Rogor E" (Dimetheoate) was used at the rate of the litre of the product/ha to control thrips. Later at the pod setting stage "Nuracron" was applied twice until maturity to control the pod sucking insects at the same rate as "Rogor E".

## Experimental Design:

Experiments were laid out in a completely randomised design (CRD) with each variety being replicated six times. Varieties and frequency of sampling were used as treatments. The two varieties were 'Katuli 107' and 'MM4'. Sampling frequency were at 2, 4, 6, 8 and 10 weeks after seedling emergence.

## Sampling Procedure:

There were ten rows of cowpeas in every plot. The two outer rows in every plot were the guard rows while the middle two were the net rows to be harvested for the final grain yield. The remaining six rows were the sampling ones.

The first samples were taken four weeks after planting and thereafter at two weeks interval. Sampling involved taking two whole plants per row in the six sampling rows. The total sample therefore contained twelve plants. Every sample was divided into roots, stems and leaves plus petioles. Each of these was further sub-divided into five samples for the analysis of Nitrogen (N), phosphorus (P), potassium (K), calcium (Ca), magnesium (mg) and sulphur (S). Dry matter accumulation was also studied during the sampling stages. Soil sample was taken.

The randomly sampled materials were put in polythene bags, bulked and the sub-sampled to give about 200 - 300 g weighed and then dried to a constant weight at 75$^{o}$C. The samples were then milled in a stainless grinder and securely preserved in 50 ml pvc container with a lid.

The various samples were then analysed for the total Nitrogen by modified micro Kijedahl method while P, K, Ca and Mg were determined by a wet digestion of 2 g of the ground material with concentrated sulphuric acid and perchloric acid mixture. Phosphorus and Sulphur were then determined by the calorimetric method while Ca and Mg were determined by an atomic absorption spectrophotometer and K by flame photometer. Nutrient content was calculated from the dry matter yield and percentage nutrient composition.

## Parameters of Observation:

The data recorded included the stand count of the two cowpea varieties. This was done two weeks after seedling emergence and at harvesting. Days to 50% flowering was also recorded to determine the earliness of the two cowpea varieties. Seed yield was determined by harvesting, threshing and weighing the two net rows in the middle and then converting the final grain yield to kg/ha. Other data recorded and closely associated with grain yield were 1000 seed weight, number of pods per plant and number of seeds per pod. Dry matter accumulation of the two cowpea varieties was determined at two weeks interval from seedling emergence up to harvesting. Number of nodules per plant was also determined at fortnight interval.

## Data Analyis:

The data collected was subjected to statistical analysis in accordance to Snedecor and Cochran (1976). Means of dry matter accumulation and nutrient concentrations were separated by Duncan's Multiple range test at 5% level of significance. The dry matter accumulation was further subjected to a complete analysis of variance in accordance to Snedecor and Cochran (1976). A multiple linear correlation coefficient (r) and coefficient of determination ($r^2$) between the total dry matter, sampling frequency and nutrient concentration was also computed, Snedecor and Cochran (1976).

# RESULTS

## Dry Matter:

### Whole plant

The dry matter production in both varieties was low during the seedling stage but increased steadily in the subsequent stages of growth. At the seedling stage, 'Katuli' had accumulated twice the amount of dry matter than 'MM4'. Later at flowering, dry matter production more than doubled in both varieties but increased slowly at pod setting stage (Table 4.1).

There was a sharp increase in dry matter production between pod setting and pod filling stages but thereafter increased gradually. Throughout the growing period, Katuli accumulated more dry matter than 'MM4'. The increase in dry matter production in both varieties followed a sigmoid pattern (Fig. 4.1).

Although there were differences in the accumulation of dry matter by the two varieties, it was only at 6th week after emergence where 'Katuli' had accumulated significantly higher amounts of dry matter than 'MM4' (Table 4.1).

### Roots:

The roots dry matter accounted for a very small fraction of the total dry matter in both varieties. For example at the seedling stage, the dry matter of the roots

Table 4.1 Dry matter distribution in different parts of two cowpea varieties during their growth period (kg/ha).

| Sampling frequency (weeks after seedling emergence) | Mm4 | | | | Katuli | | | |
|---|---|---|---|---|---|---|---|---|
| | Roots | Stems | Leaves | Total | Roots | Stems | Leaves | Total |
| 2 | 6.44a* | 16.01a | 41.40a | 63.85a | 7.68a | 24.77a | 93.99a | 126.45a |
| 4 | 18.40b | 20.73a | 122.19b | 161.33b | 31.26b | 26.53a | 220.71b | 278.50b |
| 6 | 21.47b | 52.73a | 173.49bc | 247.60b | 15.16ab | 82.50b | 228.90bc | 326.65bc |
| 8 | 64.05c | 152.51c | 265.39bc | 481.95c | 22.71b | 131.37b | 383.44c | 537.53c |
| 10 | 66.15c | 157.97c | 286.78c | 510.90c | 25.59b | 143.03b | 347.30bc | 515.92c |

*Mean separation within columns by Duncan's multiple range test, 5% level.

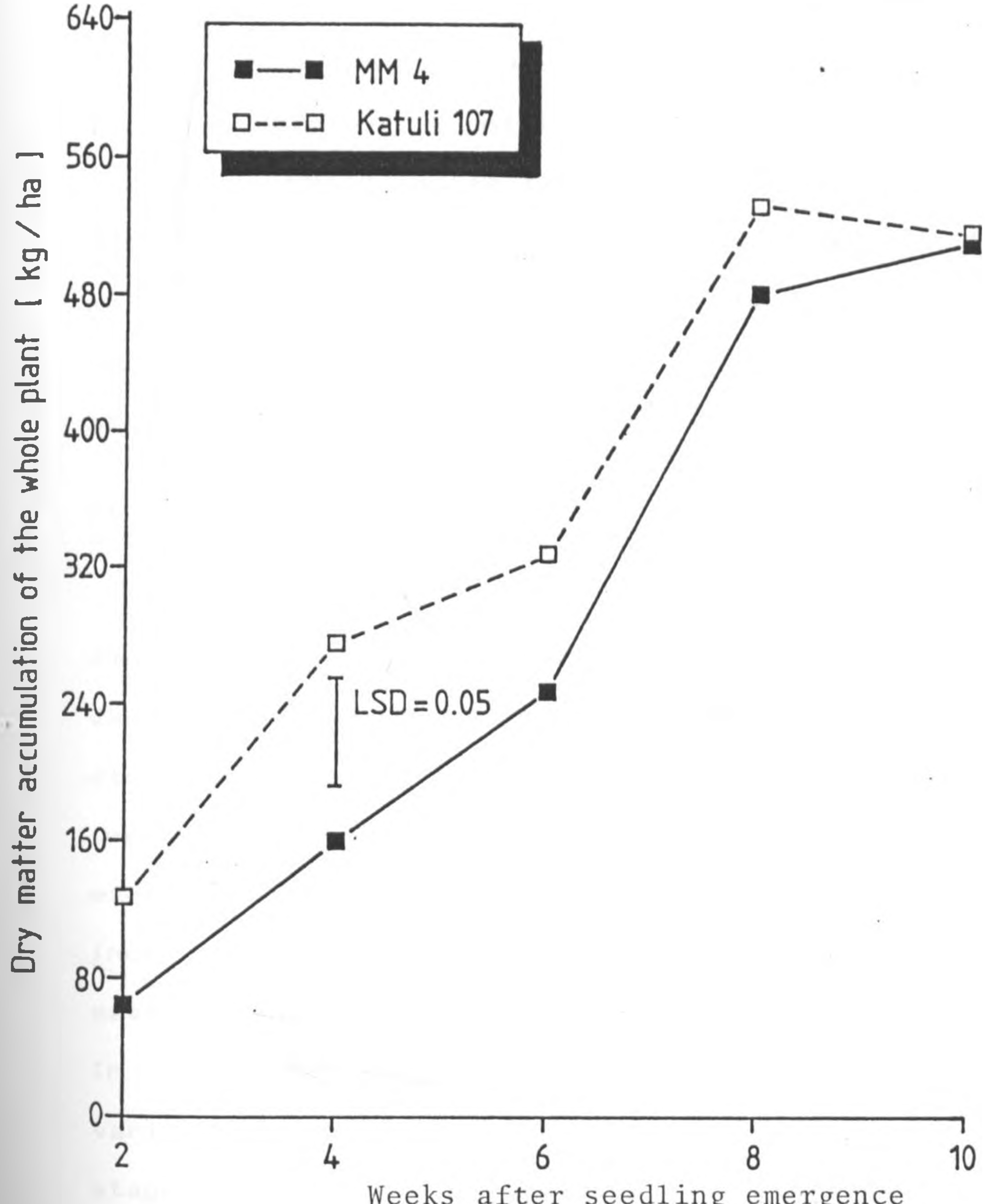


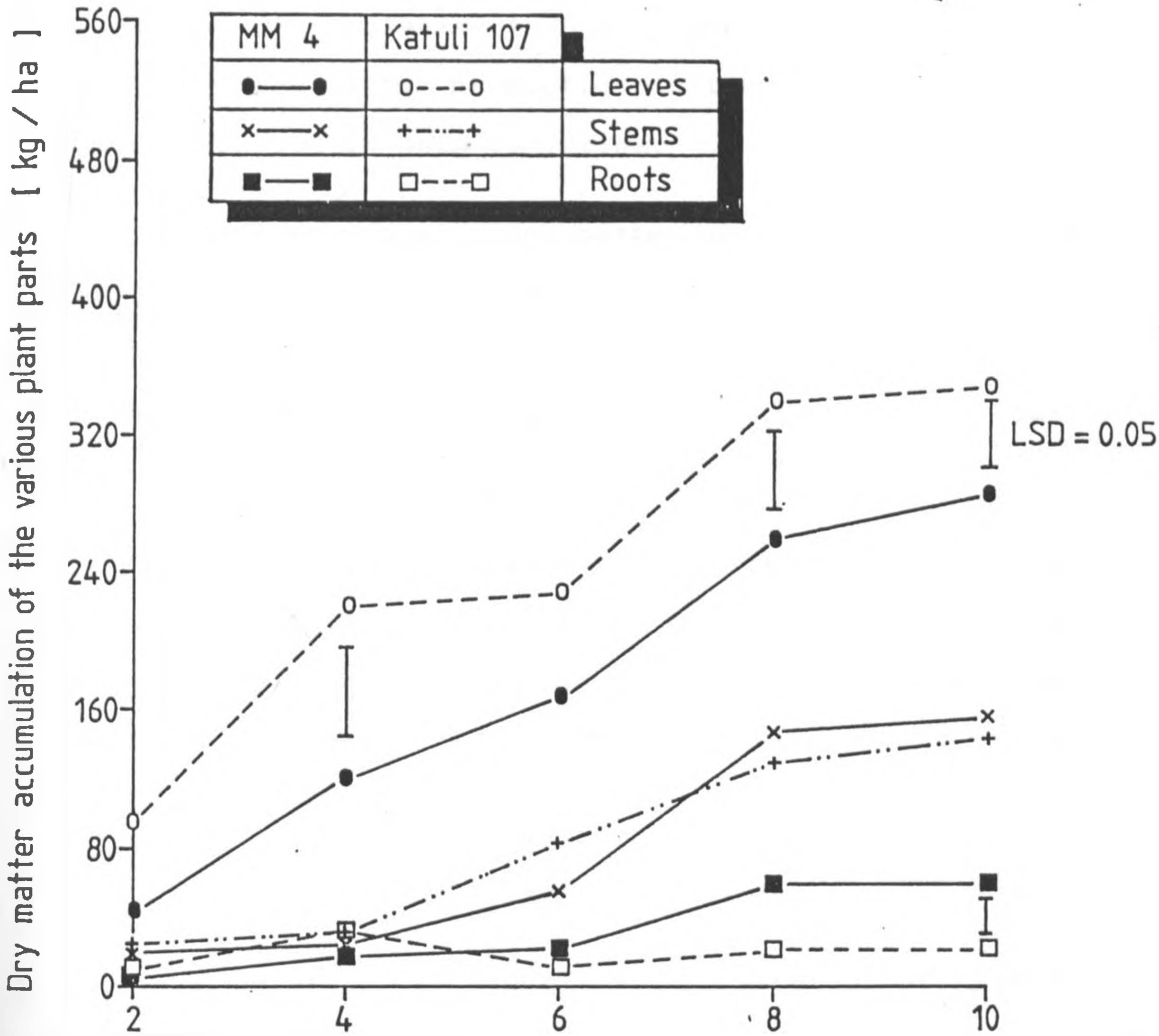

Fig. 4.1. Effect of sampling frequency on the dry matter accumulation of the entire cowpea plant (kg/ha).

of 'MM4' accounted for 10% of the total dry matter while that of 'Katuli' accounted for only 7% (Table 4.1).

Although there was a continuous increase in dry matter production in the roots at all sampling stages, the increase was only significant (P = 0.05) at pod filling stage in 'MM4', and at flowering in 'Katuli'. There was also a varietal difference in the increase of the dry matter production at the 8th and 10th week after emergence. At these stages 'MM4' had accumulated significantly higher dry matter than 'Katuli' (Fig. 4.2).

Stems:

Apart from the leaves, the stems had the highest amount of dry matter production in the two cowpea varieties. Like in the roots, dry matter production in the stem was lowest in the initial stages of growth but increased tremendously in the later stages of growth. For example from seedling stage to flowering, dry matter had increased by only 6% but had increased by 30% at pod setting and over 100% at pod filling stages (Table 4.1). In the later stages, dry matter production in the two varieties remained fairly constant. Up to the pod forming stage 'Katuli' had accumulated higher dry matter in its stems than 'MM4' but the situation was reversed in later stages of growth. The increase in dry matter production in stems was not significantly different in the two varieties at various sampling times (Fig. 4.2).




Weeks after seedling emergence

Fig. 4.2. Effect of sampling frequency on the dry matter accumulation of various parts of cowpea plant (kg/ha).

Leaves and Petioles:

The leaves and their petioles had the highest dry matter accumulation than any other plant part. At flowering, dry matter production in the leaves increased by more than 50% in both varieties.

The increase in dry matter in the leaves at pod filling stage was significant (P = 0.05) in both varieties. There was a sharp but insignificant increase in dry matter production in the two varieties at the last sampling date (table 4.1, fig. 4.2).

Except at the flowering stage where 'Katuli' accumulated significantly higher amounts of dry matter than 'MM4', both varieties accumulated fairly the same amount of dry matter in all the sampling periods (fig. 4.2).

Grain Yield and Yield Component:

'Katuli' had significantly higher grain yields than 'MM4' (table 4.2). The number of pod per plant and the number of seeds per pod were again significantly higher in 'Katuli' than in 'MM4' (P = 0.05). The 1000 seed dry weight was however significantly higher in 'MM4' than in 'Katuli'.

Days to 50 percent flowering and to maturity were significantly lower in 'Katuli' than in 'MM4' (P = 0.05). There were no significant differences (P = 0.05) in

Table 4.2. Mean seed yield components and other morphological data of two cowpea varieties.

| Variety | Days to 50% flowering | Days to maturity | Pods per plant | Seeds per pod | 1000 seed weight (g) | Shelling (%) | Grain yield (kg/ha) |
|---|---|---|---|---|---|---|---|
| MM4 | 52 | 103 | 9.8 | 7.5 | 132.3 | 63.7 | 849 |
| Katuli | 43 | 81 | 14.6 | 11.3 | 120.7 | 64.3 | 1687 |
| LSD(P=0.05) | 1.97 | 0.99 | 0.46 | 0.72 | 1.29 | 1.63 | 11.22 |

Table 4.3 Mean number of nodules per plant at various growth stages of two cowpea varieties.

| Variety | Weeks after emergence | | | | | | |
|---|---|---|---|---|---|---|---|
| | 2 | 4 | 6 | 8 | 10 | Total | Mean |
| MM4 | 2.75 | 6.18 | 8.91 | 9.63 | 9.71 | 37.18 | 7.44 |
| Katuli | 1.95 | 4.19 | 4.82 | 5.73 | 4.35 | 21.04 | 4.21 |

LSD (P = 0.05= = 3.19

the shelling percentages of the two varieties (table 4.2).

Number of Nodules per Plant:

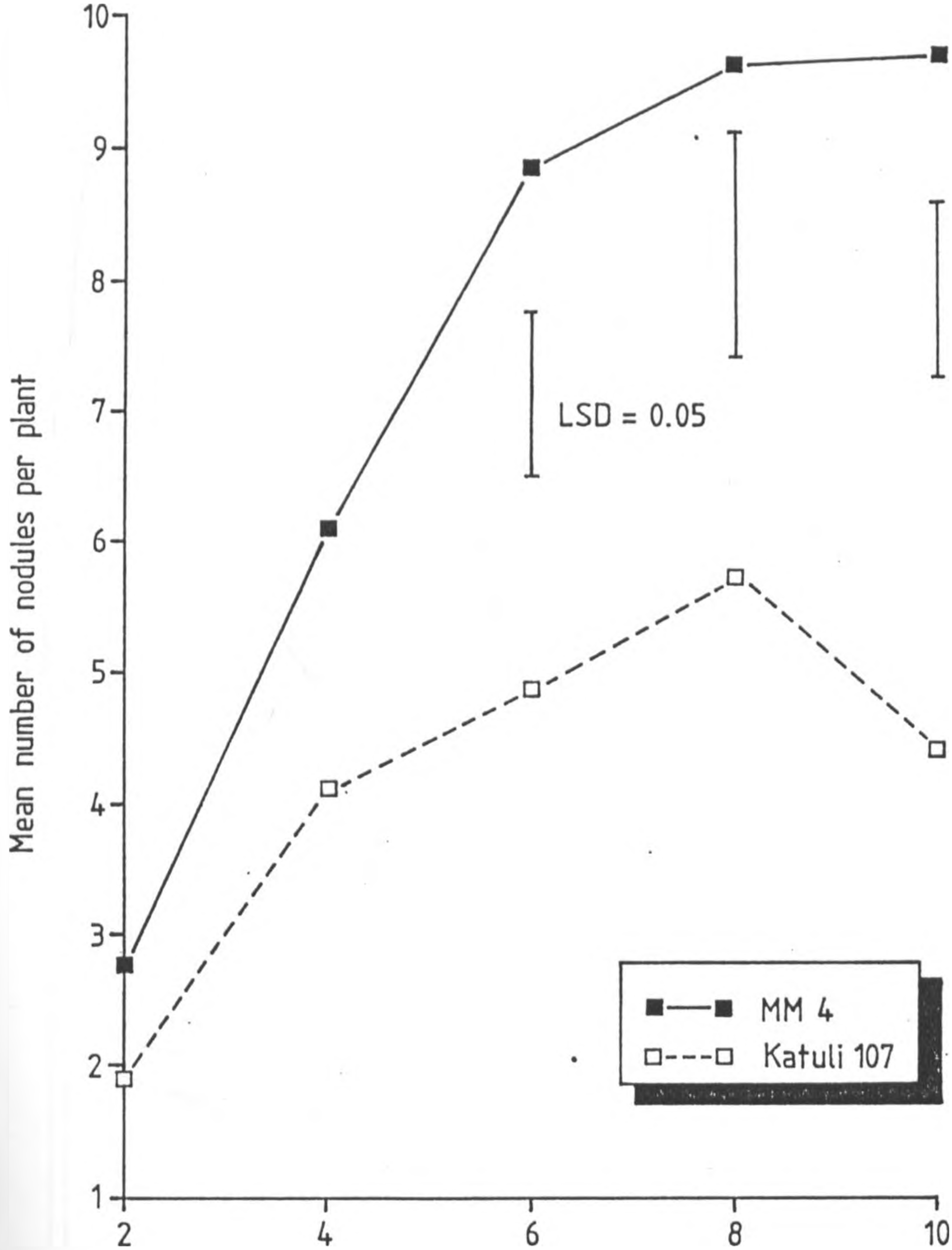
The number of nodules were low at the seedling stage, but increased by more than 10% at the flowering and remained relatively stable in the subsequent stages of growth in both varieties (table 4.3). The highest increase in the number of nodules per plant occurred between seedling and flowering and also between flowering and pod setting stages of growth.

In all the sampling periods, 'MM4' maintained a significantly (P = 0.05) higher number of nodules than 'Katuli' (fig. 4.3).

Total Mineral Element Concentration in the Two Cowpea Varieties at Different Sampling Times:

Table 4.4 summarises the various mineral elements in two cowpea varieties at different sampling times. The highest concentration of the mineral nutrient in the two cowpea varieties was nitrogen, followed by potassium and calcium. The rest of the mineral elements were accumulated in small quantities.

There was a significant (P = 0.05) increase in the concentration of all mineral elements analysed at pod filling stage except for phosphorus where the only significant increases (P = 0.05) occurred at flowering and pod setting stages of growth in 'Katuli' and 'MM4'




Weeks after seedling emergence

Fig. 4.3. Effect of frequency sampling on the number of nodules per plant of two cowpea varieties.

Table 4.4 Total nutrient concentration (%) of two cowpea varieties during their growth period.

| Sampling frequency (weeks after seedling emergence) | Mm4 | | | | | | Katuli | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | N | P | K | Ca | Mg | S | N | P | K | Ca | Mg | S |
| 2 | 2.377a* | 0.082a | 2.161a | 0.906a | 0.268a | 0.145a | 5.190a | 0.183a | 4.341a | 2.455a | 0.384a | 0.252a |
| 4 | 6.624b | 0.415b | 4.316a | 2.255b | 0.632a | 0.060a | 11.816ab | 0.751b | 7.245ab | 3.901a | 1.100b | 0.093a |
| 6 | 7.977b | 0.636bc | 7.864c | 3.353bc | 1.212bc | 0.449b | 10.390ab | 0.766b | 7.842ab | 4.218ab | 1.521bc | 0.460b |
| 8 | 15.845c | 0.796c | 9.405c | 4.422c | 2.347c | 0.891c | 16.446b | 0.727b | 9.383b | 6.883b | 2.853c | 0.752b |
| 10 | 16.625c | 0.718bc | 8.48c | 3.961bc | 2.354c | 0.551b | 14.425b | 0.734b | 9.302b | 5.319b | 2.762c | 0.601b |

*Mean separation within columns by Duncan's multiple range test, 5% level.

respectively (table 4.4).

There was no significant (P = 0.05) varietial difference in the content of the various minerals in both cultivars at various stages of growth (Table 4.4).

Nitrogen:

Whole plant:

Nitrogen in the whole plant was low during the initial sampling period but continued to increase as the plant matured. For example, from seedling to flowering stages, nitrogen concentration in the whole plant more than doubled in both varieties (table 4.5).

At pod setting, there were no changes in N concentration in the two varieties but increased considerably at pod filling (fig. 4.4). In all the sampling stages except at pod filling 'Katuli' maintained higher levels of N than 'MM4'.

Roots:

The roots of the two cowpea varieties had the lowest amount of N during the entire growing season. For example at the seedling stage the roots accounted for only 4% of the total nitrogen in the plant. At flowering, N concentration in the roots increased by more than threefold in both varieties. From seedling stage to flowering, the roots of 'Katuli' had higher N concentration than those of 'MM4' but the situation was

Table 4.5 Nitrogen concentration (%) in different parts of two cowpea varieties during their growth period.

| Sampling frequency (weeks after seedling emergence emergence) | Mm4 | | | | Katuli | | | |
|---|---|---|---|---|---|---|---|---|
| | Roots | Stems | Leaves | Total | Roots | Stems | Leaves | Total |
| 2 | *0.118a | 0.405a | 1.854a | 2.317a | 0.258a | 0.624a | 4.408a | 5.190a |
| 4 | 0.386b | 0.447a | 5.791b | 6.624b | 0.718b | 0.578a | 10.520b | 11.816ab |
| 6 | 0.407b | 0.769a | 6.801bc | 7.977b | 0.256a | 1.213b | 8.927ab | 10.390ab |
| 8 | 1.440c | 2.050b | 12.355c | 15.845c | 0.438b | 1.668b | 14.340c | 16.446b |
| 10 | 1.217c | 3.775b | 11.633c | 16.625c | 0.355ab | 1.530b | 12.540bc | 14.425b |

*Mean separation within columns by Duncans Multiple range test, 5% level.

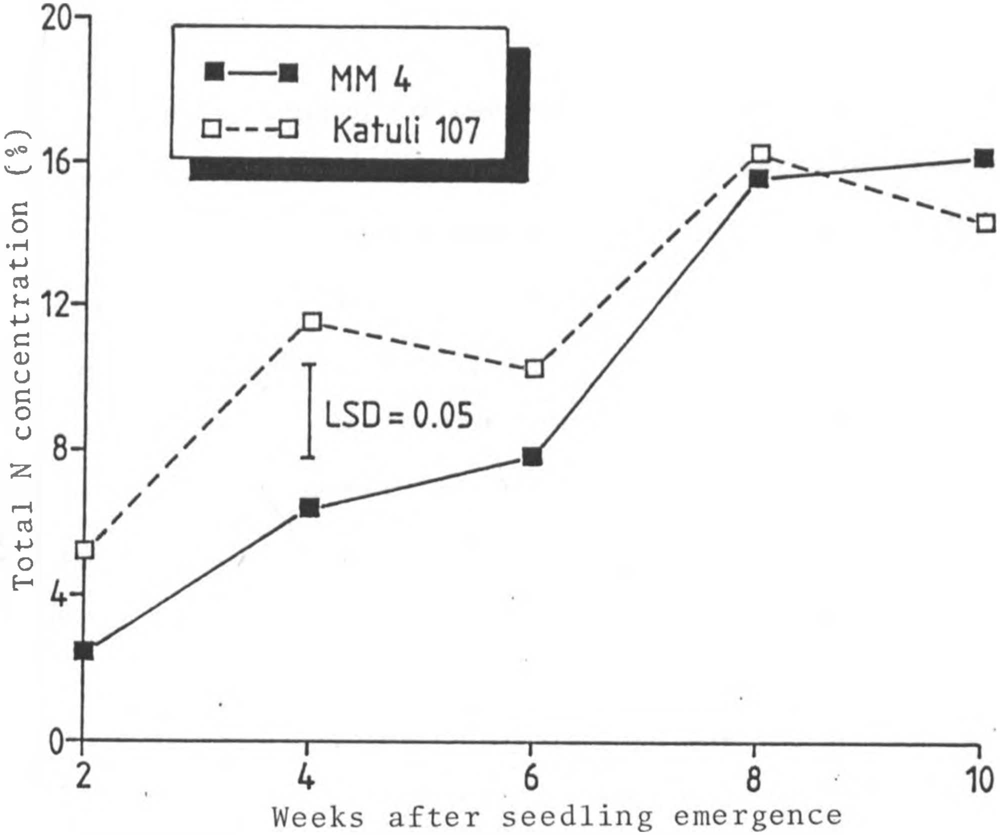



Fig. 4.4. Effect of sampling frequency on N concentration of the entire cowpea plant.

reversed in the subsequent stages of growth. It should be noted that the N-concentration in the roots of Katuli increased significantly (P = 0.05) at flowering while those of 'MM4' increased significantly only at pod setting (fig. 4.5).

Stems:

The nitrogen concentration in the stems of the two cowpea varieties was second highest after the leaves. At the seedling stage the stems contained 10 and 17% of the total N in the plant in 'Katuli' and 'MM4', respectively (table 4.5). Later, during flowering, nitrogen concentration in the stems tended to decrease but increased significantly in the pod setting stage. From maintained a higher N concentration but the situation was reversed thereafter (fig. 4.5).

Leaves and Petioles:

The leaves of both varieties accumulated the highest N concentration than any other plant part throughout the growing period. For example, at the seedling stage the leaves of both varieties contained more than 75% of the total nitrogen contained in the whole plant (table 4.5). During the same period, the N concentration in the leaves of 'Katuli' was three times more than that of 'MM4'.

There was a significant increase in N concentration at flowering (P = 0.05), however remained

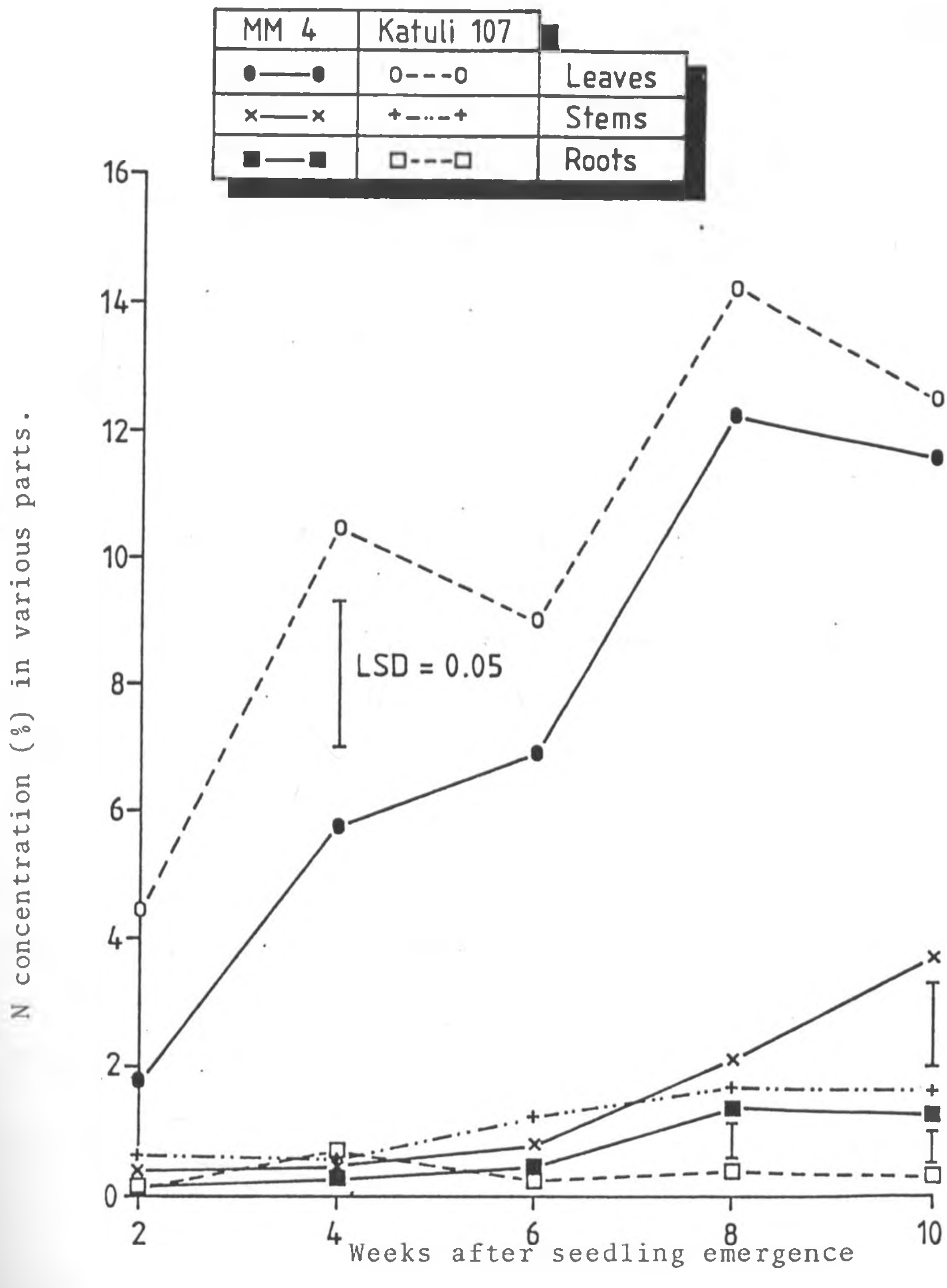



Fig. 4.5. Effect of sampling frequency in N concentration of various plant parts of cowpeas

relatively constant at pod setting stage, but increased steadily thereafter in both varieties (fig. 4.5). Throughout the growing season, the leaves of 'Katuli' maintained higher nitrogen concentration than 'MM4'.

Phosphorus:

Whole plant:

The P concentration in the whole plant was low during the initial stages of growth but high in later stages. From seedling to flowering, the P concentration doubled in both varieties, but remained fairly constant at pod setting stage. The increase in P concentration in subsequent stages of growth was slow and gradual (table 4.6).

In nearly all the sampling stages, Katuli maintained higher P concentration than MM4. For example, at flowering, Katuli had accumulated about 50% more phosphorus than 'MM4' (fig. 4.6).

Roots:

The P content in the roots was lowest in all sampling periods in the two varieties. At flowering there was a sharp increase in P concentration of the roots in both varieties, but decreased by almost 20% at pod setting (table 4.6). In 'MM4' there was a significant ($P = 0.05$) increase in phosphorus concentration in the roots at pod filling and a decrease thereafter, 'Katuli' on the other

Table 4.6 Phosphorus concentration (%) in f different parts of two cowpea varietis during the growing season.

| Sampling frequency (weeks after seedling emergence) | Mm4 | | | | Katuli | | | |
|---|---|---|---|---|---|---|---|---|
| | Roots | Stems | Leaves | Total | Roots | Stems | Leaves | Total |
| 2 | 0.014a* | 0.019a | 0.049a | 0.082a | 0.017a | 0.035a | 0.131a | 0.183a |
| 4 | 0.029ab | 0.044a | 0.342b | 0.415b | 0.056b | 0.056a | 0.639b | 0.751b |
| 6 | 0.034ab | 0.116b | 0.486b | 0.636bc | 0.024a | 0.124b | 0.618b | 0.766b |
| 8 | 0.096c | 0.198b | 0.502b | 0.796c | 0.021a | 0.132b | 0.575b | 0.727b |
| 10 | 0.053bc | 0.126b | 0.539b | 0.718a | 0.018a | 0.085a | 0.631b | 0.734b |

*Mean separation within columns by Duncan's multiple range test, 5% level.

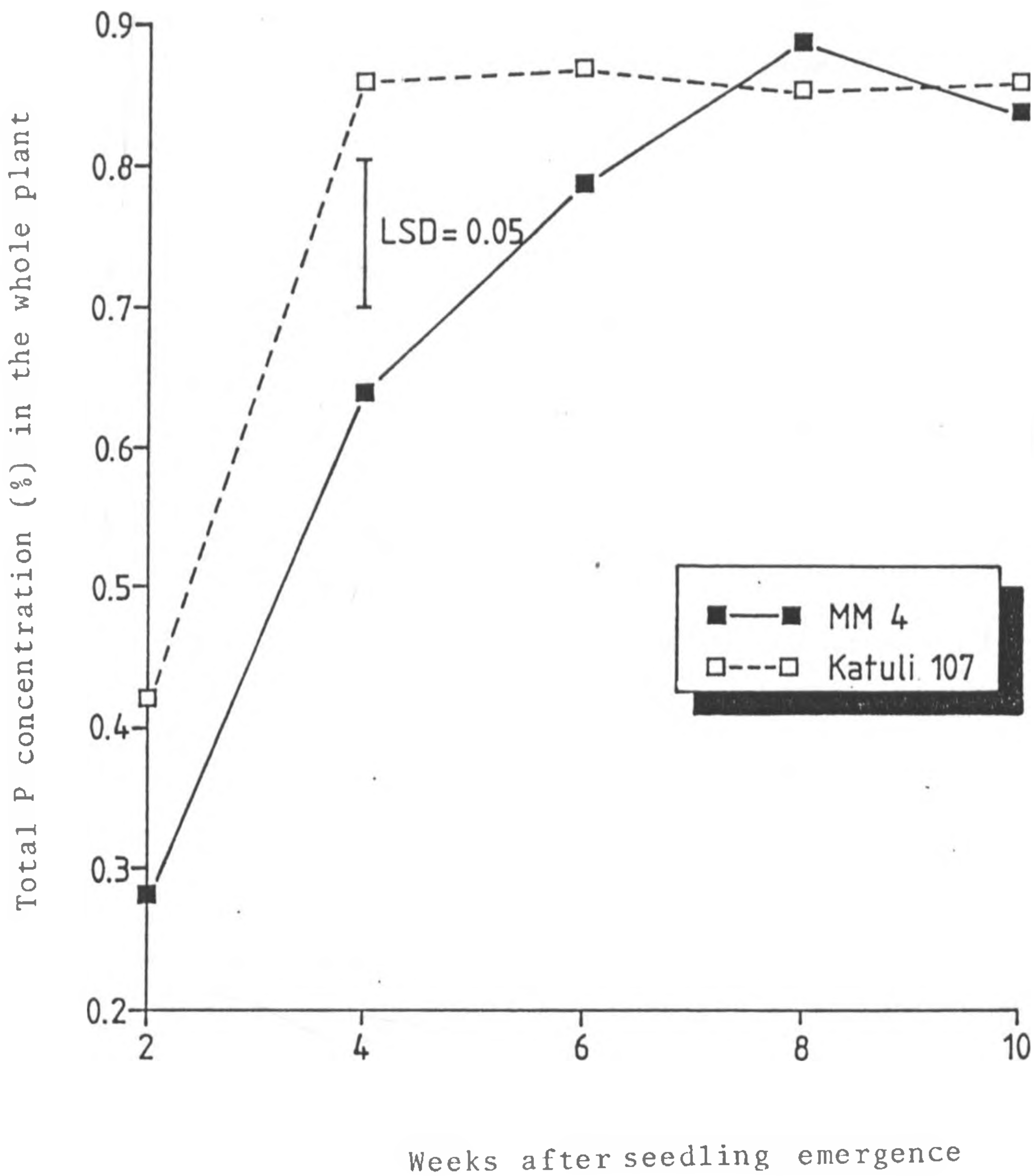



Fig. 4.6. Effect of sampling frequency on P concentration of the entire cowpea plant

hand had significant (P = 0.05) changes in phosphorus concentration at flowering and not in any other growth stage (fig. 4.7).

Stems:

There was an almost linear increase in phosphorus concentration in the stems of the two varieties from emergence up to the pod filling stage and decreased thereafter (fig. 4.7). At the seedling stage 'Katuli' had twice as much P in its stems as in 'MM4', but at flowering the two varieties were at par. From seedling to flowering the P concentration in the stems of both varieties doubled and a similar increase occurred between flowering and pod setting (table 4.6).

The P concentration in the stems of the two varieties increased significantly (P = 0.05) both at flowering and pod filling stages of growth.

Leaves and Petioles:

Like in nitrogen, P concentration was low at seedling stage but increased in the subsequent growth stages. The largest increase occurred at flowering where both varieties had an increase of more than 50% as compared to seedling stage (4.6). In 'Katuli', the P concentration in the leaves tended to remain fairly constant after flowering while that of 'MM4' had slight increase at pod setting and remained fairly constant thereafter (fig. 4.7).

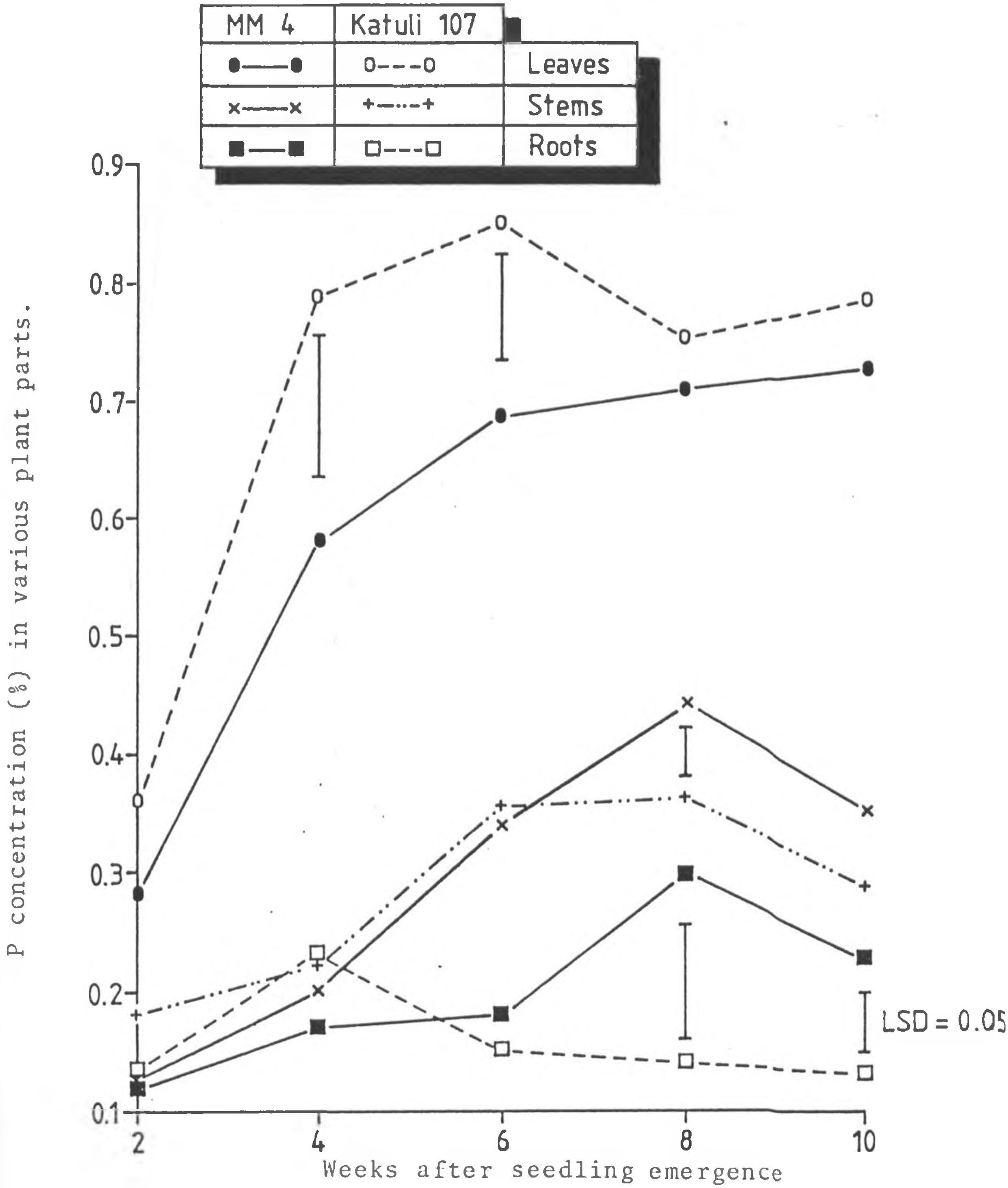



Fig. 4.7. Effect of sampling frequency on P concentration of various plant parts of cowpeas.

In all the sampling periods, 'Katuli' maintained a higher P concentration in its leaves than 'MM4'. There was a significant increase in the P concentration ($P = 0.05$) at flowering in both varieties, but not in any other growth stage.

Calcium:

Whole plant:

Calcium concentration was low in the initial stages of growth but increased steadily thereafter. At the seedling stage, 'Katuli' had accumulated more than double the amount of calcium than 'MM4', but at flowering the two varieties were almost at par (table 4.7).

Between flowering and pod setting, the Ca accumulation in both varieties was low but increased steadily in the later stages of growth. Throughout the sampling times, Katuli maintained higher amounts of Ca than 'MM4' (fig. 4.8).

Roots:

The roots of the two cowpea varieties maintained xfairly low amounts of $Ca^{++}$ than the other parts throughout the growing season. For example, at seedling stage the roots accounted for approximately 2% of the total $Ca^{++}$ in the plant. Later at flowering, the Ca concentration doubled in the roots of 'MM4',but trebled in 'Katuli' (table 4.7).

Table 4.7. Calcium concentration (%) in different parts of two cowpea varieties during their growth period.

| Sampling frequency (weeks after seedling emergence) | Mm4 | | | | Katuli | | | |
|---|---|---|---|---|---|---|---|---|
| | Roots | Stems | Leaves | Total | Roots | Stems | Leaves | Total |
| 2 | 0.032a* | 0.175a | 0.699a | 0.906a | 0.032a | 0.299ab | 2.124a | 2.455a |
| 4 | 0.075ab | 0.126a | 2.053b | 2.255b | 0.131b | 0.194a | 3.576a | 3.901a |
| 6 | 0.099b | 0.374ab | 2.880bc | 3.353bc | 0.068a | 0.396bc | 3.754b | 4.218ab |
| 8 | 0.051a | 0.442b | 3.928c | 4.422c | 0.045a | 0.473bc | 5.365b | 5.883b |
| 10 | 0.059a | 0.348ab | 3.554c | 3.961bc | 0.105b | 0.654c | 4.560b | 5.319b |

* Mean separation within columns by Duncan's multiple range test, 5% level.

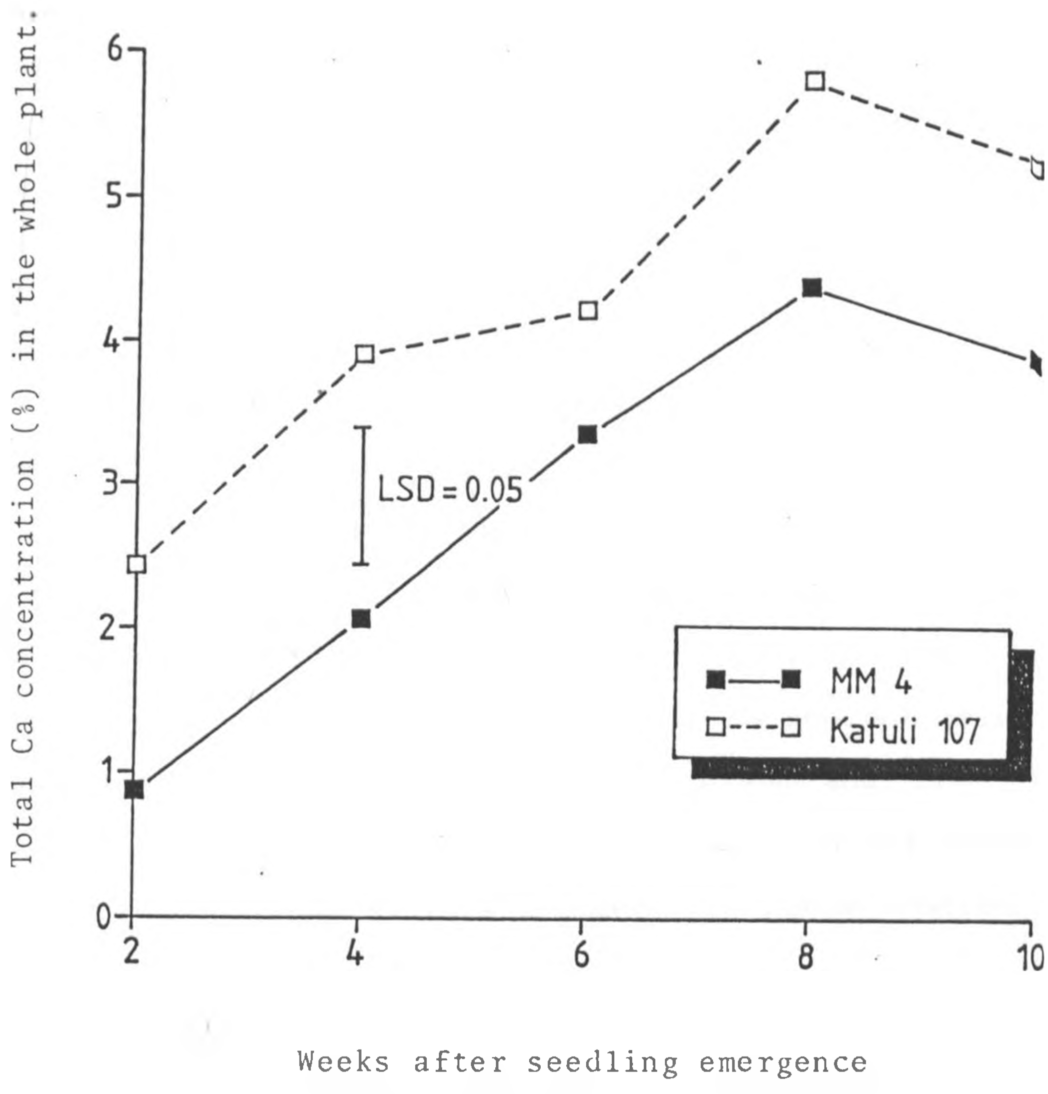



Fig. 4.8. Effect of sampling frequency on Ca concentration of the entire cowpea plant.

In the later stages of growth, Ca concentration in the roots tended to decrease in both varieties. During the growing season, the two varieties seemed to have a fairly close Ca concentration in their roots. There was a significant increase (P = 0.05) in Ca concentration at flowering and pod setting stages of growth in 'MM4', but only at flowering in 'Katuli' (table 4.7).

Stems:

The stems had the highest Ca concentration after the leaves in both varieties throughout the growing season. For example, at the seedling stage, the stems of 'MM4' accounted for 20%, while those of 'Katuli' accounted for 12% of the total Ca in the plant (table 4.7). There was a significant change (P = 0.05) in Ca concentration at flowering and pod setting stages of growth and 'MM4' but only at the 5th sampling time in 'Katuli'. In all sampling times, 'Katuli' maintained a higher Ca concentration in its stems than 'MM4' (fig. 4.9).

Leaves and Petioles:

As in N, P, K, the Ca concentration in the leaves was higher than in any other part of the plant sampled. At seedling stage for example, the leaves contained more than 75% of the total Ca in the plant in both varieties. At seedling stage, the Ca concentration in the leaves of 'Katuli' was more than three times that of 'MM4' (table 4.7).

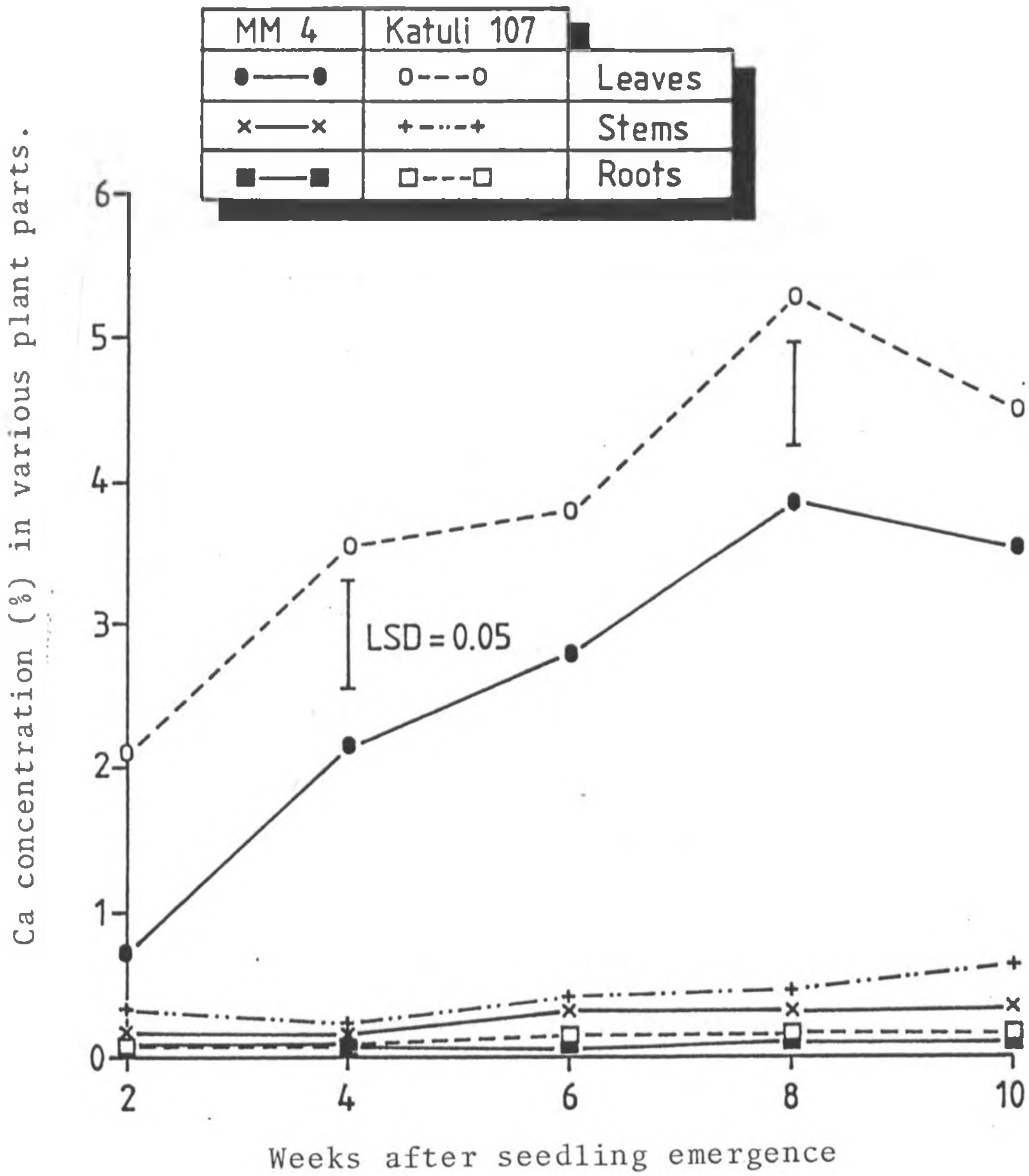



Fig. 4.9. Effect of sampling frequency on Ca concentration of various plant parts of cowpeas

Between flowering and pod setting, there was almost no increase in Ca concentration in the leaves of the two varieties but increased steadily in the subsequent growth stages. In all the sampling times, 'Katuli' maintained a higher Ca concentration than 'MM4'. There was a significant increase (P = 0.05) in Ca concentration at pod filling stage in both of the varieties (fig. 4.9).

Potassium

Whole Plant:

The potassium concentration in the two varieties was low during the initial stages of growth but increased steadily in the later stages of growth. At seedling stage, 'Katuli' had accumulated over 50% more potassium than 'M44' (table 4.8). In both varieties the K content doubled at the seedling stage, but there was only a slight increase at pod setting time. In all the sampling stages, 'Katuli' accumulated higher potassium than 'MM4' (fig. 4.10).

Roots:

Like in N and P, K concentration was lowest in the roots than any other part of the cowpea plant.

At the seedling stage, the potassium in the roots only accounted for 5% of the total potassium in the plant, but this doubled at flowering in both varieties

Table 4.8 Potassium concentration (%) in different parts of two cowpea varieties during their growth period.

| Sampling frequency (weeks after seedling emergence) | Mm4 | | | | Katuli | | | |
|---|---|---|---|---|---|---|---|---|
| | Roots | Stems | Leaves | Total | Roots | Stems | Leaves | Total |
| 2 | 0.165a* | 0.618a | 1.378a | 2.161a | 0.211a | 1.263a | 2.867a | 4.341a |
| 4 | 0.405ab | 0.802a | 3.091b | 4.316b | 0.591b | 1.048a | 5.606b | 7.245ab |
| 6 | 0.681b | 1.598c | 5.586b | 7.864c | 0.465ab | 1.609a | 5.768b | 7.842ab |
| 8 | 1.403c | 2.242c | 5.760b | 9.405c | 0.223a | 2.143ab | 7.017b | 9.383b |
| 10 | 0.959bc | 1.785bc | 5.673b | 8.418c | 0.212a | 2.689b | 6.401b | 9.302b |

*Mean separation within columns by Duncan's multiple range test, 5% level.

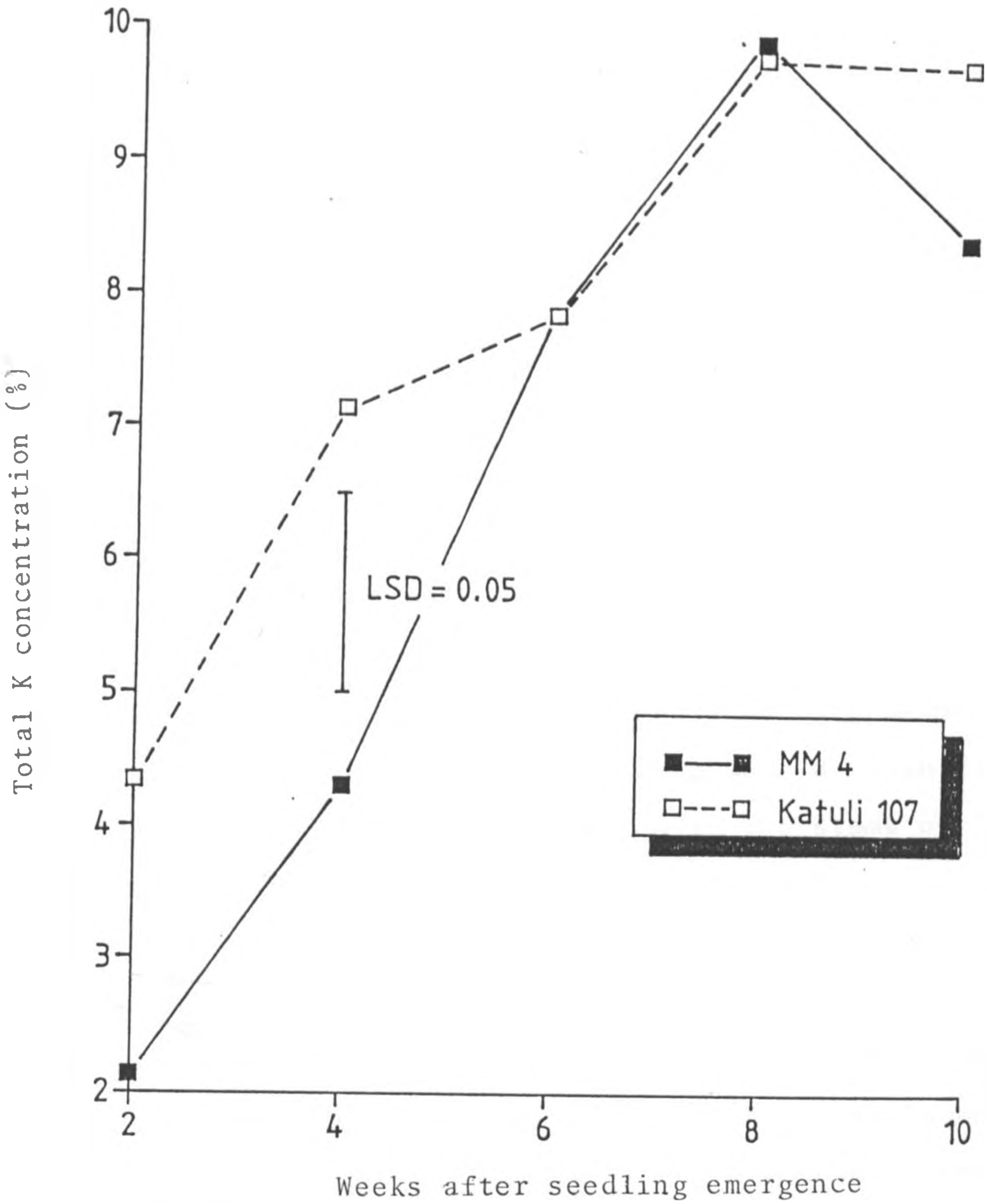



Fig. 4.10. Effect of sampling frequency on K concentration of the entire cowpea plant.

(table 4.8). The K in the roots of 'MM4' continued to increase up to pod setting while that of 'Katuli' decreased throughout after flowering. Throughout the growing season, the roots of 'MM4' accumulated slightly higher K concentration than those of 'Katuli' (fig. 4.11). Except for the pod filling stage where K concentration was significantly (P = 0.05) high, the K concentration remained relatively the same in the rest of the sampling period.

Stems:

The K concentration in the stems of 'Katuli' was double that of 'MM4' at the seedling stage. Later at flowering there was only a slight increase in potassium concentration of the stems of 'MM4' and a decrease in 'Katuli' (fig. 4.11). In the later stages of growth i.e. at pod setting and pod filling, there was a significant increase in potassium concentration in the stems of both varieties but decreased thereafter (table 4.8).

Leaves and Petioles:

Like in N and P, K concentration in the leaves was higher than in any other of the plant parts sampled. For example, at the seedling stage the K concentration in the leaves accounted for more than 60% of the total K in the plant in both varieties (fig. 4.11). At the seedling stage again 'Katuli' had accumulated twice as much K than 'MM4'.

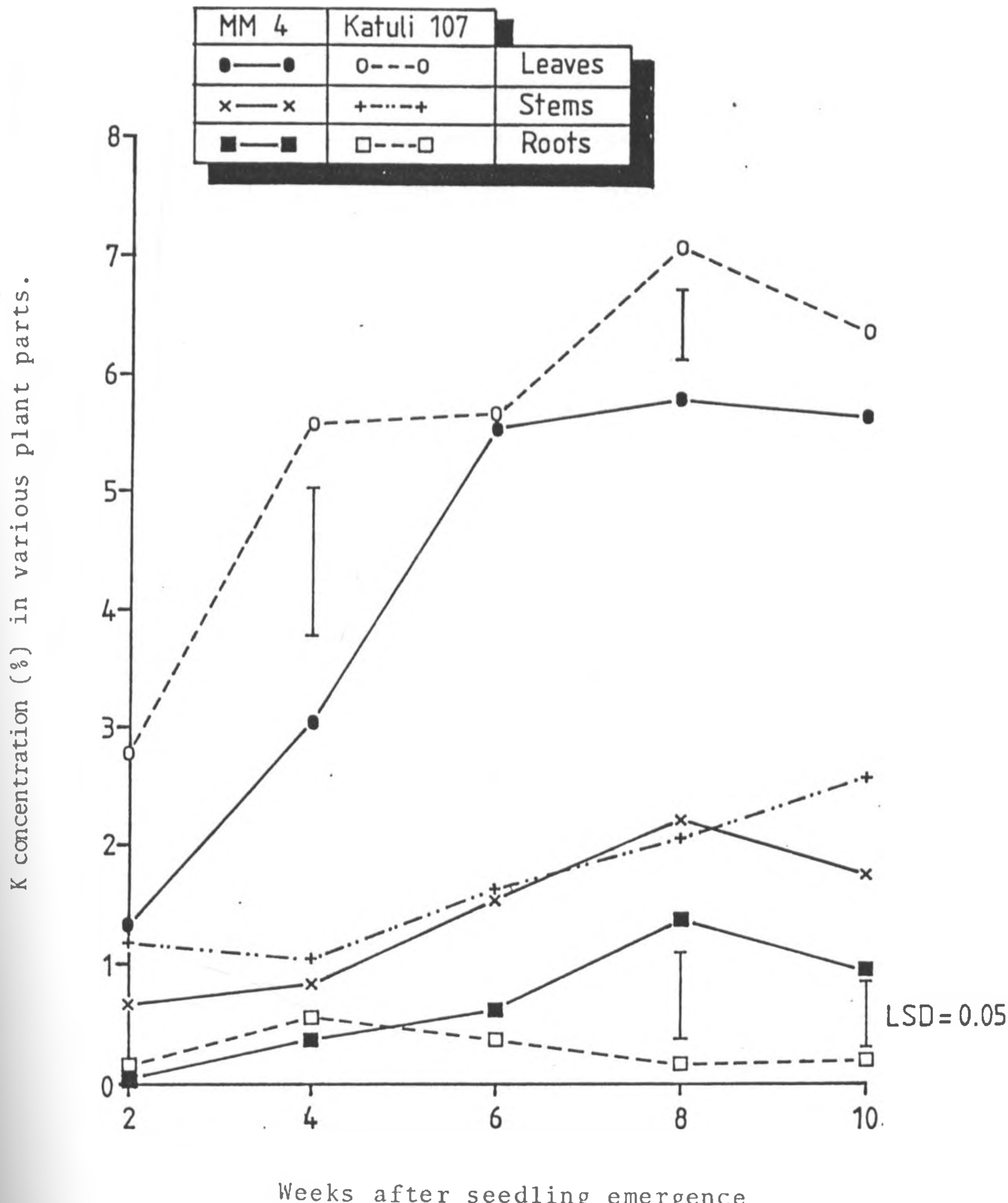



Fig. 4.11. Effect of sampling frequency on K concentration of various plant parts of cowpeas

At flowering, there was a sharp increase of K in the leaves of both varieties but increased steadily in the later stages of growth. Throughout the growing season, 'Katuli' had a higher concentration of K in its leaves than 'MM4'. There was no significant change ($P = 0.05$) in K content in all the sampling stages except the fifth sampling stage in both varieties (table 4.8).

Magnesium:

Whole Plant:

The Mg concentration in the whole cowpea plant was low during the initial growth stages, but increased by more than 5 times at pod filling stage (table 4.9). At seedling and flowering stages 'Katuli' had accumulated more than twice the amount of Mg than 'MM4'. In the later stages of growth however, i.e. at pod setting and pod filling stages; the Mg concentration in the two varieties were fairly the same (Fig. 4.12).

The highest increase in Mg concentration occurred at flowering and pod development stages of growth in both varieties (fig. 4.12).

Roots:

The roots of the two varieties had the lowest Mg concentration throughout the growing season. At the seedling stage for example, the roots of 'MM4' accounted for 8% while those of 'Katuli' 4% of the total magnesium

Table 4.9 Magnesium concentration (%) in different parts of two cowpea varieties during their growth.

| Sampling frequency (weeks after seedling frequency ) | Mm4 | | | | Katuli | | | |
|---|---|---|---|---|---|---|---|---|
| | Roots | Stems | Leaves | Total | Roots | Stems | Leaves | Total |
| 2 | 0.022a* | 0.068a | 0.178a | 0.268a | 0.025a | 0.126ab | 0.433a | 0.584a |
| 4 | 0.042ab | 0.089a | 0.501ab | 0.632a | 0.062ab | 0.114a | 0.927ab | 1.100b |
| 6 | 0.062b | 0.248b | 0.902bc | 1.212bc | 0.057ab | 0.388ab | 1.076bc | 1.521bc |
| 8 | 0.167c | 0.763bc | 1.418c | 2.347c | 0.125b | 0.696bc | 2.032c | 2.853c |
| 10 | 0.139c | 0.900c | 1.315c | 2.354c | 0.128b | 0.772bc | 1.862c | 2.762c |

*Mean separation within columns by Duncan's multiple range test, 5% level.

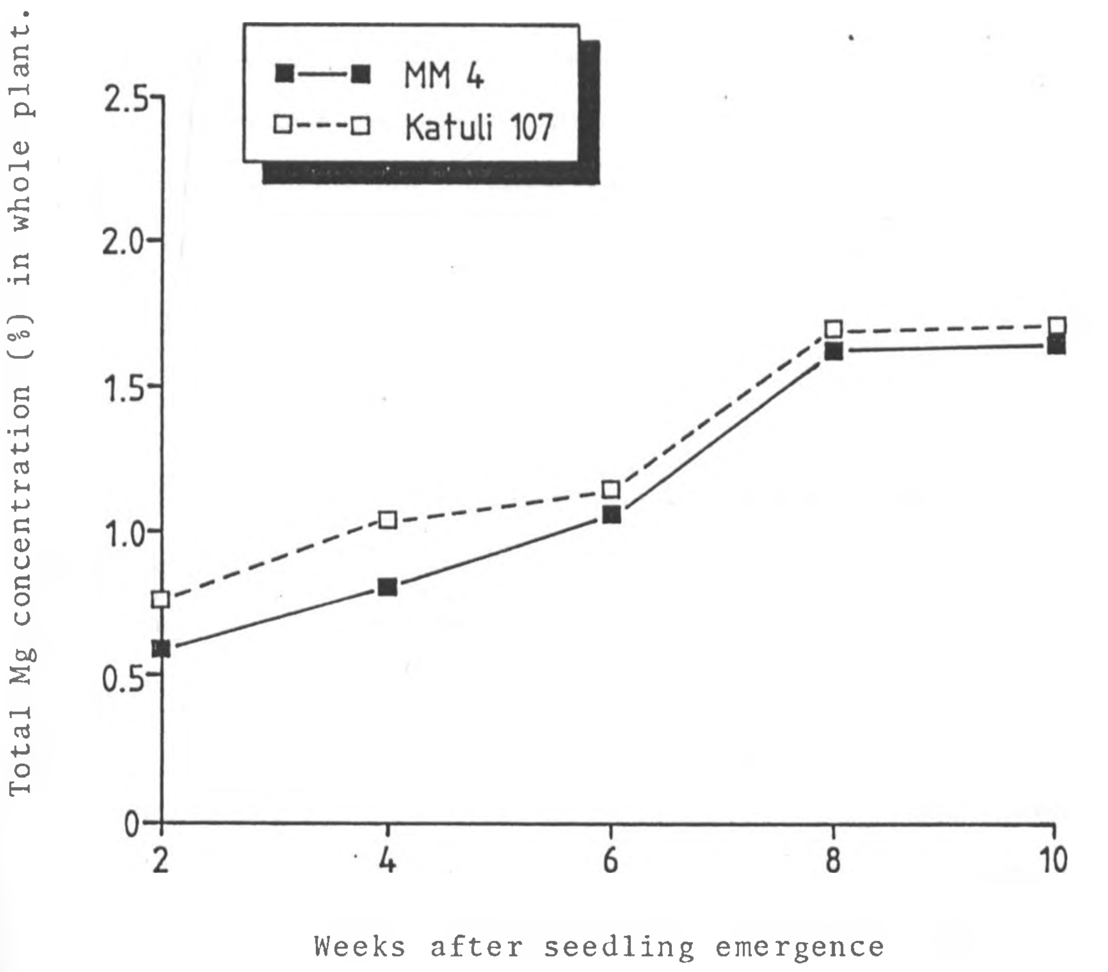



Fig. 4.12. Effect of sampling frequency on Mg concentration of the entire cowpea plant.

in the plant (table 4.9).

At flowering, the Mg concentration in the roots of both varieties doubled but remained fairly constant at pod setting time. Later during pod filling stage, there was a significant increase in Mg in the roots of both varieties but decreased thereafter. Throughout the growth period of the two cowpea varieties, the Mg concentration in the roots was highest in 'MM4' than in 'Katuli' (fig. 4.13).

Stem:

After the leaves, the stems had the highest amount of magnesium throughout the sampling period. For example, at two weeks after emergence, the stem had accumulated approximately 25% of the total magnesium in the plant in each variety (table 4.9). Later during flowering there were no changes in the magnesium concentration but increased significantly at pod setting and pod (seed) development and later levelled off (fig. 4.13).

From seedling up to flowering, 'Katuli' had maintained a higher magnesium concentration in its stems than 'MM4' but the situation was reversed thereafter.

Leaves and Petioles:

The leaves and petioles had the highest Mg concentration in the entire plant throughout the growing

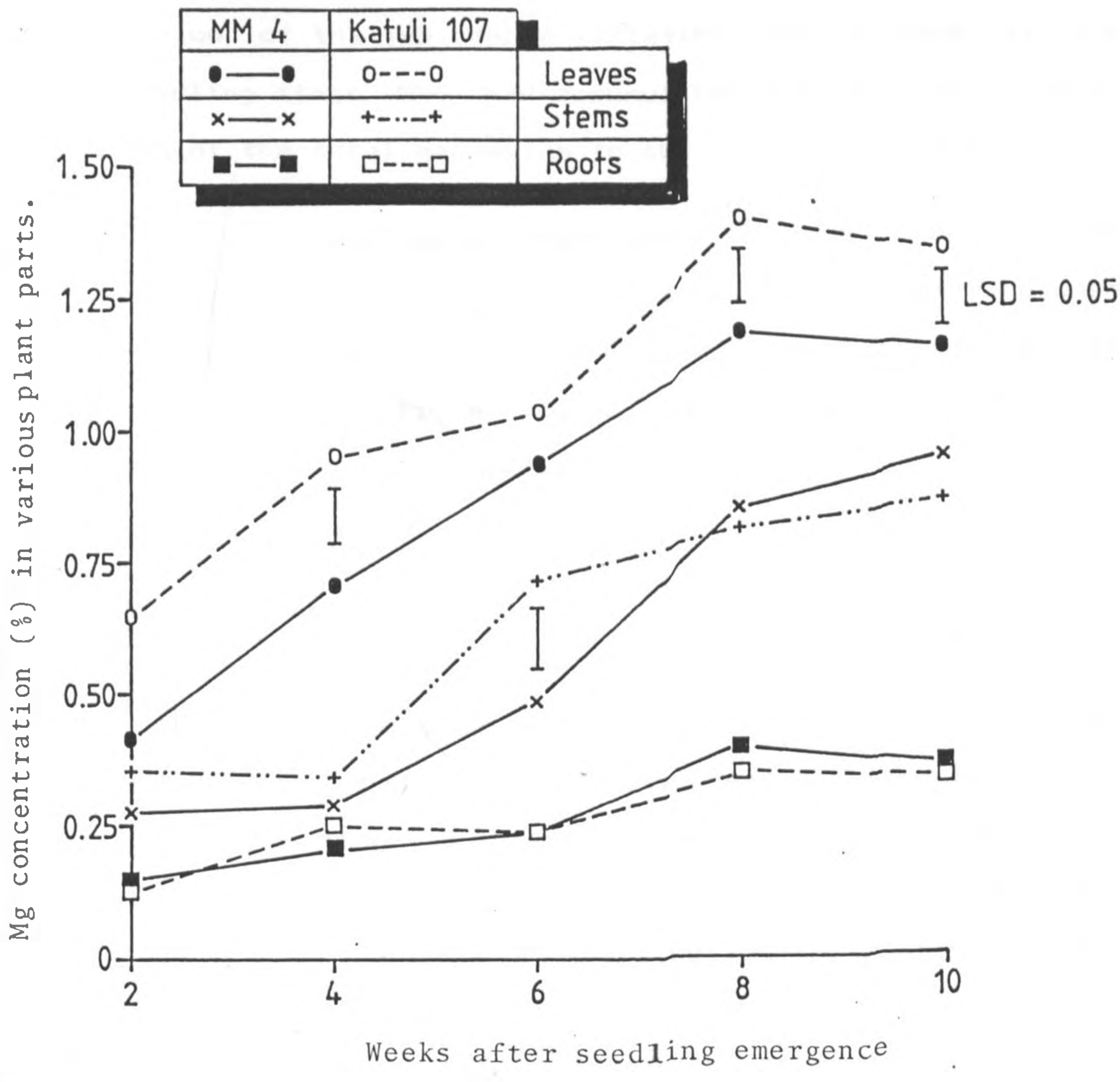



Fig. 4.13. Effect of sampling frequency on Mg concentration of various plant parts of cowpeas.

period of the two cowpea varieties. For instance at the seedling stage 'MM4' had accumulated over 65% and 'Katuli' 75% of the total magnesium in the plant (table 4.9).

There was a slight increase in Mg concentration during the pod setting but a fairly significant increase at pod filling stage (P = 0.05). In all the stages of sampling, 'Katuli' maintained a higher Mg concentration than 'MM4' in their leaves (fig. 4.13).

Sulphur:

Whole plant:

The sulphur concentration decreased sharply during the second sampling and increased in the third and fourth sampling in the two varieties (table 4.10). The increase in sulphur concentration in both varieties between second and fourth sampling is linear (fig. 4.14). The sulphur decreased sharply after the fourth sampling. The two varieties accumulated fairly the same amount of sulphur over the sampling periods.

Roots:

Like in the whole plant, the sulphur concentration in the roots decreased sharply in the second sampling (fig. 4.15). In the subsequent growth stages, 'MM4' had a sharp increase particularly in the third and fourth sampling but decreased in the final sampling. 'Katuli' on the other hand maintained a fairly constant

Table 4.10 Sulphur concentration (%) in different parts of two cowpea varieties during their growth period.

| Sampling frequency (weeks after seedling emergence) | Mm4 | | | | Katuli | | | |
|---|---|---|---|---|---|---|---|---|
| | Roots | Stems | Leaves | Total | Roots | Stems | Leaves | Total |
| 2 | 0.027ab* | 0.056ab | 0.062ab | 0.145a | 0.033b | 0.087ab | 0.132a | 0.252a |
| 4 | 0.011a | 0.012a | 0.037a | 0.060a | 0.018a | 0.013a | 0.062ab | 0.093a |
| 6 | 0.069bc | 0.102bc | 0.278bc | 0.449b | 0.035b | 0.173bc | 0.252bc | 0.460b |
| 8 | 0.103c | 0.412c | 0.384c | 0.899c | 0.024ab | 0.381c | 0.345c | 0.752b |
| 10 | 0.079bc | 0.269c | 0.207bc | 0.551b | 0.034b | 0.172bc | 0.394c | 0.601b |

*Mean separation within columns by Duncan's multiple range test, 5% level.

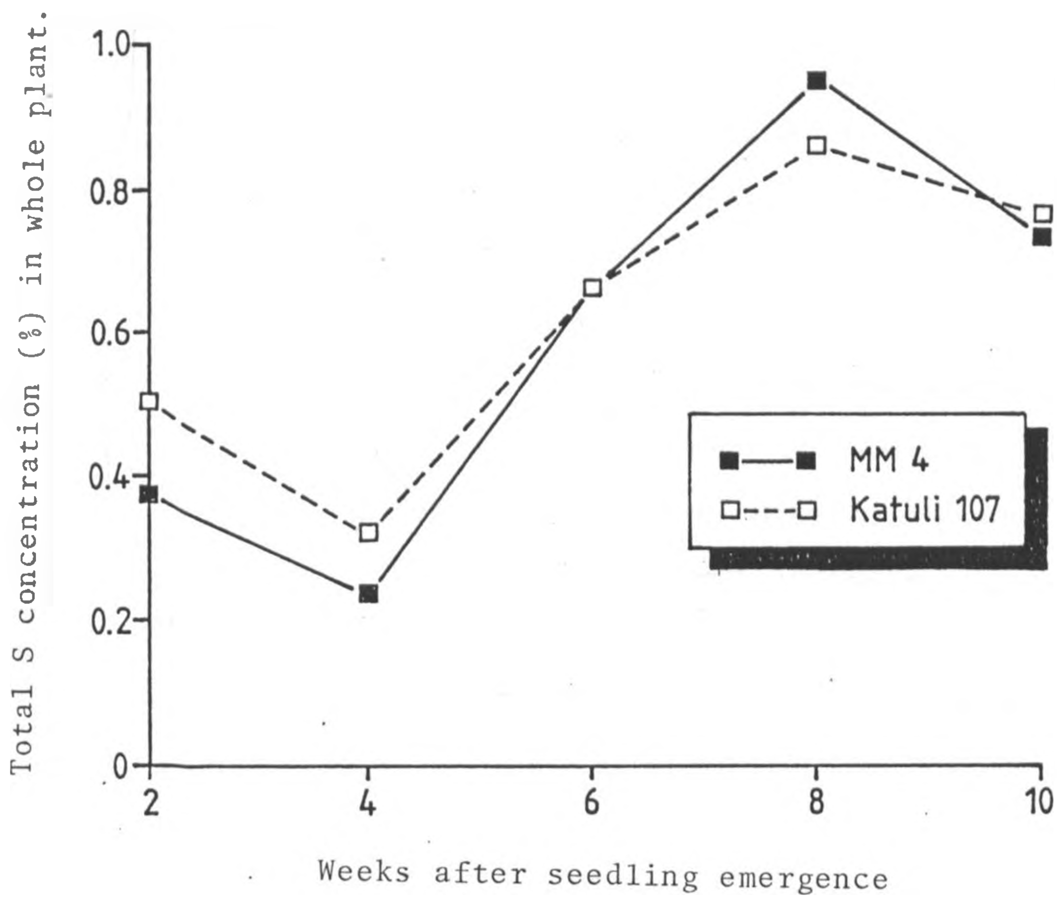



Fig. 4. 14. Effect of sampling frequency on S concentration of the entire cowpea plant.

amount of sulphur in its form from the second sampling up to the final sampling stage. There was a significant difference in the sulphur concentration at the 2nd and 4th sampling stages (P = 0.05) only (fig. 4.15 and table 4.10).

Stems:

Like in the whole plant and the roots both varieties were characterised by a decrease in the sulphur concentration during the second sampling (fig. 4.15). From the second sampling up to the fourth, both varieties had a sharp increase in sulphur concentration in their stems but decreased sharply in the final stage of sampling (fig. 4.15). In all the sampling stages except in the 4th sampling where there was a significant increase (P = 0.05) both varieties accumulated fairly the same amount of sulphur in the rest of the sampling periods (table 4.10).

Leaves and Petioles:

As in the other plant parts, the sulphur content decreased in the leaves in the second sampling (table 4.10). There was a significant (P = 0.05) increase in sulphur concentration in the third and fourth sampling stages in both varieties. The fifth sampling was characterised by a gradual decrease of S concentration (fig. 4.15).

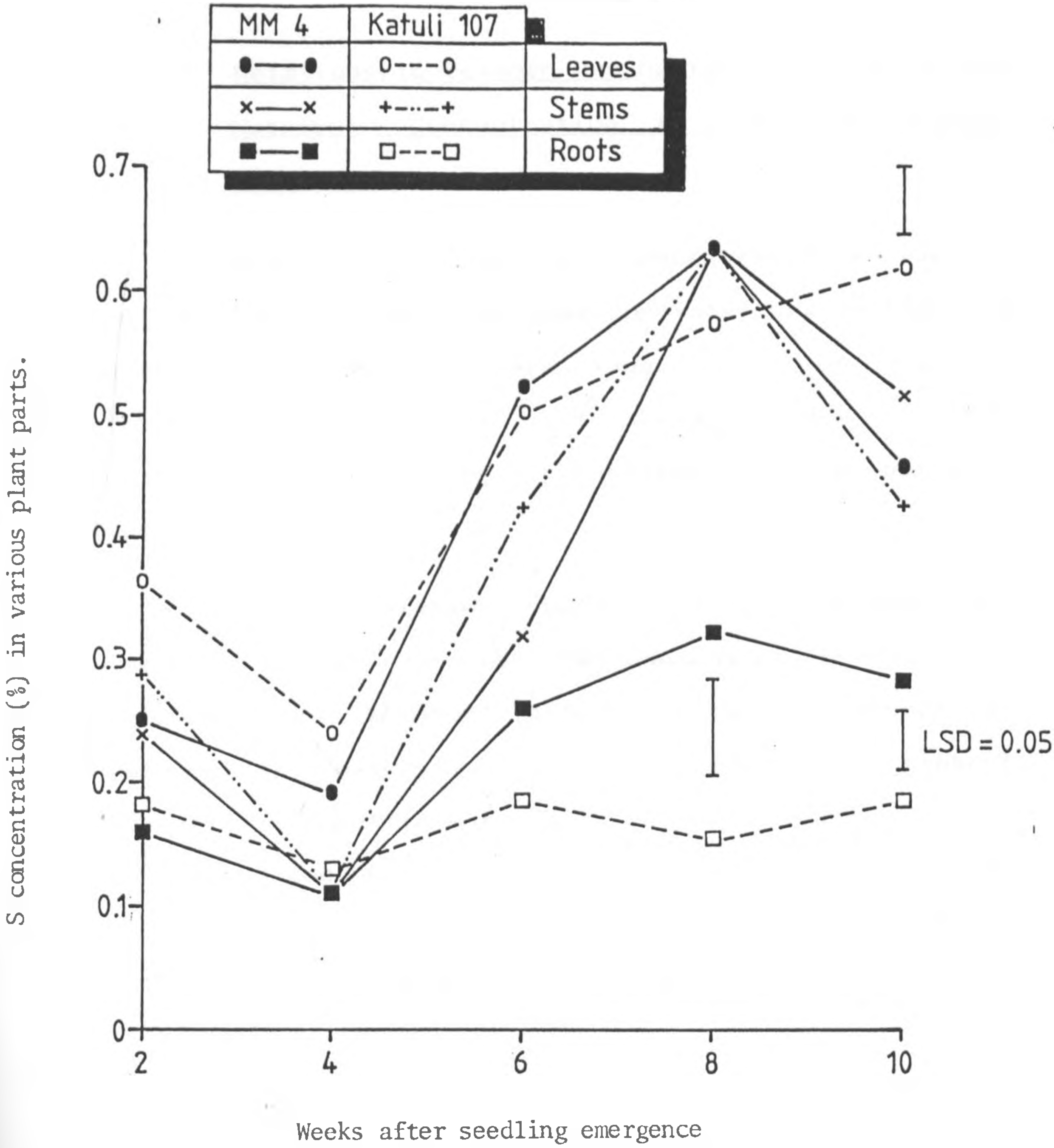



Fig. 4.15. Effect of sampling frequency on S concentration of various plants parts of cowpeas.

Relationship Between Dry Matter Accumulation and Nutrient Concentration in the Two Cowpea Varieties:

When the total nutrient concentration in various sampling periods were regressed on total dry matter, a number of observations were made. First of all the correlation coefficients (r) between dry matter accumulation and nutrient concentration were positive (Table 4.11).

The correlation coefficient (r) between dry matter accumulation and nitrogen concentration was high and significant in nearly all growth stages except at physiological maturity (Table 4.11). The highest correlation coefficient (r) between dry matter accumulation and phosphorus concentration occurred between seedling emergence and flowering but decreased significantly in the subsequent stages of growth (Table 4.11).

The correlation coefficients (r) between potassium and calcium concentrations and the total dry matter was low and insignificant in all growth stages except at flowering in both varieties (Table 4.11). As for magnesium and calcium, the correlation coefficients between their concentrations and dry matter was low and insignificant in all growth stages (Table 4.11). There was no significant varietal differences in the correlation

Table 4.11. Correlation coefficient (r) between dry matter accumulation and nutrient concentration at specific growing period of two cowpea varieties.

| Frequency weeks after seedling emergency | 'MM4' | | | | | | 'Katuli 107' | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | N | P | K | Ca | Mg | S | N | P | I | Ca | Mg | S |
| 2 | 0.99 | 0.91 | 0.37 | 0.19 | 0.22 | 0.71 | 0.99 | 0.99 | 0.63 | 0.34 | 0.68 | 0.73 |
| 4 | 0.96 | 0.99 | 0.85 | 0.88 | 0.63 | 0.56 | 0.97 | 0.99 | 0.96 | 0.71 | 0.51 | 0.32 |
| 6 | 0.98 | 0.87 | 0.27 | 0.99 | 0.19 | 0.37 | 0.97 | 0.95 | 0.59 | 0.87 | 0.45 | 0.16 |
| 8 | 0.82 | 0.85 | 0.51 | 0.62 | 0.48 | 0.29 | 0.97 | 0.69 | 0.38 | 0.78 | 0.56 | 0.27 |
| 10 | 0.35 | 0.49 | 0.26 | 0.23 | 0.27 | 0.42 | 0.96 | 0.53 | 0.36 | 0.49 | 0.33 | 0.59 |

coefficients (r) between their dry matter accumulation and nutrient concentration.

There was a high multiple linear correlation coefficient (r) between dry matter accumulation, nitrogen concentration and sampling frequency with a coefficient of determination $R^2 = 0.97$ and 0.84 ($P = 0.05$) in 'MM4' and 'Katuli 107' respectively (Table 4.12). Phosphorus had also a high and significant coefficient of determination $R^2 = 0.95$ and 0.90 ($P = 0.05$) in 'MM4' and 'Katuli 107' respectively.

Table 4.12. Multiple linear correlation coefficient (r) coefficient of determination ($R^2$) between total dry matter, time and nutrient of two cowpea varieties.

| | 'MM4' | | | | | | 'Katuli 107' | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | N | P | K | Ca | Mg | S | N | P | K | Ca | Mg | S |
| r | 0.98 | 0.97 | 0.46 | 0.72 | 0.61 | 0.67 | 0.92 | 0.90 | 0.68 | 0.69 | 0.76 | 0.53 |
| $R^2$ | 0.97* | 0.95* | 0.22 | 0.52 | 0.37 | 0.45 | 0.84* | 0.81* | 0.46 | 0.48 | 0.57 | 0.28 |

*Significant P = 0.05

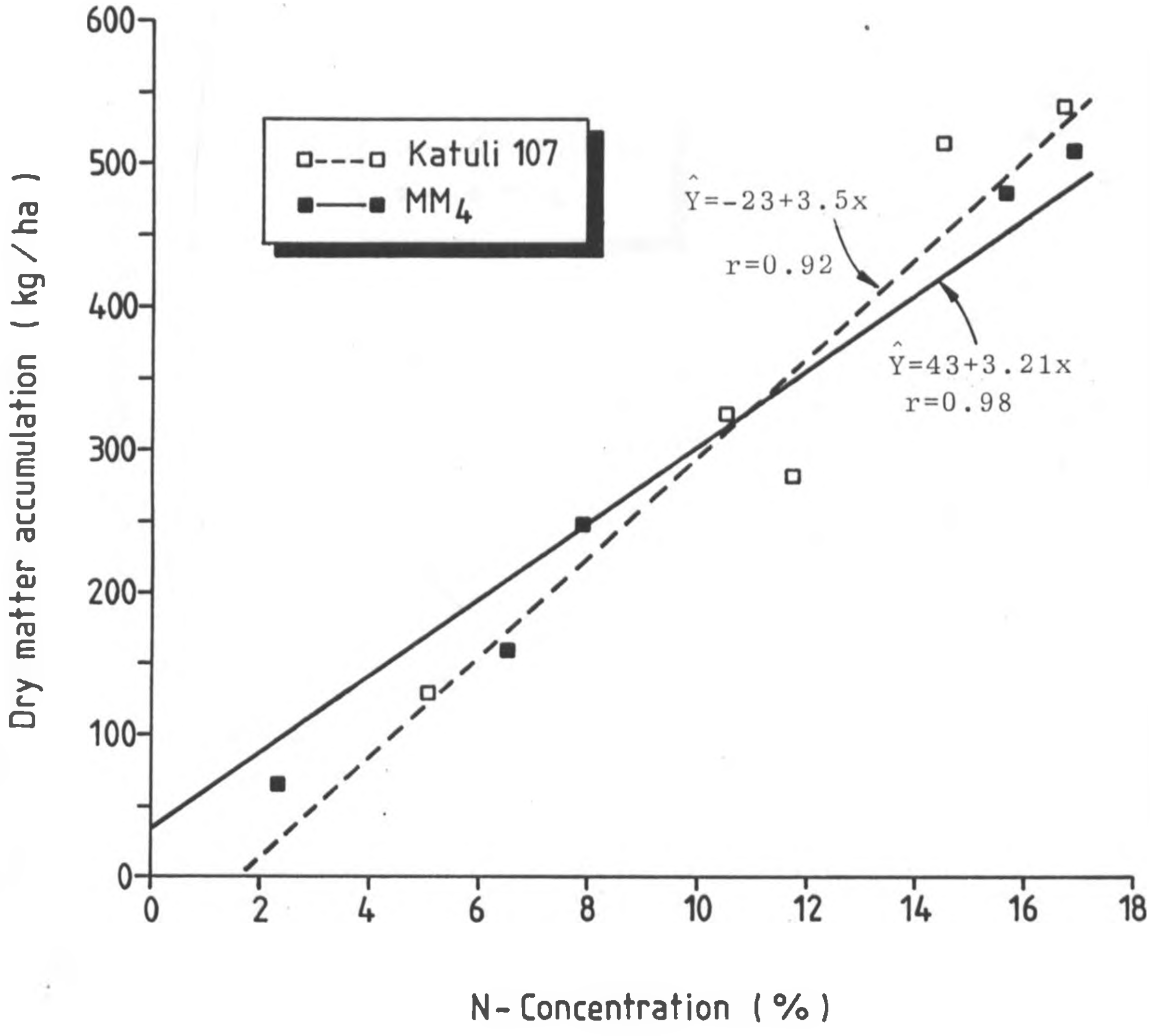



Fig. 4.16 : Relationship between N concentration (%) and dry matter accumulation (kg/ha).

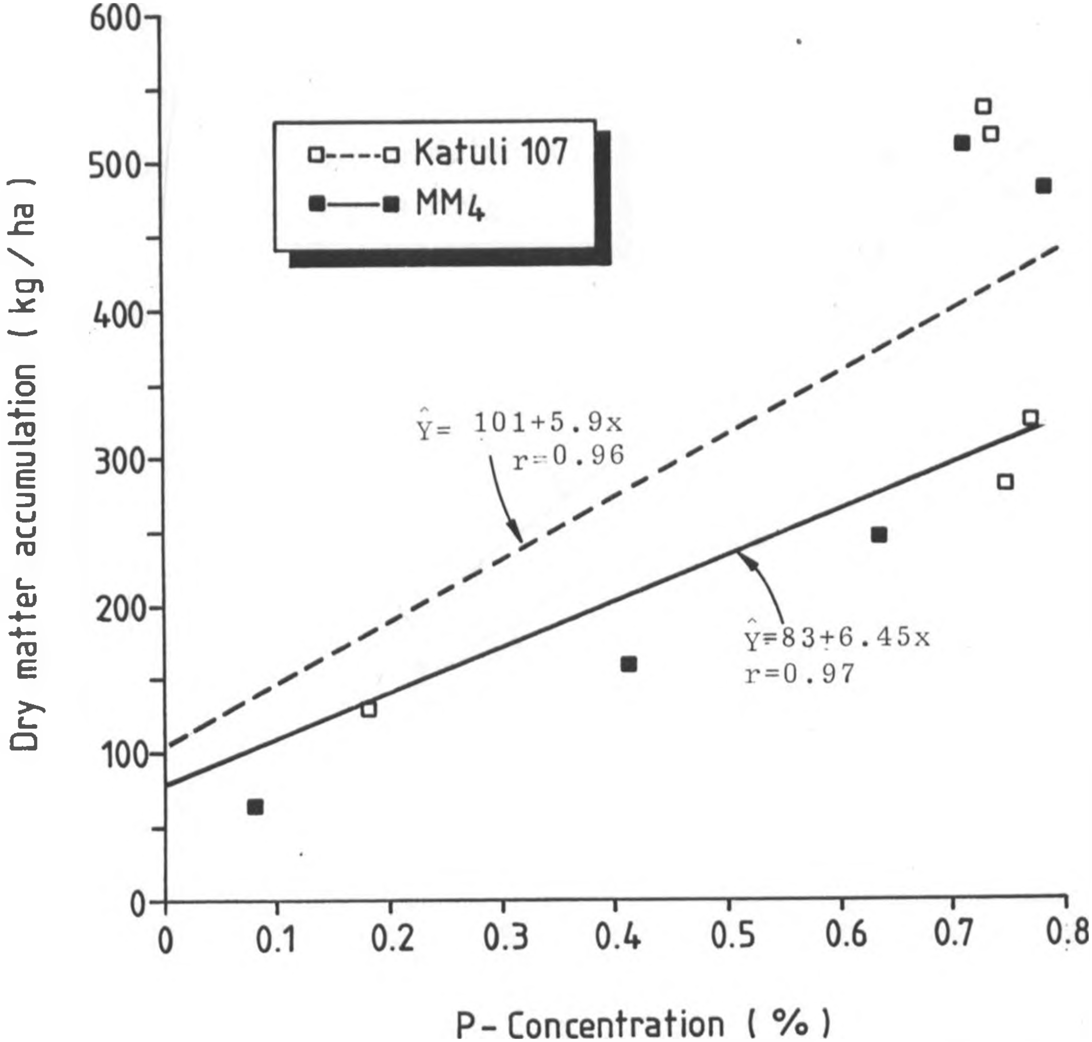



Fig. 4. 17: Relationship between P concentration (%) and dry matter accumulation (kg/ha).

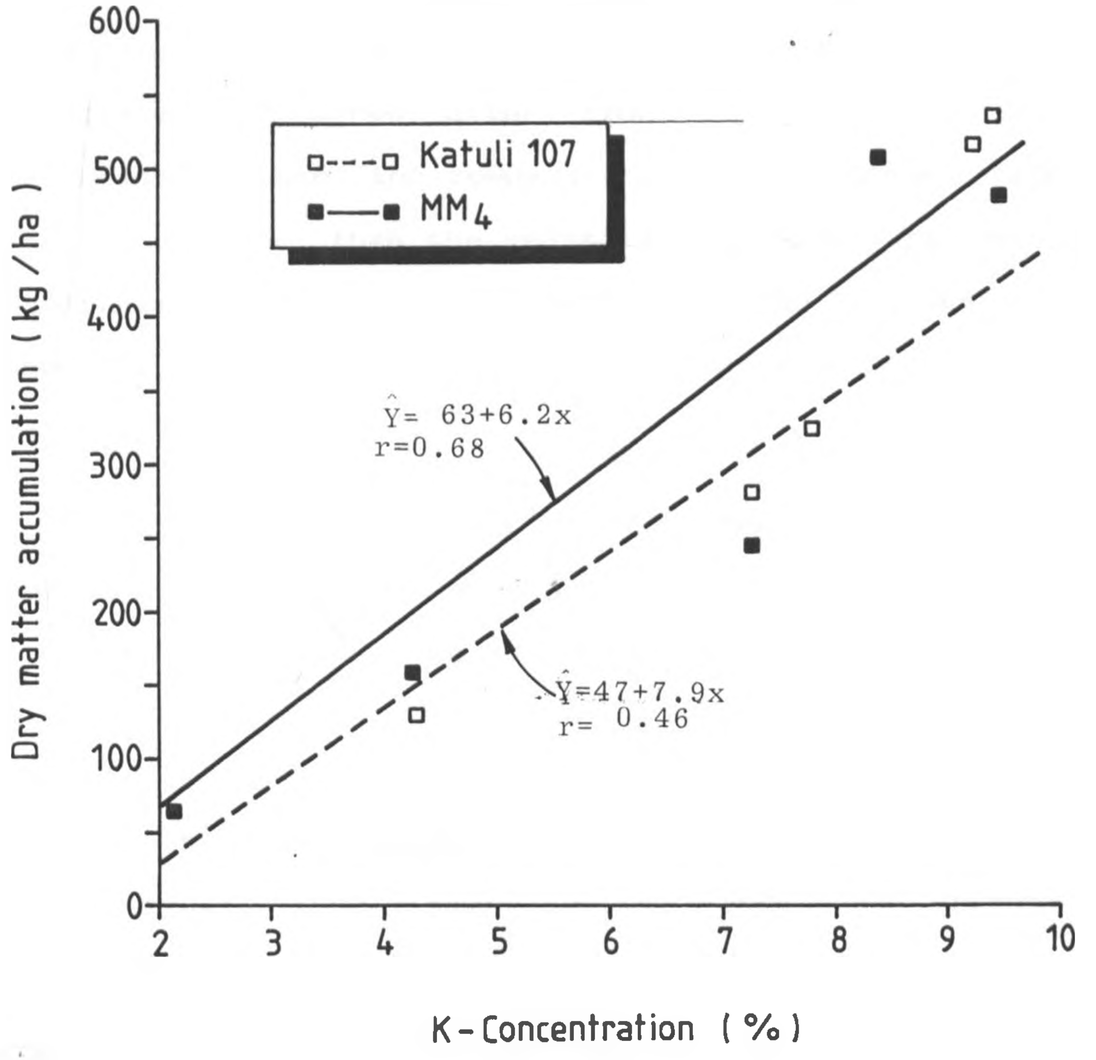



Fig. 4.18 Relationship between K-concentration (%) and dry matter accumulation (kg/ha).

# DISCUSSION

## Dry Matter:

The dry matter yields reported in this study showed that the major part of the total dry matter accumulation occurred after flowering. During this reproductive phase the cowpeas accumulated three times more dry matter than the vegetative phase. The major contributor to the total dry matter in the reproductive phase were the leaves which accounted for over 70% of the total dry matter.

Eaglesham *et al.* (1977) reported similar findings in cowpeas and attributed the large increase of dry matter after flowering to continued expansion of those leaves which were immature at flowering. They also attributed the increase in stems dry matter after flowering to the progressive thickening of the stems. Karlem *et al.* (1980) also observed that the highest increase in the total dry matter increased significantly after flowering. They attributed this increase in dry matter primarily due to vegetative development.

At pod filling stage, there was a slight decrease in the dry matter accumulation in the stems and leaves. This slight decrease in the dry matter was attributed to the fall of senesced leaves (Littleton *et al.*, 1978).

In this study, dry matter apportioned to various parts showed that the leaves accounted for the highest dry matter (over 70%) while stems and root accounted for 20 - 25% and 7 - 10% of the total dry matter, respectively. As in cowpeas, the leaves of sweet peppers contributed most of the dry matter for up to 56 days after transplanting (Miller *et al.*, 1979). Littleton *et al.* (1979) in their study of growth and development of cowpeas similarly noted that the roots contributed the least to the total dry matter. They further observed that the dry matter of the stems increased steadily up to 52 days after emergence while the dry matter of the leaves tended to decrease after mid pod fill. This continuous increase in the dry matter of the leaves up to mid pod fill may have been due to production of new leaves at flowering.

At all sampling stages, Katuli accumulated higher total dry matter than 'MM4'. One possible reason is that 'Katuli' and more branches and more leaves than 'MM4' which resulted in more dry matter production.

There seemed to be a definite relationship between dry matter production and seed yield. In this study 'Katuli' produced the highest dry matter and also the highest grain yield. Shakoor *et al.*, (1984) also observed that the variety that gave the highest dry matter production also gave the highest seed yield. However, Afolabi, (1980) working with local and improved cowpea varieties noted that the local varieties accumulated more dry matter than the improved varieties but with no grain yield advantage.

Eaglesham *et al.* (1977) noted that the highest dry matter accumulation was in the effectively nodulating cowpeas. In this study 'MM4' produced significantly more nodules than 'Katuli'. Most of the nodules produced by these two varieties were small and distributed all over the plant roots. In accordance to F.A.O. manual on "Legume innoculants and their use" (1984) such nodules are considered ineffective in fixing nitrogen symbiotically. It is probably for this reason that although 'MM4' produced higher number of nodules than 'Katuli' it still had low dry matter production. This ineffectiveness of the nodules could have been brought about by lack of effective rhizobium bacteria in the soil or probably due to deficiency of certain mineral elements such as molybdenum which is essential for effective nodulation (Summerfield *et al.*, 1976).

Grain Yield and its Components:

Grain yield of 'Katuli' was significantly higher than that of 'MM4'. This indicated that there was a striking difference in the ability of the two varieties to produce seeds. It appeared that the most important variable was the number of pods per plant. Closely related to this was the number of seeds per pod. As shown on table 4.2, 'Katuli' had an average of 14.6 pods per plant while 'MM4' produced an average of 9.8 pods per plant. That was a difference of almost 5 pods per plant.

It appeared that the seed weight played a minor role in the seed yield. Although 'MM4' had a significantly higher seed weight (per 1000 seeds), it was nevertheless outyielded by 'Katuli'. Afolabi (1980) and Shakoor *et al.* (1983) attributed the grain yield of several cowpea varieties to the number of pods per plant and the number of seeds per pod and not seed size or seed weight per 1000 seeds. It would therefore appear that a good cowpea variety is one with heavy podding ability and a greater capacity to fill those pods. Once these conditions are met, it appears that what is lost in seed size or weight can be regained by the increased number of seeds in the pods (Afolabi, 1980).

'Katuli' is an early maturing variety and flowers 10 days earlier than 'MM4' and also matures almost one month earlier than 'MM4'. Since cowpeas are mostly grown in the semi-arid and arid areas of this country (Muruli *et al.*, 1980) an early maturing variety like 'Katuli' would be suitable in areas where the rains are both erratic and short.

Contrary to the findings of Afolabi (1981) who observed that local varieties which had higher dry matter than improved varieties had lower grain yield, the results of this study showed that 'Katuli' which had accumulated higher dry matter had also higher grain yield than 'MM4'. Shakoor *et al.* (1984) similarly observed that Katumani 80 which produced higher dry matter than the local varieties also gave the highest grain yield. Since most of the dry matter accumulation occurred at the pod filling stage and was mainly contributed by the leaves, it would therefore appear that the leaves offered a rich carbohydrate source for the seed (sink) development.

Nodules per Plant:

Several factors affect the degree of nodulation in cowpeas. Nodule production in cowpeas in Malaya was trebled by mulching and significantly increased by watering and was decreased by repeated cultivation (Mansefield, 1957). The degree and effectiveness of nodulation also increased with the application of P (Tewari, 1965; Mansefield, 1957; and Terada, 1971) and by low N application during early seedling growth (Dart, 1973; Ezedinma, 1964; Pate and Dart, 1961). In the current study, the number of nodules per plant in 'MM4' was significantly higher than that of 'Katuli 107'. The increase in the number of nodules per plant did not however reflect an increase in seed yield, dry matter or total N concentration in the plant. This would suggest that although the two varieties were nodulating, the nodules were not effective in N-fixation. Most of the nodules produced by the two varieties were small and distributed throughout the root system. According to F.A.O. Manual on "Legume innoculants and their use" (1984) such nodules are classified as ineffective. These ineffective nodules were reported not able to fix nitrogen. Cowpea varieties Ife Brown and Vita I were reported to have ineffective nodules (Summerfield *et al.*, 1977). Nodulation in 'MM4' and 'Katuli 107' was similar to those other cowpea varieties having ineffective nodules.

Results from several scientists working with cowpeas have indicated that effectively nodulating cowpeas were able to produce both high grain and dry matter yield. Summerfield *et al.* (1977) observed that effectively nodulating cowpeas were able to produce up to 57% higher seed yield than the non-nodulating cowpeas. They noted that the yield differences were largely due to the number of pods per plant which in itself depended on the product of three other components viz. branches/plant, peduncles/branch and pods/peduncle.

Nitrogen is a vital element in plant growth and since effectively nodulating cowpeas are known to fix about 87% of their N requirement (Eaglesham, 1977), then effective nodulation should be one of the major criteria for selecting local and exotic cowpea varieties. This would reduce the cost of applying N fertilizers to cowpeas and still obtain high grain and dry matter yields.

Nitrogen:

Hanway and Webber (1971) and Summerfield *et al.* (1977) working with soyabean and cowpeas, respectively observed that the total nitrogen accumulation was slow in the early stages of plant development but increased tremendously after flowering. They attributed this increase in N-accumulation to the effective nodulation which resulted to symbiotic N fixation.

Results of this study showed a similar trend. The leaves contained the highest N concentration at flowering and the roots contained the lowest. There was a general decrease of N concentration in the leaves at mid pod fill. This decrease in N concentration was also eminent in the roots and stems. Summerfield *et al.* (1977) and Patel *et al.* (1977) working with cowpeas and tomatoes respectively suggested that there was translocation of nitrogen from the vegetative to the reproductive parts.

There seemed to be a direct relationship between nitrogen concentration in the leaves and dry matter yields. Dart *et al.* (1977) observed that cowpea varieties that are capable of accumulating high N concentration either through fertilization or symbiotic N fixation are also capable of accumulating higher dry matter. In this study, 'Katuli' which accumulated higher nitrogen had higher dry matter production,

The relationship between seed yield and nitrogen concentration in the plant is still debatable. Cassman *et al.* (1981) indicated that high nitrogen accumulation in cowpeas resulted in increased vegetative growth and therefore delayed harvesting time without increasing seed yield. Minchin *et al.* (1976) however observed that increased N concentration in cowpeas either through fertilization or symbiotic N fixation resulted in increased grain yield. In fact they suggested that with certain rhizobium strain it may be necessary to provide the cowpea with inorganic nitrogen in order to maximise early vegetative growth and hence optimise subsequent seed yield. 'Katuli' significantly outyielded 'MM4' yet it also had a higher N concentration. Perhaps this higher grain and dry matter yields in 'Katuli' were due to genetic influence and not the nitrogen accumulation.

Several workers in U.S.A. have reported an increase in grain yield of cowpeas due to application of 40-600 kg of N/ha. they did not however report on the indigenous levels of soil N nor the effectiveness of nodulation and symbiotic N fixation (Dart *et al.*, 1977). Summerfield *et al.* (1977) on the other hand observed that effectively nodulating cowpeas without added N gave 57% higher yields than non-nodulating cowpeas which received 50 kg N/ha. In the current study, 'Katuli' and 'MM4' were found to have ineffective nodulation. Since N was found to be inadequate in the site, then N fertilization in the two varieties may result in an increase of both grain and dry matter yields. In these varieties would in return fix adequate symbiotic N necessary for protein synthesis and therefore higher grain and dry matter yields.

Phosphorus

In this study the total phosphorus in the whole plant was low at seedling stage but increased by almost 300% at flowering in both varieties. From mid pod fill up to harvest the total P concentration tended to decrease. The decrease was more eminent in the stems and leaves. This decrease in P concentration particularly in the leaves and stems at mid pod fill was explained by Hanway and Webber (1977). They suggested that there was mobilisation of P from these plant parts to the developing seeds. The leaves and the stems therefore offers a rich source of P for the seed (sink) development at the later stages of plant growth.

Adeptu (1979, and Bisen (1969) in their studies on nutrient flux in cowpeas found that P concentration was highest at flowering. Their results concurred with the results of this study. This would therefore suggest that P fertilization should be done at planting or in the early stages of plant growth before flowering to meet the high demand for P at flowering and pod filling stages. Nathan X.J. (1963) reported that P provided early in the life of the plant is important in laying down the primordia for its reproductive parts. Agarwala and Sharma (1976) have also shown that P provided early in plant growth improves root development and therefore enhances the plants ability to utilise other growth resources like water and mineral nutrients.

Although the two varieties in this study did not differ significantly in their P concentration, 'Katuli' accumulated slightly higher P concentration than 'MM4' in most of the growth stages. Whether the higher grain and dry matter yields realised from 'Katuli' were as a result of this high P concentration needs to .be investigated further. Cassman *et al.* (1981) and Summerfield *et al.* (1974) working on cowpeas noted a significant increase in both dry matter and grain yield upon P application on well nodulated cowpeas. They attributed this increase to well developed nodules which resulted to higher symbiotic nitrogen fixation.

The trial site where this study was conducted was low in soil P (table 3.2). This could have resulted in poor nodule development and hence low symbiotic N-fixation. This would suggest that P fertilization on cowpeas would therefore be necessary in soils low in P. The applied P would improve root and nodule development which in turn would enhance symbiotic N-fixation resulting in higher grain and dry matter yields.

Potassium:

As in P, the increase in Potassium concentration in the whole plant was highest in the early stages of growth i.e. between seedling and flowering. At mid pod fill, 65% of the K was contained in the leaves, 28% in the stems and 7% in the roots. There was however a decrease in K concentration in the leaves and stems after mid pod fill. Adeptu (1979) in his study of growth and nutrient influx in cowpeas had similar findings. He attributed the decrease of K concentration in the leaves after mid fill to mobilisation of K from the leaves to the developing seeds.

No major metabolic process is known where K has a direct effect in plant growth (Abrol *et al.*, 1977). However K has been reported to be involved in a number of catalytic process, e.g. incorporation of amino acids in protein synthesis and synthesis of peptide bonds (Agarwala and Sharma, 1976). It is perhaps for this reason that K content was high in the early stages of growth when the plant was actively growing. Hanway and Webber (1971) working with soyabeans observed that there was no increase in either dry matter or grain yield by application of K. They however, noted that application of K in combination with P gave significantly higher grain yield.

Summerfield *et al.* (1974) working with cowpeas noted that although there was no significant increase in grain yield of cowpeas after applying 40 kg of K/ha, they however noted that there was an increase in the number of effective nodules. According to a soil survey report (Siderius and Muchena, 1977) most of the soils in Kenya have been shown to have adequate amount of K. Recent work on fertilizer requirement of dry beans *(Phaseolus vulgaris)* carried out by National Horticultural Research Station (Thika) (unpublished) indicated that beans did not respond to various rates of K applied in terms of grain influx in cowpeas had similar findings. He attributed the decrease of K concentration in the leaves after mid fill to mobilisation of K from the leaves to the developing seeds.

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In this study although the two varieties accumulated fairly high amounts of K (tables 4.8), this may not however reflect the importance of the mineral nutriet to the plant in terms of dry matter production or grain yield. Williams (1980) noted that although nappier grass removed huge quantities of K from the soil, added K did not however increase the herbage yield significantly. It can therefore be suggested that K may not be a limiting factor in cowpeas production in Kenya at present.

Calcium:

The calcium accumulation in the whole plant was highest at flowering and pod filling stages of plant growth. The leaves accounted for over 85% of the total calcium contained in the plant. Summerfield *et. al.* (1974) observed that the highest Ca concentration was also in the leaves and that it occurred 40-50 days after plant emergence which agrees with the findings of this study. Agarwala and Sharma (1976) observed that Ca was necessary for cell elongation and hence in the development of meristematic tissues. They also noted that Ca is a constituent of middle lamella of the cell walls and it is for this reason that it tends to accumulate more in the leaves. Since 'Katuli' had more branches and leaves and more meristematic tissues than 'MM4', this explains the reason for the high accumulation of calcium in the variety.

The relationship between seed yield and Ca content may be difficult to establish in this study because there is a strong interdependence between $Ca^{2+}$, $Mg^{2+}$ and $K^{+}$. An imbalance of any one of these mineral nutrient tends to inhibit the influx of the other and may therefore blur the measurable parameter (Halmark and Barber, 1981). This study however, showed that 'Katuli' which had a higher grain and dry matter yield also had higher Ca content. Direct effect on Ca on yield can probably be determined in pot experiments where other mineral nutrients are controlled.

Jacques *et al.* (1975) Karlem and Whitney (1980) and Adeptu and Akapa (1977) working on sorghum, wheat and cowpeas respectively reported that there was no grain yield advantage by applying high amounts of Ca to these crops. Summerfield *et al.* (1974) observed that Ca added as agricultural lime in U.S.A. where soils were acidic improved the grain yield of cowpea. According to Siderius and Muchena (1977) soils low in Ca are commonly found in high rainfall (pH values below 4.5) and where leaching is high. In the trial site where this study was conducted leaching is low, has average annual rainfall of 800 mm (averaged over 10 years) and has sufficient amount of Ca (Table 3.2). Calcium is also adequate in most of the arid and semi-arid areas of Kenya where cowpeas are grown.

It may however be necessary to examine the effect of applied Ca on grain and dry matter yields of the high rainfall areas and in areas where cowpeas are grown under irrigation. It may further be necessary to establish whether there is a relationship between high Ca accumulation and yields of dry matter and grain.

Magnesium:

The total Mg concentration was low at the seedling stage but increased by almost 70% by mid pod fill. In all the sampling stages, the leaves of both varieties had the highest concentration of Mg, followed by the stems and finally the roots. This high Mg concentration in the leaves have been reported by several workers in different crops. Jacques *et al.* (1975) Halbrook and Wilcox (1980) and Jacquinot (1967) working with sorghum, tomatoes and cowpeas respectively, found that the highest Mg content in these crops was in the leaves. This high Mg content in the leaves could be due to the fact that magnesium is a constituent of chlorophyll (Nathan, 1963).

Although there were no significant varietial differences ($P = 0.05$) in Mg concentration, 'Katuli' had slightly higher Mg concentration than 'MM4' in most of the sampling periods. Jacquinot (1967) working with four cowpea varieties observed that the more productive cowpea cultivars had a higher Mg concentration. In this study 'Katuli' had significantly higher ($P = 0.05$) grain and dry matter yield than 'MM4' and also higher Mg concentration. Leaves of 'Katuli' contributed over 60% of the plants dry matter and since the total Mg concentration was largely contributed by the leaves then there seems to be a relationship between dry matter yield and Mg concentration.

Magnesium is known to play a catalytic role as an activator of a number of enzymes most of which are involved in carbohydrate metabolism, phosphate transfer and decarboxylation (Nathan, 1963). It has recently been shown to be essential constituent of polyribosomes, the key organelle involved in protein synthesis (Agarwala and Sharma, 1976). Although Mg is involved in all these physiological processes, Summerfield *et al.* (1974) observed that there were no responses to Mg application in terms of vegetative growth and seed yield. Jacquinot (1967) had however reported that Mg application in combination with other mineral elements like P and K led to increased dry matter production. These trials by Jacquinot (1967) were based in the humid tropics where rainfall was over 1500 mm per annum. These soils are likely to have had low levels of Mg due to leaching.

Miller *et al.* (1979) working on sweet peppers observed that although some varieties had higher Mg uptake than others, this increase in uptake was however not reflected to the final fruit yield. This would suggest that the ability of a plant to accumulate high Mg could be due to genetic influence. A variety may have a well developed root system with numerous root hairs than the other and therefore increases the surface area of absorbing both nutrients and water. The trial site where this study was conducted had levels of Mg which could be described sufficient to rich (table 3.2). It may be however necessary to examine the effect of applied Mg on the grain and dry matter yield in high rainfall areas and also in irrigated area where leaching may be high. These areas however constitute a very small fraction of the cowpea growing areas in Kenya.

Sulphur

The S concentration in the whole plant decreased from seedling to flowering but increased thereafter sharply up to pod filling stage in both varieties (fig. 4.13). The period of high accumulation of S in the two cowpea varieties coincided with active nodulation and nitrogen fixation. Agarwala and Sharma (1976) reported that sulphur is required in N-fixation by leguminous plants and this perhaps explains the reason for the high rate of accumulation of S between these stages.

Karlem and Whitney (1980) working with wheat noted that sulphur concentration in the whole plant remained extremely variable and showed no significant statistical trends. In this study, there are three distinct trends of accumulation of sulphur in the plant. A decrease in the initial stages of plant growth an increase from flowering to pod filling and a decrease thereafter (fig. 4.13).

Jacquinot (1967) noted that although S is an important mineral nutrient, cowpeas absorbed very small quantities of S estimated at 0.4 kg per 100 kg of seed harvested. With an average production of 1600 kg of seed per ha in 'Katuli' variety, then the S requirement would be 6.4 kg of S/ha.

Although Kang *et al.* (1977) reported growth responses to S application in a cowpea experiment carried out in a greenhouse, Nangju (1980) in a field experiment observed that S application did not significantly increase the grain yield of the varieties tested. There was however an increase in the S concentration in the seeds of those varieties. Nangju (1980) further noted that when S was applied in combination with P and K, there was significant increase in the grain yield. He therefore suggested that to obtain valid comparisons of different varieties to S application, the cowpea have to be grown in a fairly homogenous soil under the same fertilizer management so that differences in S accumulation in the varieties can be attributed to their genetic variability.

In this study, 'Katuli' had a significantly higher ($P = 0.05$) grain and dry matter yield but the two varieties had the same S concentration in most of the sampling periods. One can therefore not attribute the high grain and dry matter yields to high S concentration in the tissues. One striking feature however is that both varieties had a significant increase in S accumulation between flowering and mid pod fill. This increase in S concentration was mainly attributed to the increase in S concentration in the leaves and roots during this period which suggests the involvement of S in nodule activity (Agarwala and Sharma, 1976) and also activation of a number of enzymes participating in the dark reaction of photosynthesis (Fox *et al.*, 1977).

## Relationship Between Dry Matter Accumulation and Nutrient Concentration in the Two Cowpea Varieties.

The result from this study shows that there was a positive and linear relationship between N concentration and dry matter accumulation. This would suggest that the higher the N concentration in cowpea plant, the higher the dry matter accumulation. Since the N concentration and dry matter accumulation were continuous up to physiological maturity, it would be difficult to pin point the period when the application of the nutrient would be most appropriate in terms of increased dry matter. It has however been established that effectively nodulating cowpeas are known to fix about 87% of their N requirement

(Eaglesham, 1977). Selection of such varieties would be cheaper than applying N to cowpeas. An example of such varieties are TVX and Vita 4 both developed in International Institute of Agriculture, Nigeria and K 80 developed in Katumani, Kenya. These varieties would have an average grain yield of 2.5 t/ha as compared to 'MM4' whose average grain yield is 0.90 t/ha.

The significant linear regression observed between dry matter accumulation, P concentration and frequency of sampling between seedling emergence and flowering suggests that P application should be done at planting. Application of P at planting will not only help the plant meet the high demand for the nutrient at flowering and pod filling stages but will also enhance early root development enabling the plant to absorb other nutrients including moisture (Nathan X.J. 1963). Although the soils in the experimental site had adequate amounts of P (22.28 ppm) there is need to investigate whether high P levels would significantly increase the dry matter and grain yields as reported by Cassman *et al.* (1981) and Summerfield *et al.* (1974).

The correlation between K concentration and that of dry matter accumulation was only significant at flowering. This suggests that K should be applied either at planting or top dressed just before flowering where soils are found to be deficient in potassium. In the present study, the area where the study was conducted had sufficient K (0.35-0.68%) and hence application of K would not be necessary in such soils. Summerfield *et al.* (1974) did not observe any significant increase in either dry matter or grain yield after applying 40 kg of K/ha but noted an improvement in nodulation.

The significant linear regression between Ca concentration and dry matter accumulation between flowering and pod setting stages would further suggest that application of the nutrient prior to flowering would enhance growth of cowpeas at subsequent growth stages. Summerfield *et al.* (1974) noted that application of Ca as agricultural lime in acidic soils in U.S.A. improved both grain and dry matter yields. The present study was conducted in an area where pH was moderate (5.0-5.4) and soil Ca was in sufficient quantities. This indicated that added Ca may not improve dry matter accumulation.

Magnesium and S concentrations did not have any significant correlation with dry matter accumulation at all stages of growth. This would suggest that application of these two nutrients may not improve dry matter yields of cowpeas. Jacquinot (1967) reported an increase in dry matter production when Mg was applied in combination with P and K in humid tropics where rainfall was over 1500 mm per annum. Nangju (1980) in a field experiment did not observe any significant increase in dry matter or grain yield in cowpea. The site where this study was conducted had sufficient Mg (3.75%) and S (9.5 ppm) and therefore application of these nutrients may not improve dry matter accumulation.

# CONCLUSIONS AND RECOMMENDATIONS

The results of this study have indicated that 'Katuli 107' was a more superior variety in most of the parameters studied. It accumulated higher dry matter and grain yield and it had also the ability to accumulate higher levels of the mineral elements analysed.

The high dry matter accumulation in 'Katuli 107' was due to the fact that variety has larger plants than 'MM4' and therefore had more branches and leaves per plant. The leaves alone accounted for more than 70% of the total dry matter in 'Katuli 107' and about 60% in 'Katuli 107'. As it has been reported by other workers, plants with the ability to produce high dry matter also produce higher grain yield and that was the case in this study. Such a variety would be useful in the marginal areas of this country where people utilise the young tender leaves as vegetable and also consume the seeds after harvest.

There were differences in the grain yield with 'Katuli 107' outyielded 'MM4'. The high grain yield was as a result of a higher number of pods per plant and a higher number of seeds per pod. This is one of the major criteria which should be used in selecting high yielding cowpea varieties.

Coupled closely to the grain yield is the ability for a cowpea variety to nodulate effectively. In this study 'MM4' produced higher number of nodules per plant than 'Katuli 107', however, 'MM4' accumulated lower amounts of N than 'Katuli 107' suggesting that most of the produced by 'MM4' were not effective in symbiotic N-fixation. As it has been reported by other workers selection of effectively nodulating cowpea varieties would be a major prerequisite for higher grain and dry matter yields. This would reduce the cost of N fertilizer application which would be the case in non-nodulating cowpea. Selection of such varieties need to lay emphasis on cowpea that would utilise the indigenous rhizobium strains to nodulate without artificially inoculating them.

From this study, it was also evident that the period of the highest nutrient accumulation was at pod filling stage except for P. The period of active accumulation of P occurred between seedling and flowering thus suggesting the importance of this mineral nutrient in the early stage of growth. Amongst the mineral nutrients studied, the most important in cowpea growth could be considered as N, P and S in that order.

Since P accumulation occurred in the early cowpea growth, it would be recommended therefore that P application be done at planting time to coincide with the high accumulation rate in those early stages of plant growth. The rates of application needs to be determined in different soils in different agro-ecological zones.

Sulphur appeared to accumulate at a higher rate between flowering and pod filling stages when the cowpea was actively nodulating. The response of cowpeas to S application as reported by other workers has been variable from one agro-ecological zone to the other. It may therefore be necessary to test the response of cowpeas to S application in terms of grain and dry matter yield both in the humid and semi-arid areas where cowpeas are grown.

Although K, Ca and Mg have not been reported to limit cowpea production, certain varieties have the ability of accumulating these mineral nutrients in large quantities. In this study, 'Katuli 107' accumulated higher amounts of these nutrients than 'MM4'. As reported by other workers, the ability to accumulate these mineral nutrients may not necessary reflect an increase in grain and dry matter yield. It may however be necessary to test the effect of Ca and Mg application on the grain and dry matter production in soils like "Andosols" where these cations are easily leached beyond the reach of the plant.

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Appendix I. Weather conditions 1982 - Murinduko

| Month | Total Rain- fall (mm) | Rains Days (°C) | Mean Temp. | Mean Rel. 9.00am | Humidity % 3.00pm |
|---|---|---|---|---|---|
| JANUARY | 0.2 | 1 | 19.6 | 75 | 51 |
| FEBRUARY | 0.0 | - | 21.1 | 69 | 36 |
| MARCH | 118.3 | 4 | 21.2 | 72 | 35 |
| APRIL | 23.6 | 12 | 20.0 | 89 | 63 |
| MAY | 126.3 | 16 | 19.4 | 86 | 70 |
| JUNE | 27.3 | 4 | 18.7 | 85 | 62 |
| JULY | 8.4 | 4 | 18.8 | 85 | 59 |
| AUGUST | 12.7 | 6 | 17.3 | 85 | 63 |
| SEPTEMBER | 21.1 | 3 | 19.1 | 85 | 53 |
| OCTOBER | 243.5 | 10 | 19.3 | 85 | 61 |
| NOVEMBER | 90.3 | 11 | 19.4 | 89 | 69 |
| DECEMBER | 18.1 | 3 | 18.4 | 76 | 66 |
| Mean | 904.8* | 74* | 194 | 81.6 | 57.3 |

*Totals

Appendix II. A summary of nutrient concentration and dry matter accumulation in the two cowpea varieties.

| Weeks after seedling emergence | | Dry matter (kg/ha) | Nutrient conception (%) | | | | | |
|---|---|---|---|---|---|---|---|---|
| | | | N | P | K | Ca | Mg | S |
| 2 | K | 126.45 | 5.190 | 0.183 | 4.341 | 2.455 | 0.584 | 0.252 |
| | M | 63.85 | 2.317 | 0.082 | 2.161 | 0.906 | 0.268 | 0.145 |
| 4 | K | 278.50 | 11.816 | 0.751 | 7.245 | 3.901 | 1.100 | 0.093 |
| | M | 161.33 | 6.624 | 0.415 | 4.316 | 2.255 | 0.632 | 0.060 |
| 6 | K | 326.65 | 10.390 | 0.766 | 7.842 | 4.218 | 1.521 | 0.460 |
| | M | 247.60 | 7.977 | 0.636 | 7.864 | 3.353 | 2.212 | 0.449 |
| 8 | K | 537.53 | 16.446 | 0.727 | 9.383 | 5.883 | 2.853 | 0.752 |
| | M | 481.95 | 15.845 | 0.796 | 9.405 | 4.422 | 2.347 | 0.899 |
| 10 | K | 515.92 | 14.425 | 0.734 | 9.30 | 5.319 | 2.762 | 0.501 |
| | M | 510.90 | 18.625 | 0.718 | 8.418 | 3.961 | 2.354 | 0.551 |

* K = Katuli 107

M = MM4

Appendix III. Dry matter accumulation of 'MM4' and 'Katuli 107' as influenced by different sampling periods and complete analysis of variance.

| Frequency weeks after seedling emergence | 'MM4' replications I | II | III | IV | V | V | Freq total | 'Katuli 107' replications I | II | III | IV | V | VI | Freq total |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 2 | 12.15 | 9.32 | 11.40 | 9.63 | 10.40 | 10.95 | 63.85 | 24.61 | 18.72 | 26.37 | 16.80 | 19.84 | 20.11 | 126.45 |
| 4 | 25.83 | 26.43 | 28.03 | 27.35 | 26.11 | 27.58 | 161.33 | 44.38 | 48.43 | 39.83 | 47.85 | 49.30 | 49.16 | 278.50 |
| 6 | 37.34 | 43.51 | 42.72 | 39.96 | 45.38 | 38.69 | 247.60 | 59.38 | 54.81 | 49.36 | 53.50 | 52.69 | 56.91 | 326.55 |
| 8 | 84.87 | 76.29 | 84.56 | 77.35 | 83.51 | 75.37 | 481.95 | 81.86 | 96.43 | 87.18 | 88.70 | 88.10 | 95.36 | 537.63 |
| 10 | 83.69 | 89.57 | 79.30 | 93.21 | 83.40 | 81.73 | 510.90 | 88.51 | 79.68 | 93.44 | 83.51 | 81.50 | 89.78 | 515.92 |
| Rep total | 243.88 | 245.12 | 246.01 | 247.50 | 248.80 | 234.32 | 1465.63 | 298.74 | 298.07 | 296.18 | 290.36 | 291.43 | 310.82 | 1785.17 |

ANALYSIS OF VARIANCE

| Source of variation | df | Sum of square | Mean square | F Cal |
|---|---|---|---|---|
| Total | 59 | 148 129.02 | | |
| Replication | 5 | 139.19 | 27.83 | 0.02 NS |
| Varieties | 1 | 1683.20 | 1683.20 | 0.01 NS |
| Frequency | 4 | 44984.68 | 11246.17 | 5.96** |
| Frequencyxx variety | 4 | 16416.66 | 4104.12 | 2.18 NS |
| Error | 45 | 84905.29 | 1886.78 | |

Appendix IV. Deficiency and sufficiency range for soil nutrients

| Nutrients | Deficients | Sufficient | Rich |
|---|---|---|---|
| Na M.e% | Seldom | 0-2.0 | 2.0+ |
| K M.e% | Less than 0.2 | 0.2-1.5 | 1.5+ |
| Ca M.e% | Less than 2.0 | 2.0-10.0 | 10.0+ |
| Mg M.e% | Less than 1.0 | 1.0-3.0 | 3.0+ |
| Mn M.e% | Less than 0.1 | 0.1-2.0 | 2.0+ |
| P ppm | Less than 20.0 | 20-80 | 80 |

The generalised guide is adapted from Kempton, 1962