EFFECTS OF PLANT DENSITY AND PHOSPHATE FERTILIZER ON THE GROWTH, FLOWER - AND POD-ABSCISSION, YIELD AND YIELD COMPONENTS OF PIGEON PEAS (*CAJANUS CAJAN* (L.) MILLSP.).

A thesis submitted in part fulfilment for the Degree of Master of Science in Agronomy of the University of Nairobi.

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

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To my father, the late Samuel Otieno and my mother Dorcas Adoyo who paid for my education I dedicate this work.

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ABSTRACT

This thesis reports on 3 field experiments carried out in 1976 and 1976/77 at the Field Station of the Faculty of Agriculture, University of Nairobi at Kabete. The main objective was to determine the effects of plant density and phosphate fertilizer on the growth, flower - and pod-abscission, yield and yield components of pigeon pea (*Cajanus cajan*(L.) Millsp.). Cultivar PP1 developed at Makerere University in Uganda, as a medium maturing type and bulked at Kitale for distribution in Kenya was used. Because of the lack of knowledge on the growth and development of the cultivar, observation plots were planted besides the main experiment in 1976 to provide information on growth and development.

A description of the pigeon pea plant, its ecological requirements, its uses and importance in Kenya and elsewhere was given. Information available on the present topic was reviewed.

Plant density and phosphate fertilizer experiments were carried out in 1976 and 1976/77. Three levels each of plant density, 10,000, 40,000 and 81,633 plants per hectare, and phosphate fertilizer, 0, 26 and 52kg P per hectare were used giving nine treatment combinations. The observation plots had two plant densities, 10,000 and 81,633 plants per hectare and only one phosphate fertilizer level, 26kg P per hectare and were planted only in the 1976 experimental season.

It has been found that plant density affected the growth of the cultivar. The more space available to the plantsthe bigger the plants grew. The growth of the cultivar was affected by the season. The factors involved are discussed. Plant height was not affected by plant density except when soil moisture was limiting. While shoot dry weight per plant decreased with increasing density, shoot dry weight per hectare increased and did not reach its maximum at the highest density used.

Plant density also affected flower-and pod-abscission, numbers of flowers, of pods and seed yield per plant. The trend of and reasons for the effects are discussed. However, plant density had no effect on the number of seeds per pod except when soil moisture was limiting, on 100 seed weight and on seed yield per hectare. The most sensitive yield component was found to be the number of pods per plant which decreased with increasing plant density. The lack of response in seed yield per hectare to plant density was attributed to the adaptability of the cultivar.

Various levels of phosphate fertilizer had no effect on the growth, flower - and pod-abscission, yield and yield components. The reasons for this are discussed.

The growth of the cultivar has been described at two plant densities from germination to harvest. Various growth phases of the cultivar were distinguished and discussed. The implication of various growth phases to intercropping has also been discussed. Shoot dry weight production, its distribution and relationship to seed yield at two plant densities are given. Higher plant density was found to favour vegetative growth at the expense of seed yield per plant and per hectare. Comparisons were made between leaf area indices, crop growth rates and net assimilation rates of this crop with those of others like maize, beans and Brussels sprouts.

A number of areas have been identified where more research should be done before concrete conclusions on the present topic can be made.

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CHAPTER ONE

1. INTRODUCTION

1.1. General

The two groups of plants of greatest importance to world agriculture belong to the plant families, Gramineae and Leguminosae. Members of the latter family, one of which is the topic of the present study have been grown as crops for at least 6,000 years (Whyte et al. 1953). The importance of this group of crops lies both in their food value to human beings and in the fact that they supply proteinaceous fodder for livestock. In addition, legumes are important in replenishing soil nitrogen through symbiotic root nodule bacteria.

1.2. The pigeon pea plant

Pigeon pea (*Cajanus cajan* (L.) Millsp., syn. *C. indicus* Spreng) is known by many other common names such as red gram, Congo pea, Angola pea, no-eye pea, tur, arhar, gandul, pois pigeon, ambrévade, mbaazi, nzuu, njugu and obong'. Pigeon pea is the commonly seen representative of the monotypic genus *Cajanus* DC. of the tribe Phaseoleae, sub-family Papilonaceae in the family Leguminosae (Cobley 1956, Purseglove 1968, Pathak 1970, Westphal 1974, Royes 1976, Smartt 1976). Pigeon pea is a tropical perennial or annual woody shrub 0.5 to 5 metres tall, believed to have originated in Africa but now widely spread throughout the tropics and subtropics (Cobley 1956, Gooding 1962, Stanton et al. 1966, Purseglove 1968, Dunbar 1969, Acland 1971, Khan and Rachie 1972, Westphal 1974, Smartt 1976).

The growth habit of pigeon pea is generally erect although some cultivars are more spreading in growth. There is a pronounced deep tap-root with longer laterals in the spreading than in the erect cultivars. Young stems are angular and hairy. Leaves are trifoliate spirally arranged with 2/5 phyllotaxy; petioles are 2 to 8 cm long and grooved above; pulvini are found at the bases of both leaflets and petiole. The leaflets are 5 to 10 cm long with the terminal leaflet on a longer stalk and larger than the laterals.

Inflorescences are small, terminal and/or axillary racemes 4 to 12 cm long with several flowers. The flowering period can extend over several months. Flowers are about 2.5cm long; and the calyx has four lobes with the upper two united; the standard petal is large, broad and auricled at the base, while the keel is obtuse and incurved; flowers are yellow and sometimes tinged red or purple; wings and keel are equal in length; there are 9 + 1 stamens with a free vexillary stamen and the rest connate of unequal length; the anthers are uniform, small, oblong, yellow and dorsifixed. The ovary and base of style are hairy while the stigma is terminal and knob-shaped. The pods are flattened with diagonal depressions between seeds which are 2 to 8 in number. Pods are 4 to 10 cm long and 0.6 to 1.5cm wide, beaked. usually hairy, green, dark, maroon or blotched with maroon and do not shatter in the field. Seeds vary in size, shape and colour; they are usually round or oval, about 8 mm in diameter, white, greyish, red, brown, purplish or speckled, with a small white hilum and weighing 11 to 13 grams per 100 seeds. The germination of the seeds is hypogeal.

Two distinct types are known within the species which are recognized as botanical varieties (Purseglove 1968, Pathak 1970, Smartt 1976): Var. <u>flavus</u> DC. is a relatively small-sized, short-lived and early maturing type with yellow flowers, green and glabrous pods usually containing 3 seeds. Var. <u>bicolor</u> DC. is a late-maturing, perennial type with flowers which are streaked with red and purple, hairy pods containing up to 5 seeds, which are blotched with dark red or purple.

These distinctions are however, open to doubt as the varieties cross readily, while many of the characters such as colour and shape of the flowers, pods and seeds follow simple Mendelian inheritance and are distributed in both varieties. It is, therefore, concluded that there are numerous cultivars of pigeon peas differing in height, time to maturity, colour, size and shape of pods and seeds.

1.3. Ecological requirements

Pigeon peas show a wide range of climatic and edaphic adaptability, but are more associated with the drier than the wetter tropics. The crop can be grown very successfully even in very poor soils under semi-arid conditions with less than 600 mm mean annual rainfall. It is, therefore, normally thought to be one of the most drought resistant grain legumes (Cobley 1956, Landrau and Samuels 1959, Johnson and Raymond 1964, Stanton et al. 1966, Purseglove 1968, Dunbar 1969, Acland 1971, Arnon 1972, Westphal 1974, Akinola, Whiteman and Wallis 1975, Royes 1976, Smartt 1976). This is possibly due to the crop's deep tap-root system (Cobley 1956, Purseglove 1968, Pathak 1970, Smartt 1976). Most cultivars of pigeon peas are sensitive to frost and cannot withstand water-logging (Stanton et al. 1966, Purseglove 1968, Pathak 1970, Westphal 1974, Smartt 1976). Most cultivars, particularly the tall late-maturing ones, exhibit a photoperiodic effect, being short-day plants. This affects the time to maturity and also the height of the plant according to the date of sowing.

1.4. Uses and importance of pigeon peas

In Kenya, as in many parts of the world, pigeon peas are grown primarily for the dry seeds. These are usually either boiled mixed with maize or fried and eaten as a vegetable with "Ugali". At the Coast, the dry seeds are cooked with coconut and eaten with either bread or "mandazi" especially for breakfast. The green immature seeds are occasionally harvested and eaten as a vegetable. There is a canning industry at Thika, also using the unripe green seeds with a big market potential, particularly for export. Pigeon peas are often grown as boundary plants, hedges or wind breaks. The woody stems are used for firewood.

Pigeon peas can be used in a number of other ways as is done elsewhere in the world (Whyte et al. 1953, Saville and Wright 1958, Gooding 1962, Oyenuga 1968, Purseglove 1968, Pathak 1970, Khan and Rachie 1972, Westphal 1974). In India the ripe dry seeds are split and made into "dhal". The dried husks, seeds and broken dhal are also used as cattle feed in India. The immature green pods are sometimes used as a vegetable in Hawaii, West Indies and India. The young green seeds are also eaten as a vegetable in many countries and are canned in Puerto Rico and Trinidad. The tops of the plants with fruits provide excellent fodder and are also made into hay and silage. Pigeon peas may be planted alone or in pastures as browse plants. They are also planted as green manures, as cover crops, as temporary shade in young cocoa and other crops and for erosion control. Pigeon peas are especially useful as soil-improving plants are frequently planted at the end of the rotation as a fertility restoring crop. The dried stalks are not only used for firewood and charcoal making but also as material for roofing, walling sides of carts and basket making.

The role of pigeon peas and other grain legumes in human and animal nutrition is largely that of supplying protein. The protein content of the dry seeds ranges from 17.5 to 28 percent with a mean of 20.9 percent (Aykroyd and Doughty 1964, F.A.O. 1970, Hulse 1975). The protein content, its amino acid composition and the biological value of pigeon pea seeds do not compare very favourably with most grain legumes (Table 1). However, the special value of pigeon peas lies in their security of yield even on exhausted soils of the semi-arid tropics where few alternative crops are available (F.A.O. 1965).

TABLE 1: Protein content (g/100g), essential amino acid composition (mg/100g N) and biological value of some grain legumes compared to that of whole fresh chicken egg (F.A.O. 1970).

Protein content Amino Acid Biological value	Broad beans	Chick peas	Common beans	Cow peas	Peas	Pigeon peas	Whole fresh Chicken egg
Protein content	23.4	20.1	22.1	23.4	22.5	20.9	12.4
Arginine	556	588	355	400	595	304	381
Cystine	50	74	53	68	70	61	152
Histidine	148	165	177	204	143	232	152
Isoleucine	250	277	262	239	267	194	393
Leucine	443	468	476	440	425	394	551
Lysine	404	428	450	427	470	481	436
Methionine	46	65	66	73	57	32	210
Phenylalanine	270	358	326	323	287	517	358
Threonine	210	235	248	225	254	182	320
Tryptophan	54	54	63	68	56	35	93
Tyrosine	200	183	158	163	171	126	260
Valine	348	284	287	283	294	225	428
Total essential amino acids	2979	3179	2921	2913	3089	2783	3734
Biological value	54.8	68.0	59.0	56.8	63.7	57.1	93.7

Among the grain legumes grown primarily for human consumption pigeon peas rank fifth in world production with 1,960,000 tons or 4.3 percent of the total grain legume production of 45,995,000 tons (Table 2) and occupies 2,803,000 hectares or 4 percent of the 69,560,000 hectares under grain legumes (F.A.O. 1975).

TABLE 2: World production of grain legumes (F.A.O. 1975)

Crop	Production of dry grain (tons)
Common beans	13,227,000
Peas	10,623,000
Broad beans	6,337,000
Chick peas	5,741,000
Pigeon peas	1,960,000
Vetches	1,556,000
Lentils	1,207,000
Cowpeas	1,097,000
Lupins	577,000
Others	3,670,000
Total	45,995,000

In Kenya, pigeon peas rank third in importance after Phaseolus beans and cow peas occupying 61,200 hectares or 12.8 percent of the 479,600 hectares under grain legumes (Anon 1973). The major part of the crop is cultivated in the lower drier parts of Eastern and Central Provinces (Acland 1971) where crop failure due to drought is common, and also in extensive areas at the Coast (Anon. 1973).

As a drought resistant crop with many uses, pigeon peas should play a more important role than at present in Kenyan agriculture as over 75 percent of the country is classified as low potential area with less than 625mm mean annual rainfall (Swynnerton 1955, Brown 1963). In the development plan of 1970 to 1974 the Kenya Government recognized that pulses, of which pigeon peas is one of the most important, are attractive crops since they can be grown in many parts of the drier areas of the country where few alternative crops are available. The Government, therefore, proposed a research programme on pulses to include the identification of the causes of low yields, selection of improved varieties and improvement of agronomic practices. When this research programme was initiated most of the efforts were initially concentrated on Phaseolus beans with little regard to other grain legumes (Mukunya 1977). In view of the importance of pigeon peas and the fact that little research has been done on the crop in Kenya as had been appropriately put by Eijnatten et al. (1974) when they said that "the beans and other grain legumes have not been given the attention they deserve", an improvement programme has been started in the Department of Crop Science, Faculty of Agriculture, University of Nairobi in order to produce short duration, drought resistant, high yielding cultivars and to identify agronomic and management practices suitable for Kenyan conditions.

Plant density, time of planting, weed control and fertilizer application are some of the vital agronomic practices known to influence crop yield. Therefore, the present study was undertaken to provide information on the effects of plant density and phosphate fertilizer on the growth, flower-and-pod-abscission, yield and yield components of pigeon pea cv PP1.

1.5. Objectives of the study

The objectives of the present study are:

(a) To identify the effects of plant density and phosphate fertilizer on growth parameters of pigeon pea cv PP1.

(b) To establish the extent of flower-and pod-abscission in pigeon pea cv PP1 at different levels of plant density and phosphate fertilizer.

(c) To determine the effect of plant density and phosphate fertilizer on yield and yield components of pigeon pea cv PP1.

(d) To describe the growth and development of pigeon pea cv PP1 and to establish the pattern of shoot dry weight production and distribution in the cultivar at two levels of plant density.

CHAPTER TWO

2. REVIEW OF LITERATURE

2.1. Effects of plant density

Optimum plant density for pigeon peas has been reported to depend on the cultivar, soil type, season and the purpose for which the crop is grown (Saville and Wright 1958, Killinger 1968, Akinola, Whiteman and Wallis 1975). There is no experimental data from East Africa on optimum plant density for seed yield in pigeon peas, but Saville and Wright (1958), Dunbar (1969) and Acland (1971) have reported that in East Africa pigeon peas for seed production are planted at plant densities of 3,086 and 5,556 plants per hectare. These reports are based on the practices of the local farmers, who usually interplant the perennial cultivars of pigeon peas with other crops, resulting in low pigeon pea plant densities compared to other areas.

Experimental results available from other parts of the world give a very wide range of plant densities for maximum seed production in pigeon peas. Whyte et al. (1953) reported that in East Bengal pigeon peas for seed production were usually grown at 18,000 to 32,000 plants per hectare. Mukherjee (1960) recorded significantly higher seed yields at 26,875 per hectare over a range of seasons as compared with seed production at 6,719 to 17,819 plants per hectare. Derieux (1969) reported that when pigeon peas were grown at 10,000, 20,000 and 40,000 plants per hectare, density was linearly related to seed yield, with the result that the highest seed yield was obtained at 40,000 plants per hectare. Sen et al. (1970) working on spacing requirements of pigeon peas in the range of 13,889 to 111,111 plants per hectare at two localities found the highest average seed yield at 111,111 plants per hectare for one locality and at 37,037 plants per hectare at the other locality. Chowdhury and Bhatia (1971 b) observed the highest seed yield at 100,000 plants per hectare compared to 50,000 and 66,667 plants per hectare. Singh et al. (1971) reported that 60,000 plants per hectare gave significantly higher seed yields than 40,000 and 50,000 plants per hectare. Veeraswamy et al. (1972) who used 16,667 to 55,556 plants per hectare reported the highest seed yield in pigeon peas at 37,037 plants per hectare. Abrams and Julia (1973) also reported that seed yield in pigeon peas was greater at 36,350 plants per hectare than at 9,075 or 18,150 plants per hectare. Manjhi et al. (1973) observed significantly better seed yield at 75,000 plants per hectare than at 50,000 plants per hectare. But Ahlawat et al. (1975) observed that 100,000 plants per hectare was significantly better than 66,667 plants per hectare for grain yield.

Pigeon peas grown for seed production have given the highest yields at widely different plant densities. The wide range of plant densities for the highest seed yield in pigeon peas has led to the suggestion that plant density is not a critical factor for seed production in pigeon peas (Wilsie 1935, Gooding 1962, Rolliano et al. 1962, Acland 1971). However, most workers think that plant density is important for seed production in pigeon peas. These workers have found that the optimum plant density for seed production in pigeon peas is 36,000 to 60,000 plants per hectare (Derieux 1969, Sen et al. 1970, Hammerton 1971, Singh et al. 1971, Veeraswamy et al. 1972, Abrams and Julia 1973). But as stated earlier, there are no experimental data from East Africa and therefore, there is a need to study the required plant densities for pigeon peas under Kenyan conditions.

2.1. Effects of fertilizer application

Only the work of Evans and Mitchell (1962) has been reported from East Africa concerning the influence of fertilizer on pigeon pea seed yield. They found that seed yield was greatly increased by application of farm yard manure or a fertilizer mixture containing N, K and ground limestone on poor sandy soils.

There is a conflict in evidence from Puerto Rico and India where most of the work on fertilizer response of pigeon peas in terms of seed yield have been done. The work done in Puerto Rico suggest that pigeon peas do not show significant response to any fertilizer application. Landrau and Samuels (1959) applied up to 250kg N, 109kg P and 208kg K per hectare in clay soils and found that there was no favourable green pod yield response. This result was confirmed by Pietri et al. (1971) when they applied up to 168kg each of N, P and K per hectare with and without Mg, Ca and Si to pigeon peas on oxisols. Abrams (1975) also reported that pigeon peas do not respond to fertilizer application in Puerto Rico.

On the other hand, data from India clearly indicate that pigeon peas show a positive response to phosphate fertilizer application. Bhatawadekar, Chiney and Deshmukh (1966) in trials on mixed cropping of millet (Pennisetum typhoides) and pigeon peas found that pigeon peas responded positively only to P but that with an increase in nitrogen level seed yield in pigeon peas decreased and that the optimum fertilizer rate for the mixed crop was 22kg N plus 21.8kg P per hectare. Chowdhury and Bhatia (1971 a) reported marked responses to application of fertilizers on sandy loam soils of low fertility. The largest response was obtained when 43.6kg P per hectare was applied resulting in 110 percent increase in seed yield compared with control given no fertilizer. Veeraswamy et al. (1972) reported an increase of 5 percent seed yield in pigeon peas with application of 22.4kg N and 10.9 kg P per hectare. Lenka and SatPathy (1976) reported that application of up to 40kg N per hectare increased vegetative growth, plant height and the number of branches per plant but had no effect on grain yield. Grain yield responded significantly to increasing levels of phosphate. Singh et al. (1976) also found that grain yield in pigeon peas increased with increasing levels of phosphate and obtained the highest grain yield with application of 43.6 kg P per hectare while even a starter nitrogen adversely affected the grain yield as well as the harvest index.

Grain yield in pigeon peas has shown either no or negative response to nitrogen fertilizer in most areas, but the response to phosphate fertilizer application has been significantly positive in India only. It is possible that response to phosphate fertilizer differs for different ecological and environmental conditions. Therefore, the need for carrying out fertilizer trials under different ecological conditions, particularly for Kenya where hardly any report is available, is justifiable.

Nye and Foster (1961) reported that up to 50 days after germination pigeon peas fed closer to the base than either maize or millet, and that in the second year a little more phosphorus was extracted from the subsoil by pigeon peas than was recorded at a comparable time in the first year. This report seems to suggest that phosphorus may be better utilized if worked into the soil and that the anticipated long-term effects of fertilizer application may never be realized by surface broadcasting alone. However, Khan and Mathur (1962) observed a contrast in that superphosphate at 39.2 kg P per hectare gave better yields through broadcasting than by placement. Sheriff and Rajagopalan (1970) also reported that application of phosphate fertilizer should be by broadcasting and incorporation with the pre-sowing cultivation.

Therefore, where P has positive effect on the pigeon peas seed yield, it should preferably be incorporated into the soil before sowing the seeds.

2.3. Growth and development

It seems that only recently were the patterns of growth and development in pigeon peas described. Narayanan and Sheldrake (1974/75), Ariyanayagam (1975), Wallis, Whiteman and Akinola (1975) have given a full description of the growth and development in pigeon peas. They found that three clearly marked growth phases can be distinguished in pigeon peas. These are (i) an initial lag phase, which consists of germination and early growth, (ii) a very rapid growth phase and (iii) a final phase of slow dry weight accumulation mainly in the reproductive structures.

The relationship between dry matter yield and plant density has been given by Wallis, Whiteman and Akinola (1975). They have reported that dry matter yield per plant declined asymptotically with increasing plant density while the dry matter yield per hectare and plant density relationship was described by a parabolic curve. More work still needs to be done on growth and development of various pigeon pea cultivars and how they are affected by factors such as plant density, fertilizer application and other environmental factors and to relate these to the final seed yield.

2.4. Flower-and pod-abscission

Flower-and pod-abscission is thought to be a major problem in grain legume production (Ojehomon 1968, Ariyanayagam 1975, Fisher 1975b, Onim 1975) as it affects the number of pods per plant which is the most sensitive yield component in pigeon peas (Munoz and Abrams 1971, Sharma et al. 1971, Beohar and Nigam 1972, Khan and Rachie 1972, Singh and Malhotra 1973, Mukewar and Muley 1974/75, Akinola and Whiteman 1975a, Gunasseelan and Rao 1975, Veeraswamy et al. 1975).

For cowpeas (Vigna unguiculata (L.) Walp.) it has been reported that 47 to 88 percent of the initiated flower buds are shed before setting pods (Ojehomon 1968, Kaul et al. 1976) and that with further shedding of immature pods, a total of 84 to 94 percent flower-and pod-abscission occurs (Ojehomon 1968). The workers with broad beans (Vicia faba (L.)) have reported that about 75 to 95 percent flower-and pod-abscission occurs in the crop (Rowlands 1955, Rieldel and Wort 1960, Akhundova 1967, Anon 1970, Graman 1971). A total of 43 to 81 percent flower-and pod-abscission has been reported to occur in soya beans (Glycine max (L.) Merr.) (Schaik and Probst 1958, Fukui et al. 1959, Mitrovic and Popovic 1970). For peas (Pisum sativum (L.)) it has been observed that 19 to 30 percent flower-and pod-abscission occurs (Fundulov 1970). It has recently been reported that 65 to 98 percent flower-and pod-abscission occurs in pigeon peas (Narayanan and Sheldrake 1974/75, Ariyanayagam 1975).

Although the extent of flower-and pod-abscission has been determined for a number of legumes, the physiological factors leading to the abscission are not clear. One hypothesis is that the abscission is mainly due to the competition for assimilates

(Streeter et al. 1975, Adedipe et al. 1976), but the other proposes that the abscission is mainly due to some other internal factors such as hormones which control vital processes in embryo development (Ojehomon 1972, Narayanan and Sheldrake 1974/75, Bae et al. 1975, Bently et al. 1975, Webster et al. 1975). The evidence is more in favour of the proposition that the abscission is primarily due to hormonal control and that the availability of nutrients is only of secondary importance. It has, however been observed that flower-and pod-abscission in some of the grain legumes is influenced by factors such as plant density, fertilizer and herbicide application and other environmental factors (Fukui et al. 1959, Fundulov 1970, Mitrovic and Popovic 1970, Iswaran and Altamirano 1975, Moursi et al. 1975). The fact that no work has been done on pigeon peas in connection with the factors affecting flower-and pod-abscission in itself is enough reason for the present study; furthermore, the extent of flower-and pod-abscission in pigeon peas has not been determined for Kenyan conditions. It is, therefore, necessary to find out the influence of plant density and phosphate fertilizer on flower-and pod-abscission in pigeon peas under Kenyan conditions and how this is related to the final yield and yield components.

CHAPTER THREE

3. MATERIALS AND METHODS

3.1. The location

The experiments were located at the Kabete Field Station of the Faculty of Agriculture, University of Nairobi. The Field Station is situated in Upper Kabete about 8.5 kilometers North West of the University main campus at an altitude varying from 1777 to 1854 meters. It lies within latitudes 1^{o} 14' 20"S to 1^{o} 15' 15" S and longitudes 36^{o} 44' to 36^{o} 45' 20"E. (Wamburi 1973). The station has a mean annual rainfall of 925mm and a mean annual potential evapotranspiration of 1363mm (Brown and Cocheme 1969, Wamburi 1973). The rainfall is bimodally distributed, with the long rains from late March to June and the short rains from late October to December. The rainfall in 1976 was only two thirds of the average and in 1977 far exceeded this during the early rains. The potential evapotranspiration in 1976 was nearly the same as the annual average but during the early rains of 1977 remained far below the average (Table 3). This suggests that in 1976 the station had a much higher water deficit than in an average year and that during the early rains of 1977 the rainfall was far in excess of the potential evapotranspiration demand. The potential evapotranspiration data for 1976 and 1977 were calculated from the Penman's open pan evaporation data after Brown and Cocheme (1969).

Table 3. The monthly rainfall and potential evapotranspiration at Kabete Field Station during 1976 and 1977 compared with 30 years' average

Month	Monthly rainfall (mm)			Monthly potential evapotranspiration (mm)		
	Average (30 yrs)	1976	1977	Average (30 yrs)	1976	1977
January	45	9.9	49.8	145	142.4	112.1
February	51	46.0	82.0	137	152.1	129.7
March	101	32.8	82.0	142	158.6	117.7
April	207	138.6	414.8	113	104.3	75.3
May	160	118.8	273.9	96	84.0	99.2
June	46	33.3	49.5	79	70.1	68.1
July	19	10.7	53.6	80	67.9	45.1
August	26	1.2	31.2	88	82.8	74.4
September	26	44.5	13.6	110	99.5	75.1
October	54	12.2	53.1	128	132.6	108.2
November	108	102.1	233.9	118	106.6	82.3
December	82	57.1	89.7	127	102.4	90.1
Total	925	607.3	1427.1	1363	1303.3	1077.3

The air temperatures at the station during 1976 and 1977 were almost the same as for the average over 24 years (Woodhead 1968) (Table 4).

The soil of the station is a deep red latosol, containing more than 60 percent clay particles after complete dispersion, because of its stable micro-structure it has many of the properties of a loam (Fisher 1975 a).

Table 4. Mean monthly air temperatures at Kabete Field Station during 1976 and 1977 compared with 24 years' average.

Month	Mean monthly air-temperatures (^{o}C)		
	Average (24 years)	1976	1977
January	18.7	18.5	18.5
February	19.5	19.5	19.6
March	19.7	20.4	17.8
April	19.1	19.1	18.8
May	17.9	18.8	18.2
June	16.5	16.9	16.3
July	15.7	16.7	15.9
August	16.1	16.2	16.2
September	17.5	17.5	17.2
October	18.7	19.3	16.3
November	18.3	19.3	17.9
December	18.1	18.8	17.7

Although the experiments were located at the Kabete Field Station, this is not typical for the pigeon peas growing area of Kenya. It has a higher mean annual rainfall, a lower mean annual potential evapotranspiration and lower mean monthly air temperatures than the lower parts of Eastern and Central Provinces where the bulk of the crop is cultivated. Machakos which is situated in a typical pigeon peas growing area, has a mean annual rainfall of only 618mm and a mean annual potential evapotranspiration of 1435mm (Brown and Cocheme 1969). The mean monthly air temperatures at Machakos are higher than at Kabete throughout the year (Woodhead 1968). The Kabete Field Station had nevertheless to be chosen as the experimental site because of the availability of the necessary facilities and equipment.

3.2. The experiments

3.2.1. Plant density and phosphate fertilizer experiment I - 1976

The main experiment in this study was to provide information on the effects of plant density and phosphate fertilizer on growth, flower- and pod-abscission, yield and yield components of pigeon pea cv PP1. The source of the seed was Kenya Seed Company at Kitale which had bulked the medium maturing PP1 cultivar (100 seed weight of 12.8 grams) originally developed at Makerere University in Uganda. The experiment was planned as a 3 x 3 factorial with three levels each of plant density and phosphate fertilizer and laid out as four randomized blocks. The plots measured 6 by 6 meters.

The plant densities were:

D_1. 10,000 plants per hectare at 1 by 1 meter

D_2. 40,000 plants per hectare at 0.50 by 0.50 meters

D_3. 81,633 plants per hectare at 0.35 by 0.35 meter

The phosphate fertilizer levels were:

P_o. No fertilizer
P_1. 26 kg P per hectare
P_2. 52 kg P per hectare

A total of nine treatment combinations, D_1P_o, D_1P_1, D_1P_2, D_2P_o, D_2P_1, D_2P_2, D_3P_o, D_3P_1 and D_3P_2 was considered.

The seed bed was prepared by ploughing and harrowing in mid-March. The appropriate amount of triple superphosphate (19.62-20.49 percent P) was applied by broadcasting and hoeing into the soil a day before the seeds were sown. The seeds were dressed with "Fenasandi" (20 percent Lindane BHC plus 25 percent Thiram) which is both a fungicide and an insecticide. Three seeds were planted per hole on 8th April 1976 and three weeks after germination on the 12th May 1976, the seedlings were thinned to one per hole. The plots were hand weeded four times on 11th May, 10th June, 29th July and 21st September 1976. The crop was sprayed twice, first in the early podding stage on 3rd September and then on 12th October 1976 in the mid-podding stage using a mixture of 30ml Rogor E (dimethoate 40 percent E.C.) plus 180ml DDT 25 percent in 16 litres of water to control both flower eating and pod boring insects.

Two plants per plot were chosen at random and observed at weekly intervals from the appearance of flower buds until harvesting time. On each observation day, the length of the main stem and number of primary branches, leaves, flower buds, open flowers and pods were counted and recorded. A week before the crop was harvested, the heights of forty plants per plot were measured.

The crop was harvested on the 24th November 1976, 230 days from sowing. Twenty plants per plot were cut at ground level and the number of primary branches and pods per plant were determined. The pods were removed from the rest of the plant and then separated into pod walls and seeds. The seeds were counted and weighed. Then the seeds, pod walls and the rest of plant parts were placed into separate paper bags and oven-dried at 80°C for 48 hours before being weighed for dry weight determination.

3.2.2. Growth and development study - 1976

In 1976, alongside the main experiment observation plots were planted to provide information on the growth and development of the cultivar PP1. For these observations, two plant densities, 10,000 plants per hectare at 1 by 1 meter and 81,633 plants per hectare at 0.35 by 0.35 meter and one level of phosphate fertilizer, 26kg P per hectare, were used. The combinations of treatments were replicated twice and the plots measured 20 by 20 meters. Seed-bed preparation, phosphate fertilizer application, the source of the seed, seed treatment, planting, thinning, weeding and insect control were all done as described for the main experiment (see 3.2.1).

Growth and development of the cultivar was studied by the use of classical growth analysis methods starting three weeks after sowing. During the first nineteen weeks sampling was done at fortnightly intervals and, thereafter, at weekly intervals up to the final harvest. On each sampling day, two plants per plot were cut at ground level and for each plant the length of the main stem and the number of primary branches, leaves, flowers and pods were determined. Each plant was separated into leaves, stems, flowers and pods. The pods were separated further into pod walls and seeds. These parts were separately weighed fresh and then oven-dried at 80°C for 48 hours for dry weight determination.

Leaf area was measured on all the sampled plants throughout the season. During the early stages of growth all the leaves were outlined on square graph papers and the squares were counted to identify the leaf area. Later on, a sample of the leaves was taken, weighed fresh, traced on plain paper and the area measured by use of a planimeter. The total leaf area per plant was then calculated using the sample weight and the previously determined weight of all leaves.

3.2.3. Plant density and phosphate fertilizer experiment II - 1976/77

A second trial on plant density and phosphate fertilizer was carried out from October 1976 to October 1977. This experiment also aimed at investigating the effectsof plant density and phosphate fertilizer on the growth, yield and yield components of pigeon pea cv PP1. The experiment was planned as a 3 x 3 factorial with three levels each of plant density and phosphate fertilizer and laid out as four randomized blocks. The plots measured 6 by 6 meters. The plant densities and phosphate fertilizer levels were the same as in plant density and phosphate fertilizer experiment I (see 3.2.1.).

The seedbed was prepared by ploughing and harrowing in early October 1976. The appropriate amount of triple superphosphate (19.62 - 20.49 per cent P) was applied by broadcasting and hoeing into the soil a day before the seeds were sown. The seeds were dressed with "Fenasandi" (20 per cent Lindane BHC plus 25 percent Thiram) which is both a fungicide and an insecticide. Two seeds were planted per hole on 19th October 1976, but there were no rains until 2nd November 1976. The germination from this planting was less than 5 percent. The plots were, therefore, replanted on 4th December 1976. This time the germination improved but was still lower than in previous experiments. The plots experienced serious soil erosion as the experiment was on a sloping site. The erosion problem was solved by digging bands between the plots from 1st to 5th March 1977. A stand count of the crop was taken on 10th February 1977. The plots were hand weeded 6 times during the growing season. The experimental crop was attacked by pigeon pea leaf spots caused by <u>Mycovellosiella cajani</u>. The control of this disease was attempted by spraying with Dithane M-45 at ten days intervals starting from 1st July up to 10th September 1977. The crop was sprayed three times, on 19th July, 7th August and 10th September 1977 using a mixture of 30ml Rogor E (dimethoate 40 per cent E.C.) plus 180ml DDT 25 percent in 16 litres of water to control both flower eating and pod boring insects.

Three plants per plot were chosen at random and observed at weekly intervals from the appearance of flower buds up to 6th September. On each observation day, the length of the main stem and the number of primary branches, leaves, flower buds, open flowers and pods were determined and recorded. A week before the final harvest a stand count was taken and the heights of up to 30 plants per plot were measured. Some plots with D_1 plant density had less than 30 plants per plot and in such cases the heights of all the plants in such plots were measured.

Harvesting was done twice in the experiment, first on 10th September 1977, 280 days from sowing and finally on the 27th October 1977, 328 days from sowing. During the first harvest all the mature dry pods were picked from 5, 10 and 20 plants randomly chosen per plot at D_1, D_2 and D_3 plant densities respectively. The pods were counted and a sample of 100 pods per plot was taken and these were separated into seeds and pod walls. The number of seeds per 100 pods was determined and the seeds and pod walls were placed into separate paper bags after they had been weighed wet. The seeds and pod walls were oven-dried at 80°C for 48 hours for dry weight determination. The rest of the pods were also separated into pod walls and seeds and both their wet and dry weights determined. The rest of the plants in the field also had all the mature dry pods removed on the 12th September.

The second and final harvest was done on 27th October, 328 days from sowing when 5 or 10 or 20 plants per plot at D_1, D_2 and D_3 respectively were cut at ground level and the number of primary branches and pods per plant determined. The pods were removed from the rest of the plant. A sample of 100 pods per plot was taken and these pods separated into pod walls and seeds. The number of seeds per 100 pods was determined and the seeds and pod walls were separately weighed wet. Then the seeds, pod walls and the rest of plant parts were placed into separate paper bags and oven-dried at 80°C for 48 hours for dry weight determination. The rest of the pods were also separated into pod walls and seeds and both their wet and dry weights determined.

The shoot dry weight, pods per plant and yield are determined as a total of the two harvests while the seeds per pod and 100 seed weight are a means of the two harvests.

3.3. Analysis of the data

3.3.1. Plant density and phosphate fertilizer experiments

All the data for the plant density and phosphate fertilizer experiments have been analysed using the analysis of variance unless specifically stated otherwise. The treatment effects were separated into effects due to.

(i) Plant density

(ii) Phosphate fertilizer

(iii) Interaction between plant density and phosphate fertilizer.

3.3.2. Growth and development study

No statistical analysis has been done for the growth and development data because the numbers of both treatments and replicates were only two. The graphs for growth and development study have been smoothed by visual fitting of the curves (Williams 1946, Law and Fisher 1977) in order to minimize the sample to sample variation which was very considerable particularly at later sampling dates.

CHAPTER FOUR

4. RESULTS

4.1. Plant density and phosphate fertilizer experiment I - 1976

4.1.1. Effects of plant density and phosphate fertilizer on the growth of pigeon peas

Only plant density treatments had significant effects on the growth parameters studied (Table 6). Plant height decreased from 87.6cm at 10,000 plants per hectare to 68.6cm at 81,633 plants per hectare. Similarly, the maximum number of leaves per plant, the number of primary branches per plant and the shoot dry weight per plant decreased from 274 to 124, 11 to 7 and 159.6 grams to 29.7 grams from the lowest to the highest plant densities respectively. The reduction in the growth of the individual plants with increase in plant density was probably due to increased competition for moisture, nutrients and space. On the other hand, shoot dry weight per hectare increased from 16.0 quintals at 10,000 plants per hectare to 24.2 quintals at 81,633 plants per hectare. Therefore, increase in plant density overcompensated for the reduction on the individual plants in terms of shoot dry weight.

The various phosphate fertilizer levels did not influence the growth parameters studied (Table 6), although all the parameters, except plant height, had a common trend. The numbers of leaves per plant, of primary branches per plant and shoot dry weight both per plant and per hectare tended to increase with increase in the level of phosphate fertilizer. The interaction between plant density and phosphate fertilizer had no effect on any of the growth parameters.

Table 6. Effects of plant density and phosphate fertilizer on the growth of pigeon pea at Kabete in 1976

	Plant height in cm.	Maximum number of leaves per plant	Number of primary branches per plant	Shoot dry weight at harvest in grams per plant	Shoot dry weight at harvest in quintals per ha.
Plant density (plants per ha)					
10,000	87.6 a	273.7 a	11.2 a	159.6 a	16.0 a
40,000	76.0 b	203.9 b	9.3 b	59.4 b	23.8 b
81,633	68.6 c	124.4 c	6.6 c	29.7 c	24.2 b
SE(24df)	1.75	26.04	0.82	7.01	1.28
Significance	P <.01	P <.01	P <.01	P <.01	P <.01
Phosphate fertilizer (kg P per ha)					
0	76.8	213.40	8.8	81.2	20.0
26	78.1	239.2	8.9	82.0	21.4
52	77.2	249.2	9.5	85.5	22.6
SE (24df)	1.75	26.04	0.82	7.01	1.28
Significance	NS	NS	NS	NS	NS
Interaction between plant density and phosphate fertilizer	NS	NS	NS	NS	NS

NS = not significant

a,b,c, = same letter indicates no difference while different letters indicate differences between the treatments at P<.05

4.1.2. Effects of plant density and phosphate fertilizer on flower-and pod-abscission in pigeon peas.

Table 7. Effects of plant density and phosphate fertilizer on the number of flowers and of pods and on flower-and pod-abscission in pigeon pea at Kabete in 1976

	Number of flower buds per plant	Number of open flowers per plant	Number of pods set per plant	Number of mature pods per plant	Percentage flower-and pod-abscission
Plant density (plants per ha)					
10,000	867.8 a	371.9 a	224.7 a	174.2 a	77.6 a
40,000	383.0 b	195.3 b	101.4 b	75.6 b	80.4 a
81,633	220.8 c	94.7 c	45.1 c	35.0 c	84.1 b
SE(24 df)	50.01	33.81	20.4	14.59	1.29
Significance	P<.01	P<.01	P<.01	P <.01	P<.01
Phosphate fertilizer (kg P per ha)					
0	372.4 a	170.6 a	102.6	76.3	80.5
26	502.2 b	239.7 b	131.7	100.2	82.1
52	497.1 b	251.5 b	137.0	108.3	79.1
SE(24 df)	50.01	33.81	20.41	14.59	1.29
Significance	P<.01	P<.01	NS	NS	NS
Interaction between plant density and phosphate fertilizer	NS	NS	NS	NS	NS

NS = Not significant

a, b, c, = Same letter indicates no difference while different letters indicate differences between the treatments at P<.05.

Plant density treatments affected the numbers of flower buds initiated, of open flowers, of pods set and of mature pods per plant, all of which were inversely related to plant density (Table 7). A total of 768 flower buds per plant were initiated at the lowest density but only 174 of these matured. On the other hand, only 383 and 221 flower buds per plant were initiated at 40,000 and 81,633 plants per hectare and only 78 and 35 of these matured respectively. Percentage flower-and pod-abscission was also affected by different plant densities. Flower-and pod-abscission increased with increasing plant density with an abscission of 77.6 percent at 10,000 plants per hectare and of 84.1 percent at 81,633 plants per hectare. The competitive stresses which caused reduction in pigeon pea growth with increasing plant density, similarly reduced the numbers of flowers and pods per plant while increasing percentage flower-and pod-abscission.

Also phosphate fertilizer application affected the numbers of flower buds initiated and of open flowers. The difference was between no fertilizer application with 372 flower buds and 171 open flowers, and fertilizer application but not between the various levels of phosphate fertilizer. Application of phosphate fertilizer increased the numbers of flower buds to about 500 and of open flowers to about 246. Phosphate fertilizer application had, however, no effect on the numbers of pods set and of mature pods. Similarly, flower-and pod-abscission was not affected by phosphate fertilizer application and averaged about 80.6 percent. The numbers of open flowers, of pods set and of mature pods per plant in general tended to increase with increasing levels of phosphate fertilizer. No particular trend occurred with regard to the numbers of flower buds initiated per plant as well as with flower-and pod-abscission in relation to phosphate fertilizer application. The interaction between plant density and phosphate fertilizer had no effect on the numbers of flower buds initiated, of open flowers, of pods set, of mature pods and on the percentage flower-and pod-abscission.

4.1.3. Effects of plant density and phosphate fertilizer on yield and yield components of pigeon peas.

Seed yield per hectare was not affected by different plant densities. The yields varied from 7.0 quintals to 8.7 quintals per hectare at 81,633 and 40,000 plants per hectare respectively (Table 8). Similarly, plant density did not affect 100 seed weight which was about 11.6 grams. Pods per plant, seeds per pod and seed yield per plant were affected by different plant densities and all were inversely related to plant density. Pods per plant were reduced from 171 at 10,000 plants per hectare to 29 at 81,633 plants per hectare. Seeds per pod and seed yield per plant varied from 4 to 3 and from 76.5 grams to 8.6 grams at the lowest and highest plant densities respectively. While there were differences in the number of pods per plant and seed yield per plant among the three plant densities, there was no difference in the number of seeds per pod (3 seeds per pod) between 40,000 and 81,633 plants per hectare.

Seed yield both per plant and per hectare as well as the yield components were not affected by various levels of phosphate fertilizer. Pods per plant and seed yield per hectare increased with increasing levels of phosphate fertilizer from 84 to 89 and from 7.6 to 8.0 quintals per hectare at 0 and 52kg P per hectare respectively. Seed yield varied from 35.0 grams at 52kg per hectare to 36.3 grams at 26kg P per hectare. While the number of seeds per pod remained constant with 3 seeds per pod at various phosphate levels, 100 seed weight decreased from 12.5 grams at 0kg P per hectare to 10.9 grams at 52kg P per hectare (Table 8). The interaction between plant density and phosphate fertilizer showed no effect on seed yield and yield components.

Table 8. Effects of plant density and phosphate fertilizer on yield and yield components of pigeon pea at Kabete in 1976.

	Number of pods per plant	Number of seeds per pod	100 seed weight in grams	Seed yield in grams per plant	Seed yield in quintals per hectare
Plant density (plants per ha)					
10,000	170.5 a	3.9 a	11.7	76.5 a	7.7
40,000	60.6 b	3.1 b	11.7	21.8 b	8.7
81,633	28.5 c	2.7 b	11.4	8.6 c	7.0
SE (24 df	9.15	0.27	1.05	3.18	0.83
Significance	P<.01	P<.01	NS	P<.01	NS
Phosphate fertilizer (kg P per ha)					
0	84.2	3.1	12.5	35.5	7.6
26	86.0	3.3	11.4	36.3	7.8
52	89.4	3.3	10.9	35.0	8.0
SE (24 df)	9.15	0.27	1.05	3.18	0.83
Significance	NS	NS	NS	NS	NS
Interaction between plant density and phosphate fertilizer	NS	NS	NS	NS	NS

NS = Not significant

a, b, c, = Same letter indicates no difference while different letters indicate differences between the treatments at P<.05

4.2. Growth and development study - 1976

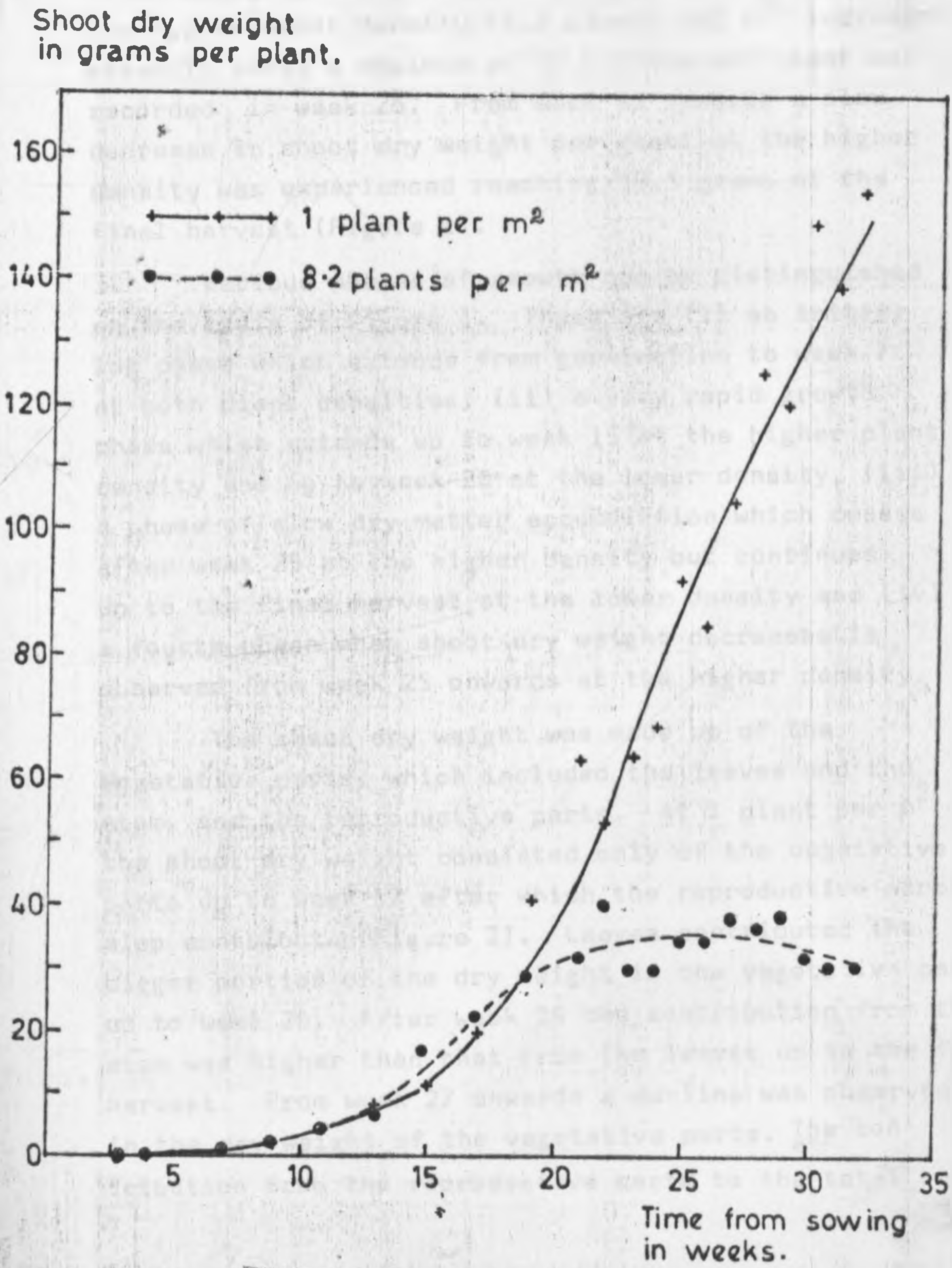
4.2.1. Shoot dry weight production and distribution in pigeon pea.

The shoot dry weight per plant at the two plant densities used in this experiment is given in Figure 1 for the whole of the growing period. The shoot dry weights per plant at 1 and 8.2 plants per m^2 (10,000 and 81,633 plants per hectare respectively) were almost the same up to about week 18 except for the period between weeks 15 and 18 when the shoot dry weight per plant at 8.2 plants per m^2 was slightly higher than at 1 plant per m^2 (Table 9 and Figure 1).

Table 9. Shoot dry weight in grams per plant at two plant densities of pigeon pea at Kabete in 1976 up to week 21.

Time from sowing in weeks	Shoot dry weight in grams per plant	
	1 plant per m^2	8.2 plants per m^2
3	0.08	0.08
7	0.56	0.72
9	2.05	2.04
11	4.15	4.80
13	8.40	6.65
15	11.61	17.01
17	19.99	21.88
19	40.67	28.83
21	62.35	32.28

Figure 1. Shoot dry weight in grams per plant at two plant densities of pigeon at Kabete in 1976.



From about week 18 onwards the shoot dry weight per plant was higher at 1 plant per m^2 than at 8.2 plants per m^2 (Figure 1). The shoot dry weight per plant at the lower density continued to increase until it reached 150.5 grams at the final sampling. The shoot dry weight per plant at the higher plant density (8.2 plants per m^2) increased steadily until a maximum of 35.5 grams per plant was recorded in week 25. From week 25 onwards a slow decrease in shoot dry weight per plant at the higher density was experienced reaching 30.5 grams at the final harvest (Figure 1).

Various phases of growth can be distinguished on the basis of Figure 1. These are (i) an initial lag phase which extends from germination to week 7 at both plant densities, (ii) a very rapid growth phase which extends up to week 15 at the higher plant density and up to week 20 at the lower density, (iii) a phase of slow dry matter accumulation which ceases after week 25 at the higher density but continues up to the final harvest at the lower density and (iv) a fourth phase when shoot dry weight decreases is observed from week 25 onwards at the higher density.

The shoot dry weight was made up of the vegetative parts, which included the leaves and the stem, and the reproductive parts. At 1 plant per m^2 the shoot dry weight consisted only of the vegetative parts up to week 17 after which the reproductive parts also contributed(Figure 2). Leaves contributed the bigger portion of the dry weight in the vegetative parts up to week 26. After week 26 the contribution from the stem was higher than that from the leaves up to the final harvest. From week 27 onwards a decline was observed in the dry weight of the vegetative parts. The contribution from the reproductive parts to the total shoot dry

Figure 2. Shoot dry weight and its distribution (g/plant) in pigeon pea at 1 plant per m^2 at Kabete in 1976.

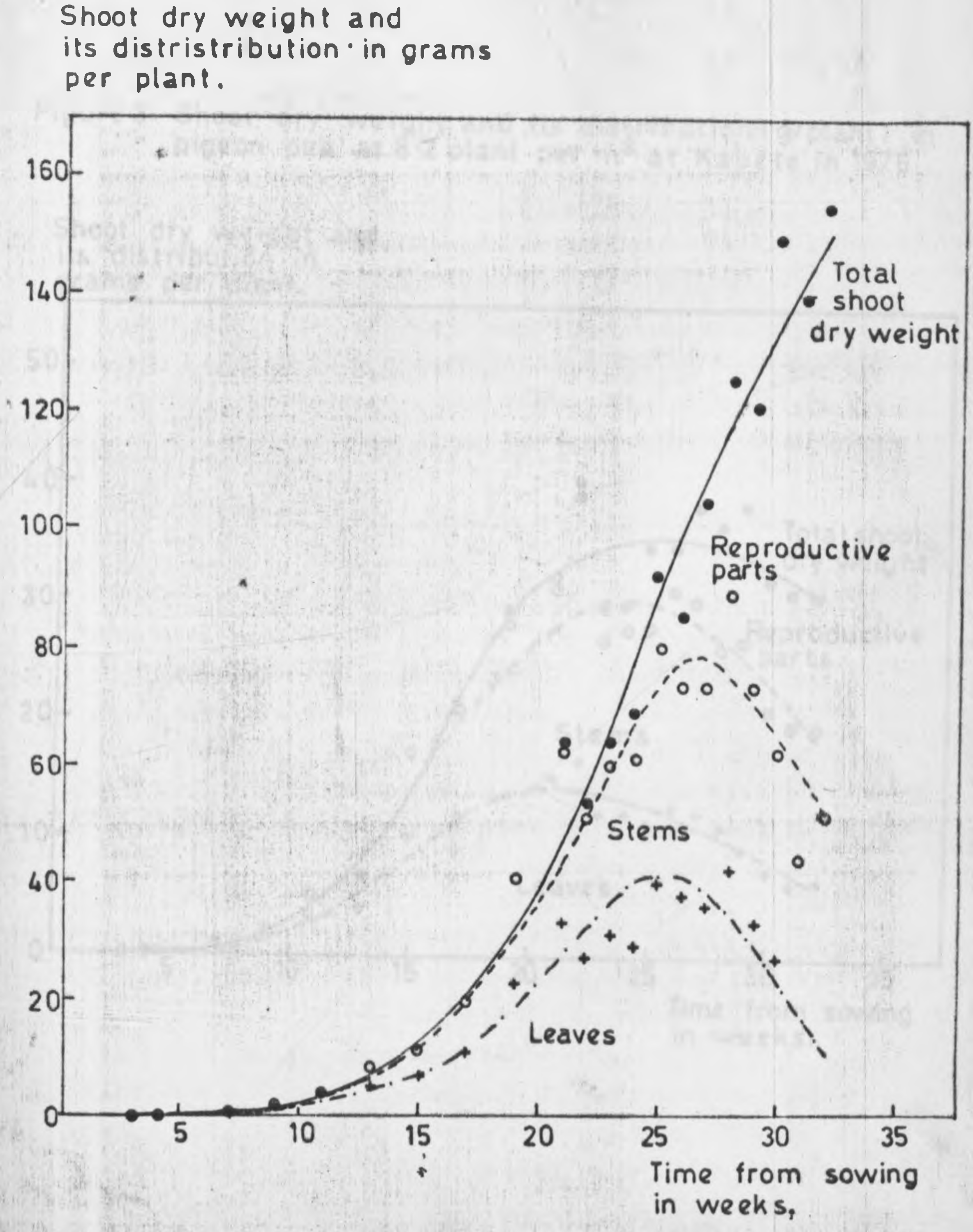
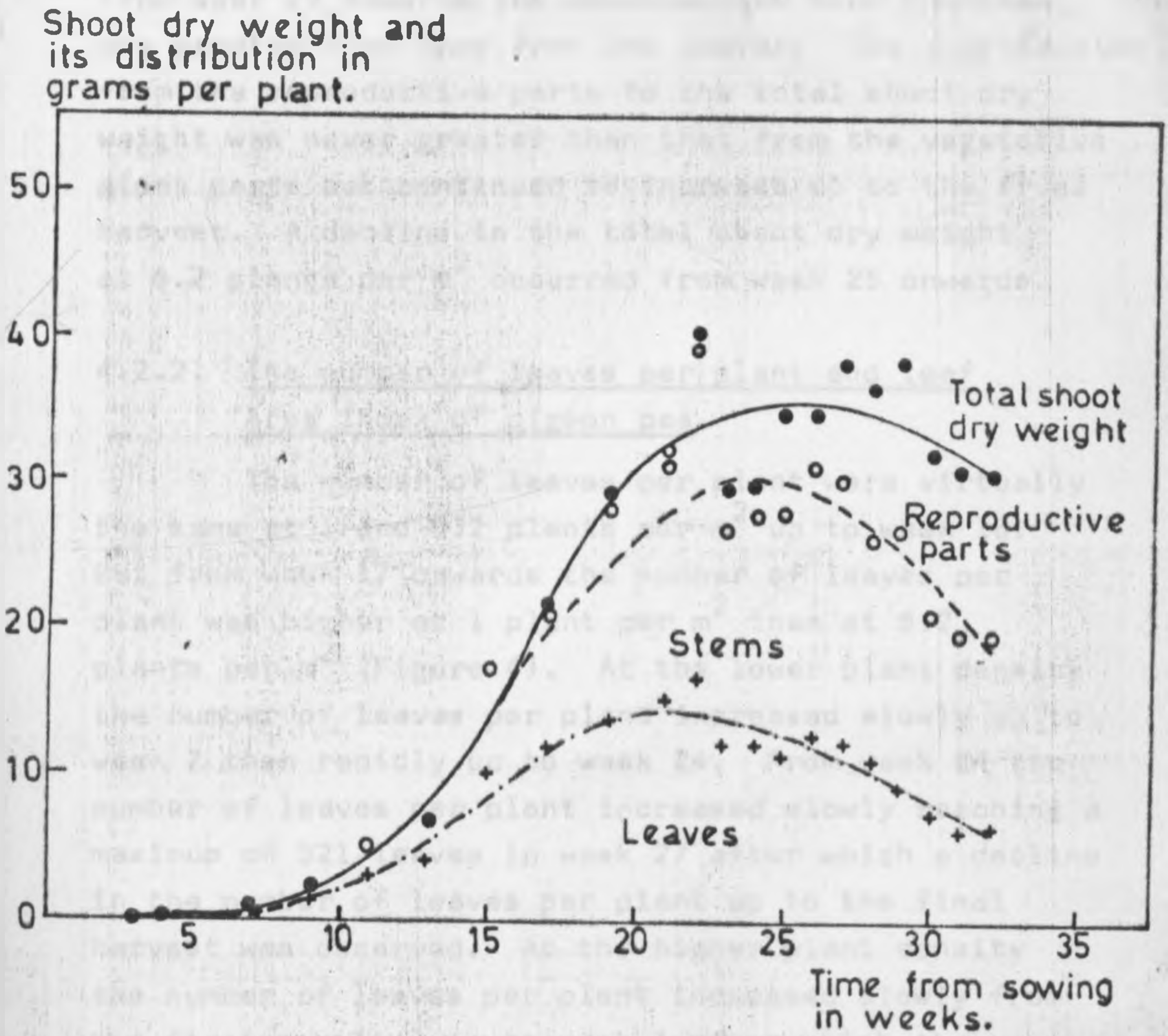


Figure 3. Shoot dry weight and its distribution (g/plant) in pigeon pea at 8·2 plant per m² at Kabete in 1976



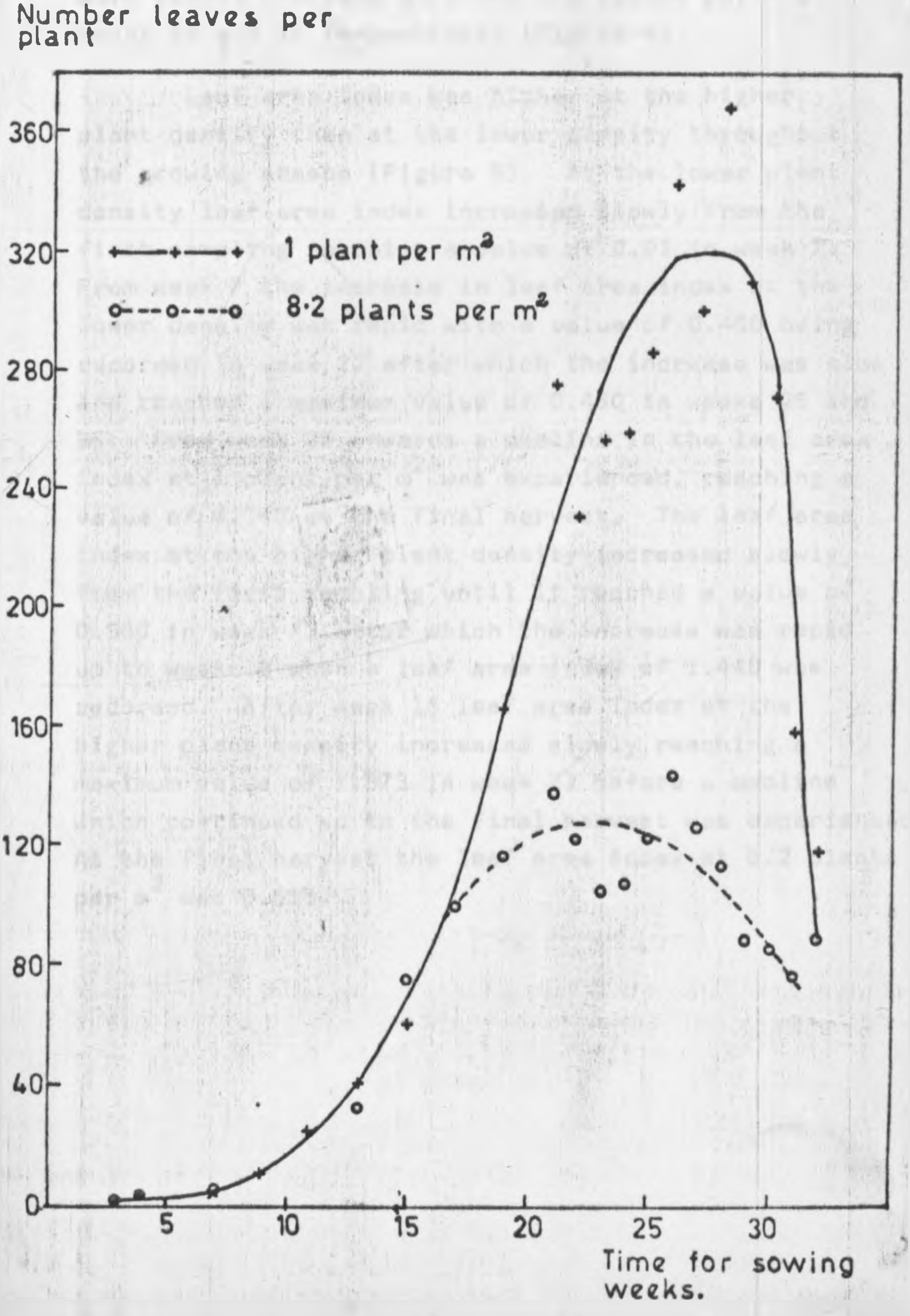
weight continued to increase up to the final harvest and surpassed that from the vegetative parts in week 20.

Total shoot dry weight at 8.2 plants per m^2 was contributed only by vegetative plant parts up to week 15. After week 15 the reproductive parts also contributed to the total shoot dry weight (Figure 3). Leaves contributed the bigger portion of the vegetative plant parts' dry weight up to week 21. From week 22 onwards the contribution from the stem was greater than that from the leaves. The contribution from the reproductive parts to the total shoot dry weight was never greater than that from the vegetative plant parts but continued to increase up to the final harvest. A decline in the total shoot dry weight at 8.2 plants per m^2 occurred from week 25 onwards.

4.2.2. <u>The number of leaves per plant and leaf Area Index of pigeon pea</u>

The number of leaves per plant were virtually the same at 1 and 8.2 plants per m^2 up to week 16. But from week 17 onwards the number of leaves per plant was higher at 1 plant per m^2 than at 8.2 plants per m^2 (Figure 4). At the lower plant density the number of leaves per plant increased slowly up to week 7 then rapidly up to week 24. From week 24 the number of leaves per plant increased slowly reaching a maximum of 321 leaves in week 27 after which a decline in the number of leaves per plant up to the final harvest was observed. At the higher plant density the number of leaves per plant increased slowly from the first sampling up to week 7 after which the increase was rapid up to week 18. From week 18 the number of leaves per plant at the higher density increased slowly reaching a maximum of 136 leaves in week 25 followed by a decrease in the number of leaves

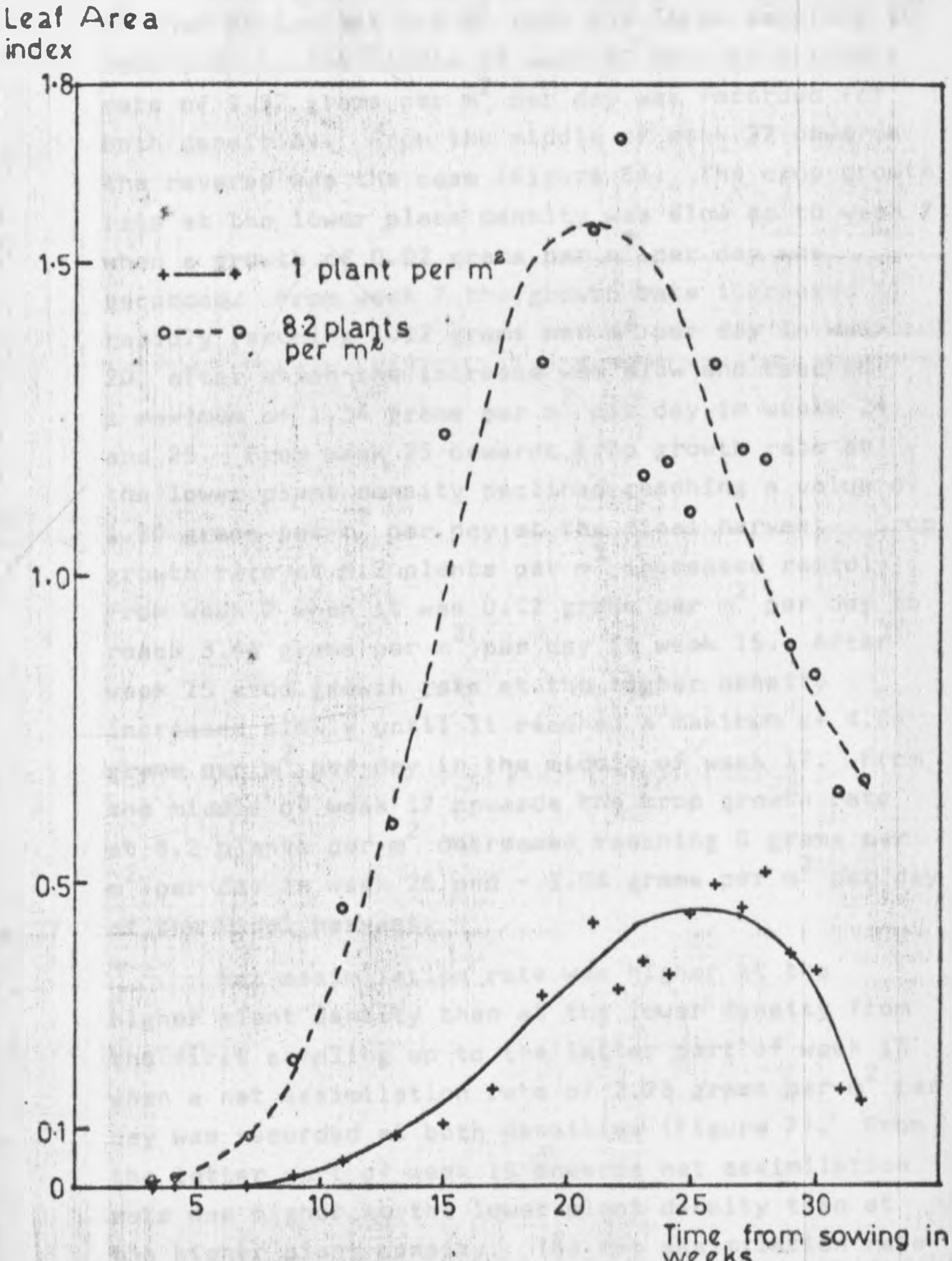
Figure 4 Number of leaves per plant at two plant densities of pigeon pea at Kabete in 1976



per plant which continued up to the final harvest. At the final harvest the number of leaves per plant were almost the same at 1 and 8.2 plants per m^2, being 88 and 76 respectively (Figure 4).

Leaf area index was higher at the higher plant density than at the lower density throughout the growing season (Figure 5). At the lower plant density leaf area index increased slowly from the first sampling reaching a value of 0.01 in week 7. From week 7 the increase in leaf area index at the lower density was rapid with a value of 0.400 being recorded in week 22 after which the increase was slow and reached a maximum value of 0.460 in weeks 25 and 26. From week 26 onwards a decline in the leaf area index at 1 plant per m^2 was experienced, reaching a value of 0.140 at the final harvest. The leaf area index at the higher plant density increased slowly from the first sampling until it reached a value of 0.080 in week 7, after which the increase was rapid up to week 18 when a leaf area index of 1.440 was recorded. After week 18 leaf area index at the higher plant density increased slowly reaching a maximum value of 1.573 in week 21 before a decline which continued up to the final harvest was experienced. At the final harvest the leaf area index at 8.2 plants per m^2 was 0.655.

Figure 5. Leaf Area Index at two densities of pigeon pea at Kabete in 1976.



4.2.3. Crop growth rate and net assimilation rate in pigeon pea.

Crop growth rate was higher at 8.2 plants per m^2 than at 1 plant per m^2 from the first sampling in week 3 up to the middle of week 22 when crop growth rate of 1.32 grams per m^2 per day was recorded for both densities. From the middle of week 22 onwards the reverse was the case (Figure 6). The crop growth rate at the lower plant density was slow up to week 7 when a growth of 0.02 grams per m^2 per day was recorded. From week 7 the growth rate increased rapidly reaching 1.12 grams per m^2 per day in week 20, after which the increase was slow and reached a maximum of 1.34 grams per m^2 per day in weeks 24 and 25. From week 25 onwards crop growth rate at the lower plant density declined reaching a value of 1.20 grams per m^2 per day at the final harvest. Crop growth rate at 8.2 plants per m^2 increased rapidly from week 7 when it was 0.52 grams per m^2 per day to reach 3.44 grams per m^2 per day in week 15. After week 15 crop growth rate at the higher density increased slowly until it reached a maximum of 4.64 grams per m^2 per day in the middle of week 17. From the middle of week 17 onwards the crop growth rate at 8.2 plants per m^2 decreased reaching 0 grams per m^2 per day in week 26 and - 1.04 grams per m^2 per day at the final harvest.

Net assimilation rate was higher at the higher plant density than at the lower density from the first sampling up to the latter part of week 18 when a net assimilation rate of 2.73 grams per m^2 per day was recorded at both densities (Figure 7). From the latter part of week 18 onwards net assimilation rate was higher at the lower plant density than at the higher plant density. The net assimilation rate at 1 plant per m^2 increased slowly from the first

Figure 6. Crop growth rate (g/m/day) at two densities of pigeon pea at Kabete in 1976.

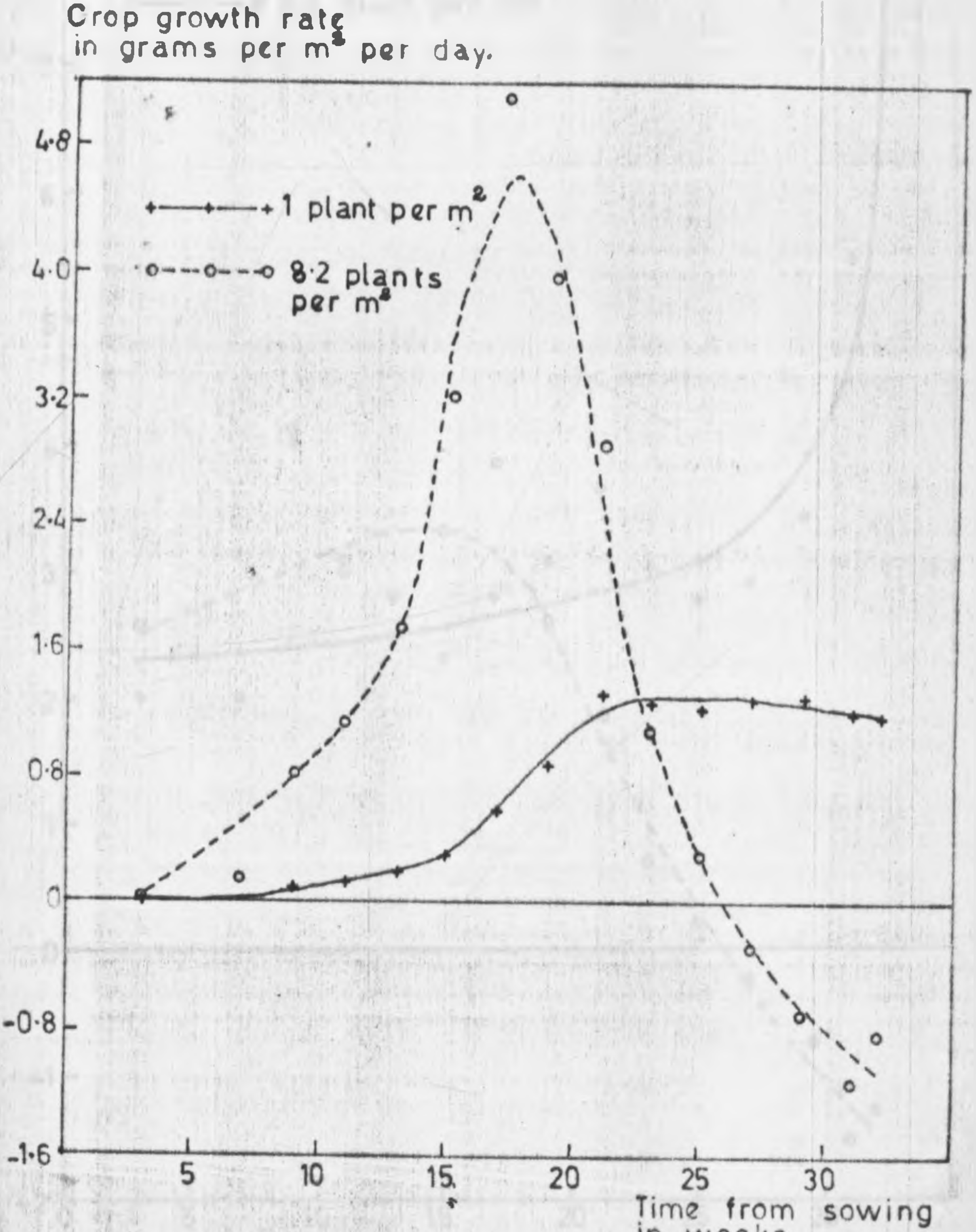
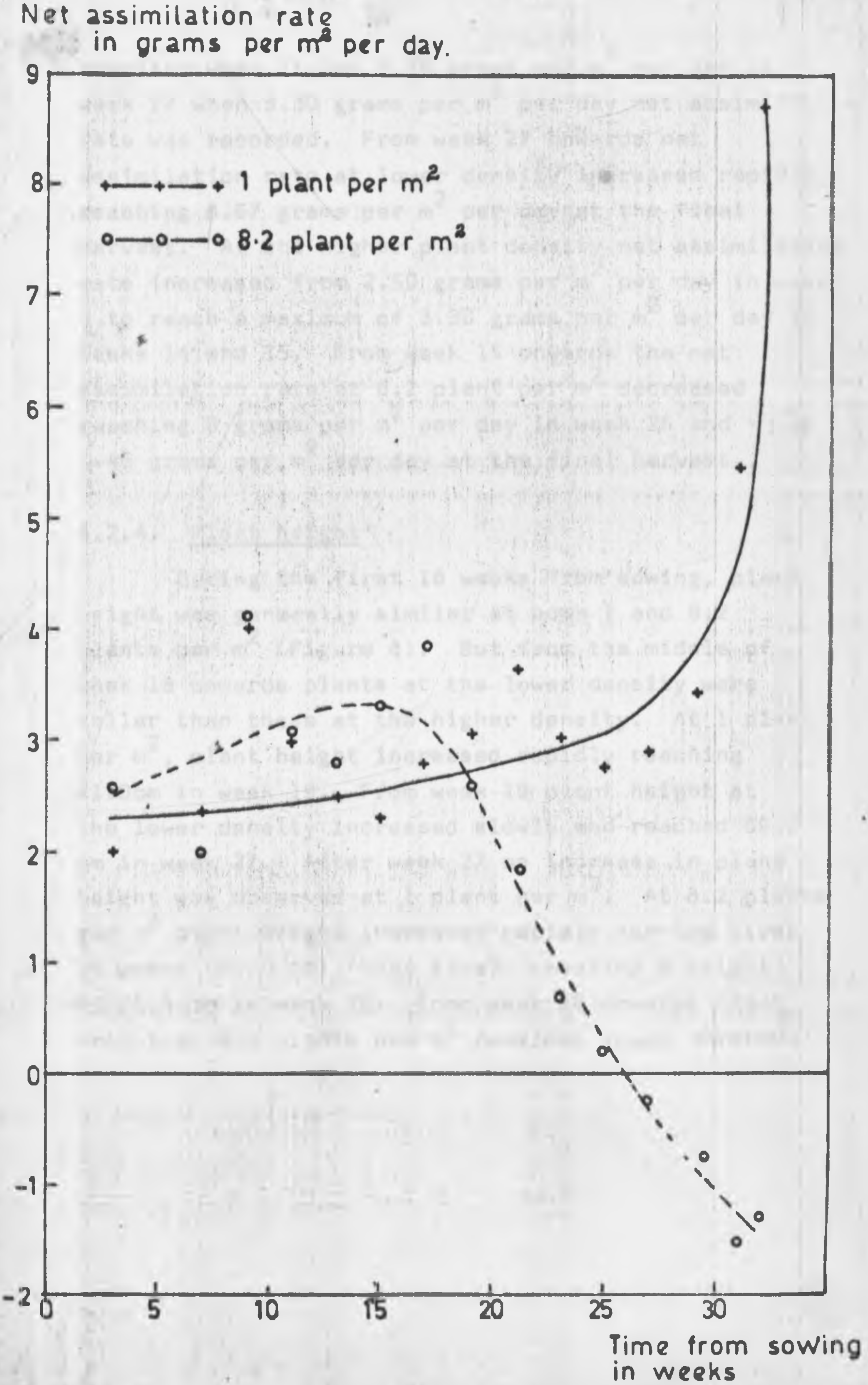


Figure 7. Net assimilation rate (g/m²/day) at two plant densities of pigeon pea at Kabete in 1976.

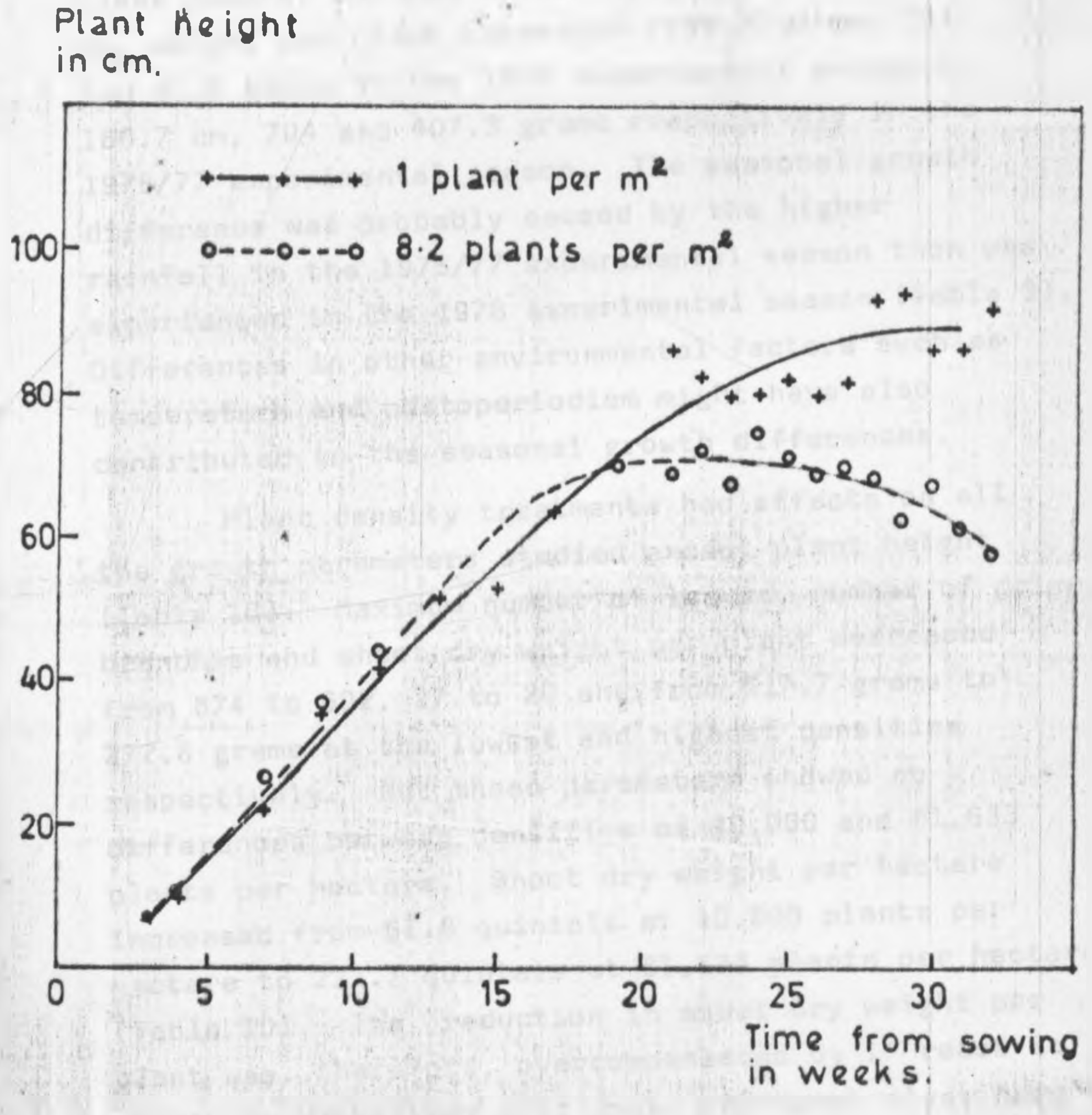


sampling when it was 2.30 grams per m^2 per day up to week 27 when 3.30 grams per m^2 per day net assimilation rate was recorded. From week 27 onwards net assimilation rate at lower density increased rapidly reaching 8.67 grams per m^2 per day at the final harvest. At the higher plant density net assimilation rate increased from 2.50 grams per m^2 per day in week 3 to reach a maximum of 3.30 grams per m^2 per day in weeks 14 and 15. From week 15 onwards the net assimilation rate at 8.2 plant per m^2 decreased reaching 0 grams per m^2 per day in week 26 and - 1.45 1.45 grams per m^2 per day at the final harvest.

4.2.4. Plant height

During the first 18 weeks from sowing, plant height was generally similar at both 1 and 8.2 plants per m^2 (Figure 8). But from the middle of week 18 onwards plants at the lower density were taller than those at the higher density. At 1 plant per m^2, plant height increased rapidly reaching 71.0cm in week 19. From week 19 plant height at the lower density increased slowly and reached 89.0 cm in week 27. After week 27 no increase in plant height was observed at 1 plant per m^2. At 8.2 plants per m^2 plant height increased rapidly for the first 15 weeks (60.0 cm), then slowly reaching a height of 70.4 cm in week 20. From week 20 onwards plant height at 8.2 plants per m^2 remained almost constant.

Figure 8. Plant height in cm at two densities of pigeon pea at Kabete in 1976.



4.3. Plant density and phosphate fertilizer experiment II - 1976/77

4.3.1. Effects of plant density and phosphate fertilizer on the growth of pigeon pea

In the 1976/77 experimental season pigeon peas at Kabete grew taller and bigger than in the 1976 experimental season (Table 6 and 10). Mean plant height, maximum number of leaves and shoot dry weight per plant increased from 77.3 cm, 234 and 82.9 grams in the 1976 experimental season to 180.7 cm, 704 and 407.3 grams respectively in the 1976/77 experimental season. The seasonal growth difference was probably caused by the higher rainfall in the 1976/77 experimental season than was experienced in the 1976 experimental season (Table 3). Differences in other environmental factors such as temperature and photoperiodism might have also contributed to the seasonal growth differences.

Plant density treatments had effects on all the growth parameters studied except plant height (Table 10). Maximum number of leaves, number of primary branches and shoot dry weight per plant decreased from 874 to 602, 27 to 20 and from 617.7 grams to 272.8 grams at the lowest and highest densities respectively. But these parameters showed no differences between densities of 40,000 and 81,633 plants per hectare. Shoot dry weight per hectare increased from 61.8 quintals at 10,000 plants per hectare to 222.7 quintals at 81,633 plants per hectare (Table 10). The reduction in shoot dry weight per plant was, therefore, overcompensated by increase in shoot dry weight per unit area. Although plant height was not significantly affected by different plant densities, a slight increase from 178.3 cm at 10,000 plants per hectare to 185.5 cm at 81,633 plants per hectare was observed.

As in the previous experiment, various levels of phosphate fertilizer had no effect on any of the growth parameters (Table 10). No particular trend was observed with regard to any of the growth parameters in relation to the levels of phosphate fertilizer. The interaction between plant density and phosphate fertilizer had no effect on any of the growth parameters.

Table 10. Effects of plant density and phosphate fertilizer on the growth of pigeon pea at Kabete in 1976/77.

	Plant height in cm.	Maximum number of leaves per plant	Number of primary branches per plant	Shoot dry weight (two harvests) in grams per plant	Shoot dry weight (two harvests) in quintals per ha
Plant density (plants per ha)					
10,000	178.3	874.1 a	26.6 a	617.6 a	61.8 a
40,000	178.4	637.3 b	16.3 b	331.6 b	132.6 b
81,633	185.5	602.1 b	19.5 b	272.8 b	222.7 c
SE (24 df)	4.22	58.41	1.30	42.78	14.42
Significance	NS	P<.01	P<.01	P<.01	P<.01
Phosphate fertilizer (kg P per ha)					
0	177.9	745.0	21.4	413.4	143.1
26	184.2	660.6	20.2	396.2	126.8
52	180.0	707.9	20.9	412.4	147.2
SE (24 df)	4.22	58.41	1.30	42.78	14.42
Significance	NS	NS	NS	NS	NS
Interaction between plant density and phosphate fertilizer	NS	NS	NS	NS	NS

NS = not significant

a, b, c, = same letter indicates no difference while different letters indicate differences between the treatments at P<.05.

4.3.2. Effects of plant density and phosphate fertilizer on yield and yield components of pigeon pea

The mean seed yields of the 1976/77 experiment were lower than those of the 1976 experiment (Tables 8 and 11). The lower yields during 1976/77 may be attributed to the attack on the crop by pigeon pea leafspots caused by *Mycovellosiella cajani*. The attack was severest at the bottom of the valley and as such plots in block 4 which was at the bottom of the valley and near some stagnant water yielded least.

Different plant densities did not affect seed yield per hectare. The yields varied from 4.5 to 7.1 quintals per hectare at 10,000 and 40,000 plants per hectare respectively (Table 11). Similarly, plant density treatments did not affect the number of seeds per pod (3 seeds per pod) and 100 seed weight which varied from 11.2 grams to 11.5 grams at 81,633 and 40,000 plants per hectare respectively. The number of pods and seed yield per plant were both significantly affected by different plant densities and were inversely related to plant density. Pods per plant varied from 186 at 10,000 plants per hectare to 34 at 81,633 plants per hectare. Seed yield per plant varied from 44.8 grams at the lowest density to 8.1 grams at the highest density. However, there were no differences in the number of pods and seed yield per plant between 40,000 and 81,633 plants per hectare.

Seed yield both per plant and per hectare as well as the yield components were not affected by various levels of phosphate fertilizer. This confirms the results of the previous experiment (Table 8). Seed yield per hectare varied from 7.0 quintals at 0 kg P per hectare to 5.6 quintals at the two levels of phosphate fertilizer (Table 11). The interaction between plant density and phosphate fertilizer had no effect neither on yield nor yield components.

Table 11. Effects of plant density and phosphate fertilizer on yield and yield components of pigeon pea at Kabete in 1976/77.

	Number of pods per plant	Number of seeds per pod	100 seed weight in grams	Seed yield in grams per plant	Seed yield in quintals per hectare
Plant density					
(plants per ha)					
10,000	185.9 a	3.2	11.4	44.8 a	4.5
40,000	67.9 b	2.9	11.5	17.8 b	7.1
81,633	33.6 b	3.0	11.2	8.1 b	6.6
SE (24 df)	52.96	0.21	0.42	10.80	1.88
Significance	P<.01	NS	NS	P<.01	NS
Phosphate fertilizer					
(kg P per ha)					
0	89.1	3.1	11.4	23.4	7.0
26	110.9	2.9	11.2	23.8	5.6
52	87.3	3.1	11.5	23.5	5.6
SE (24 df)	52.96	0.21	0.42	10.80	1.88
Significance	NS	NS	NS	NS	NS
Interaction between plant density and phosphate fertilizer	NS	NS	NS	NS	NS

NS = Not significant

a,b,c, = Same letter indicates no difference while different letters indicate differences between the treatments at P<.05

CHAPTER FIVE

5. DISCUSSION

5.1. Effects of plant density and phosphate fertilizer on the growth

The results for the two experiments show that in the first, season the plants were shorter and smaller than in the second wetter season (Tables 3, 6 and 10). The difference was probably caused by the difference in the amount of rainfall between the two experimental seasons. Mean plant height, maximum number of leaves, number of primary branches and shoot dry weight per plant as well as shoot dry weight per hectare increased from 77.3 cm, 234, 9, 82.9 grams and 21.3 quintals in the 1976 season to 180.7 cm, 704, 21, 407.3 grams and 139.0 quintals respectively in the 1976/77 season. Differences in other environmental factors such as temperature and photoperiodicity might have also contributed to the seasonal growth differences. Workers from other parts of the world have reported that photoperiodicity affects plant height, growth and time to maturity in most pigeon pea cultivars (Gooding 1962, Rolliano et al. 1962, Hammerton 1971, Singh et al. 1971, Abrams 1975, Ahlawat et al. 1975, Akinola and Whiteman 1975 a, Saxena and Yadav 1975). The cultivar used in the present study might have also reacted to differences in photoperiodicity resulting in growth differences between the two experimental seasons. However, any photoperiodic effects would be small as the experiments were located near the equator (see 3.1). The seasonal growth differences observed in the crop were probably due to differences in the amount of rainfall although other environmental factors such as temperature and photoperiodicity might have also played a smaller role. More work should be done for proper evaluation of the effects of season, rainfall and time of planting on the growth of pigeon pea crop in Kenya.

All growth parameters measured, plant height, maximum number of leaves, number of primary branches and shoot dry weight per plant as well as shoot dry weight per hectare were affected by plant density treatments as in the first experiment. Whereas plant height, maximum number of leaves, number of primary branches and shoot dry weight per plant decreased with increased plant density, shoot dry weight per hectare on the other hand increased with increased plant density. Similar results except for plant height were observed again in the second season (Tables 6 and 10). These results confirm earlier work (Wilsie 1935, Gooding 1962, Ahlawat et al. 1975, Akinola and Whiteman 1975 b). The decrease in maximum number of leaves, number of primary branches and shoot dry weight per plant as plant density increased was due to increased competitive stresses which are directly related to plant density.

While the shoot dry weight per plant decreased asymptotically with increased plant density as described by Akinola and Whiteman (1975 b), the range of plant densities was not wide enough to give a parabolic curve relationship between plant density and shoot dry weight per hectare. The highest plant density gave the highest shoot dry weight yield per hectare, 24.2 and 222.7 quintals per hectare in the first and in the second experiment respectively. This suggests that the optimum plant density for shoot dry weight yield per unit area reported by Wallis et al. (1975) as 107,639 plants per hectare hand not been reached in the current experiment. Therefore whenever shoot dry weight production is the target higher plant densities than those used in the present study would be recommended.

Plant height was significantly affected by various plant densities only in the 1976 season, when increased plant density reduced plant height from 87.6cm at 10,000 plants per hectare to 68.6cm at 81,633 plants per hectare (Table 6). The reduction in plant height with increased density suggests that there was competition for soil factors since the usual reaction to shading alone is increased plant height. In the season under discussion, the most likely explanation is competition for water. In the second season plant height was not affected by plant density (Table 10). Similar results have been reported elsewhere (Singh et al. 1971, Abrams and Julia 1973, Ahlawat et al. 1975). It is, therefore, suggested that plant density does not affect plant height in pigeon pea cv. PP1 at Kabete except when soil moisture is limiting.

In both seasons, various levels of phosphate fertilizer had no effect on any of the growth parameters studied (Tables 6 and 10). Pietri et al. (1971), Lenka and Satpathy (1976), Singh et al. (1976) have also reported this. The most probable explanation is that pigeon pea cv PP1 can effectively extract such phosphates as are found in the soil at the Kabete Field Station to attain its maximum potential growth. However, another possible reason for the lack of response to phosphate fertilizer application is that the experiments were located in a research station farm where liberal amounts of fertilizers are used regularly.

5.2. <u>Effects of plant density and phosphate fertilizer on flower - and pod-abscission</u>

The data discussed in this section refer to the 1976 experimental season only. No data were available for the 1976/77 experimental season for two reasons. Firstly, the incidence of pigeon pea leaf spot in the second season caused excessive flower - and pod-abscission (See 3.2.3. and 4.3.2). Secondly, the flowering period was more protracted in the second season than in the first season resulting in some of the pods maturing while flowering was still in progress and as such pods had to be gathered twice within a space of 48 days in the second season (see 3.2.3). Therefore, collection of the data on the parameters for determining percentage flower - and pod-abscission was discontinued in the middle of the second season.

Flower - and pod-abscission varied from 77.6 per cent at 10,000 plants per hectare to 84.1 percent at 81,633 plants per hectare with a mean of 80.8 percent. This confirms earlier work on pigeon peas (Ariyanayagam 1975, Narayanan and Sheldrake 1974/75) and also agrees with the work on other grain legumes (Rowlands 1955, Schaik and Probst 1958,Fukui et al. 1959,Rieldel and Wort 1960, Akhundova 1967, Ojehomon 1968, Anon. 1970, Mitrovic and Popovic 1970, Gramar 1971). Plant density treatments affected the number of flowers and pods per plant in a pattern similar to that on growth parameters (Tables 6, 7 and 10). Increased plant density reduced the numbers of flowers and of pods per plant but increased percentage flower-and pod-abscission (Table 7). This resulted in the closest spaced plants having the lowest number of pods per plant as a result of the greatest competitive stresses experienced. Similar results have been observed in peas (Fudulov 1970).

Application of phosphate fertilizer increased the number of flower buds and of open flowers per plant. However, most of these buds and flowers were shed either as flowers or immature pods (Table 7).

Various levels of phosphate fertilizer had no effect on the number of pods set, and of mature pods, and on flower-and pod-abscission. This is contrary to what has been reported for both cowpea and field beans (Iswaran and Altamirano 1975, Moursi et al. (1975). It is most likely that flower-and pod-abscission in pigeon pea cv PP1 depends on internal plant factors such as hormones which are not affected by phosphate fertilizer. This observation is in agreement with the more favoured proposition that flower-and pod-abscission is primarily due to hormonal control and that the availability of nutrients is only of secondary importance.(Ojehomon 1972, Narayanan and Sheldrake 1974/75, Bae et al. 1975, Bently et al. 1975, Webster et al. 1975).

5.3. Effects of plant density and phosphate fertilizer on yield and yield components

The mean seed yields both per plant and per hectare were lower in the second season than in the first season (Tables 8 and 11). The lower yields in the 1976/77 experimental season was due to the incidence of pigeon pea leafspot (see 3.2.3, 4.3.2 and 5.1.1.2.).

In both 1976 and 1976/77 seasons, different plant densities had no effect on seed yield per hectare. These results support earlier work (Wilsie 1935, Gooding 1962, Rolliano et al. 1962, Acland 1971) which suggests that plant density is not a critical factor for seed production in pigeon peas. The fact that there is no difference in seed yield per unit area when plant density varies from 10,000 to 81,633 plants per hectare is due to the growth habit of cv PP1 which readily adapts and utilizes the space available to it (Plates 1, 2, 3 and 4). The adaptability of this particular cultivar

Plate 1. Pigeon pea cv PP1 planted at 10,000 plants per hectare at Kabete in 1976.

Plate 2. Pigeon pea cv PP1 planted at 40,000 plants per hectare at Kabete in 1976.

Plate 3. Pigeon pea cv PP1 planted at 81,633 plants per hectare at Kabete in 1976.

Plate 4. Comparison of pigeon pea cv PP1 adaptability at three different plant densities, (a) at 81,633 plants per ha, (b) at 40,000 plants per ha and (c) at 10,000 plants per ha: it is clearly shown that the wider the space the bigger the plants grew and the greater the number of pods per plant.

to available space is not necessarily true for others (Narayanan and Sheldrake 1975/76). The differences in the extent to which different cultivars can adapt themselves and utilize the space available is the most probable explanation for different responses to plant density trials reported by different workers (see 2.1.).

In both seasons, 40,000 plants per hectare gave slightly better yields than either 10,000 or 81,633 plants per hectare (Tables 8 and 11). Except for the fact that the differences were non-significant this observation would have supported the group of workers who have reported that the optimum plant density for seed production in pigeon peas is 36,000 to 60,000 plants per hectare (Derieux 1969, Sen et al. 1970, Hammerton 1971, Singh et al. 1971, Veeraswamy et al. 1972, Abrams and Julia 1973). However, this group must have worked with cultivars with low adaptability to the available space unlike the cultivar used in the present study.

Seed yield per plant showed significant differences as a result of various plant densities in both seasons (Tables 8 and 11). The differences were due to the reduction in the number of pods per plant with increased plant density as the other yield components, number of seeds per pod and 100 seed weight were not consistently affected by plant density treatments. This confirms earlier reports that the number of pods per plant is the most sensitive yield component of pigeon peas (Munoz and Abrams 1971, Sharma et al. 1971, Beohar and Nigam 1972, Khan and Rachie 1972, Singh and Malhotra 1973, Mukewar and Muley 1974/75, Akinola and Whiteman 1975 a, Gunasseelan and Rao 1975, Veeraswamy et al. 1975). The reduction in the number of pods per plant with increasing plant density was a result of increased competitive stresses with higher density which reduced the numbers of flower buds initiated and of open flowers while at the same time it increased flower-and pod-abscission (see 5.1.2.). Although yield per plant decreased with increasing plant density there were no differences in yield per unit area at various plant densities because yield per plant decreased with higher densities at a rate sufficient to compensate for the increase in plant number per unit area. This was also reported by Rolliano et al. (1962).

The response in the number of seeds per pod to plant density treatments in the 1976 season (Table 8) was probably caused by moisture stress in that season resulting in higher seed abortion in the pods at higher plant densities. Thus when there was more rain during the second experimental season, no differences in the number of seeds per pod at different plant densities was observed. Plant density treatments had no effects on 100 seed weight in both seasons. The results confirm the reports of Hammerton (1971), Singh et al. (1971), Manjhi et al. (1973), Ahlawat et al. (1975), Akinola and Whiteman (1975 b) that plant density has no effect on both the number of seeds per pod and 100 seed weight.

Various levels of phosphate fertilizer had no effect on any of the yield components as well as seed yield both per plant and per hectare. Similar results have been reported from Puerto Rico (Landran and Samuels 1959, Pietri et al. 1971, Abrams 1971). But the work done in India clearly indicates that seed yield in pigeon peas show a positive response to phosphate fertilizer application (Bhatawadekar et al. 1966, Chowdhury and Bhatia 1971 a, Veeraswamy et al. 1972, Lenka and SatPathy 1976, Singh et al 1976). The lack of response to phosphate fertilizer in pigeon pea cv PP1 seed yield at Kabete is due to the same reasons given for lack of response in growth and flower-and pod-abscission (see 5.1. and 5.2). As such more similar experiments should be carried out in other locations, possibly in areas where no phosphate fertilizer has been applied as well as with other cultivars so as to find comparative results before definite conclusions can be made.

5.4. Growth Analysis

The data on growth and development provide a quantitative picture of the production and distribution of the dry weight throughout the growth of the crop at two plant densities. However, this picture is not complete for two reasons. Firstly, data on root dry weights have been omitted because of the difficulty of measuring them quantitatively. Secondly, like many other dicotyledonous crops, pigeon peas lose leaves as they grow and mature. The dry weight lost in the leaves is not recorded in the growth and development data. Some dry weight is also lost as a result of flower and pod-drop, but the amount is relatively small (Narayanan and Sheldrake 1974/75).

Figures 1, 9 and 10 clearly confirm the fact that while shoot dry weight per plant decreases with increasing plant density, shoot dry weight per hectare increases with increasing plant density (see 5.1.1.). Increased plant density favoured vegetative growth, particularly the stem and had reduced seed yield and leaf weight per plant (Figure 9). This resulted in increased shoot dry weights per unit area with increasing plant densities while the seed yield remained constant between 10,000 and 81,633 plants per hectare (Tables 6, 8, 10 and 11 and Figure 10). Similar results have been reported by Akinola and Whiteman(1975 b). The

Figure 9. Shoot dry weight distribution (g/plant) at two plant densities in pigeon pea at Kabete in 1976.

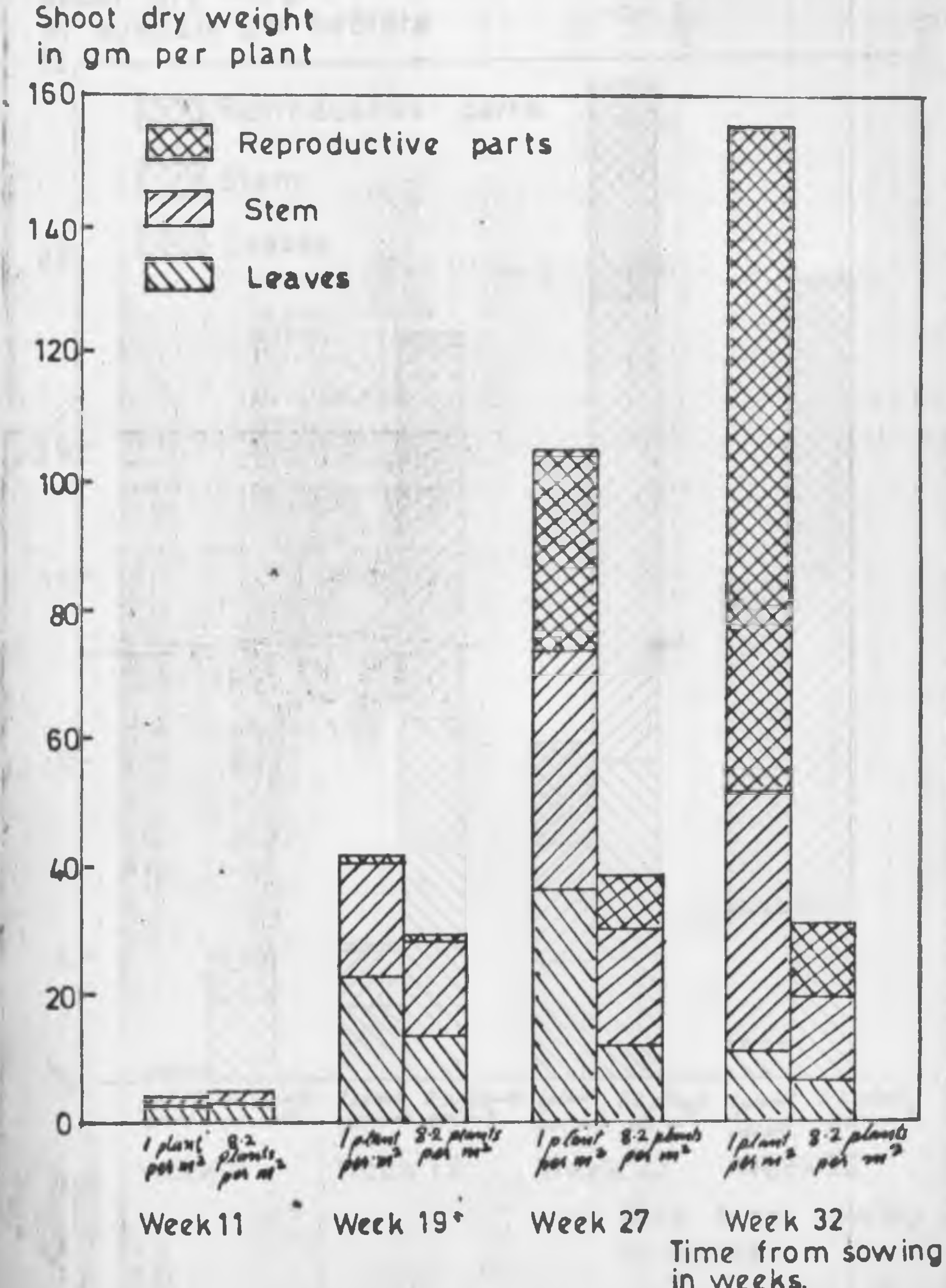
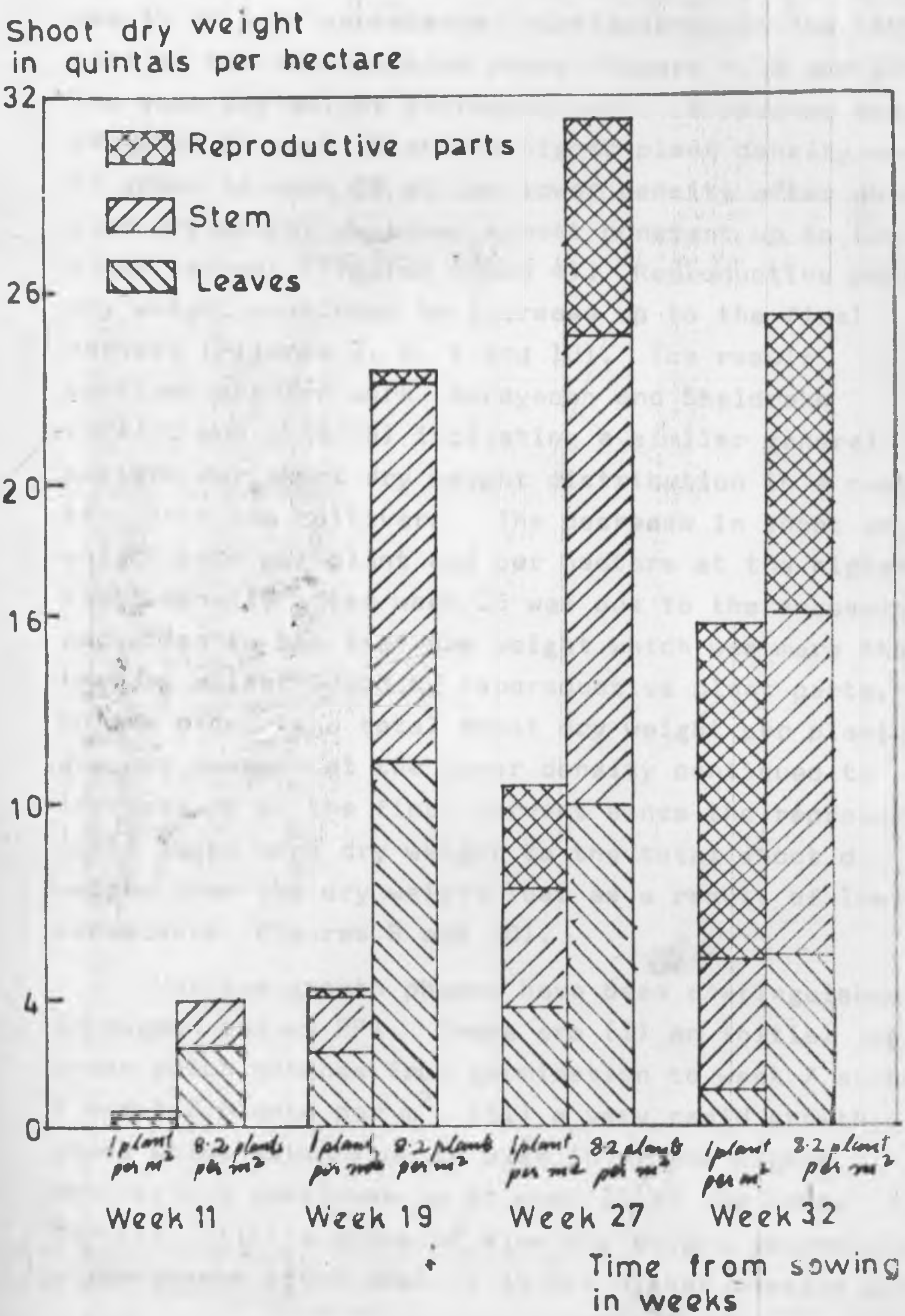


Figure 10. Shoot dry weight distribution (quintals per ha) at two plant densities of pigeon pea at Kabete in 1976.



leaf dry weight increased up to week 22 at the higher density and week 26 at the lower density after which leaf dry weight declined (Figures 2 and 3). The decline in leaf dry weight was due to reduction in the number of leaves per plant as a result of leaf senescence, particularly in the latter part of the reproductive phase (Figure 4, 9 and 10). The stem dry weight increased until it reached about 14 grams in week 19 at the higher plant density and 37 grams in week 26 at the lower density after which stem dry weight remained almost constant up to the final harvest (Figures 3 and 4). Reproductive parts dry weight continued to increase up to the final harvest (Figures 3, 4, 9 and 10). The result confirms earlier work (Narayanan and Sheldrake 1974/75 and 1975/76) indicating a similar general pattern for shoot dry weight distribution in a number of pigeon pea cultivars. The decrease in shoot dry weight both per plant and per hectare at the higher plant density after week 25 was due to the excessive reduction in the leaf dry weight which was more than the dry weight added by reporoductive plant parts. On the other hand total shoot dry weight per plant and per hectare at the lower density continued to increase up to the final harvest since the reproductive parts added more dry weight to the total shoot dry weight than the dry weight lost as a result of leaf senescence (Figures 9 and 10).

Various growth phases have been distinguished in pigeon pea cv PP1. These are (i) an initial lag phase which extends from germination to week 7 at both 1 and 8.2 plants per m^2, (ii) a very rapid growth phase which extends up to week 15 at the higher density but continues up to week 20 at the lower density, (iii) a phase pf slow dry weight accumulation which ceases after week 25 at the higher density but continues up to the final harvest at the lower density and (iv) a fourth phase when shoot dry weight decreases is observed from week 25 onwards at the higher density. Narayanan and Sheldrake (1974/75), Wallis et al. (1975) have also reported of the first three phases of growth. A fourth phase of growth which was observed only at the higher density was not observed by these workers because they had used lower densities than 81,633 plants per hectare used as the higher density in the present study.

The trend of leaf area index, leaf dry weight and the number of leaves per plant over time showed a close similarity (Figure 2, 3, 4 and 5). Narayanan and Sheldrake (1974/75) have reported of the same trend in a number of pigeon pea cultivars. Leaf area index was higher at 8.2 plants per m^2 than at 1 plant per m^2 throughout the growth season. This is contrary to an earlier report (Akinola and Whiteman 1975 b). However, the result agrees with the work on other crops (Nunez and Kamprath 1969, Fisher and Milbourn 1974, Law and Fisher 1977) who have reported that leaf area index increases with increasing plant density.

During the early stages of growth, both crop growth rate and net assimilation rate were higher at the higher density than at the lower density. But the reverse became the case after week 22 for crop growth rate and after week 18 for net assimilation rate (Figures 6 and 7). Fisher and Milbourn (1974) observed a similar pattern with Brussels Sprouts. The higher leaf area index at the closer spaced plants gave a higher crop growth rate and net assimilation rate than was achieved in the wider spaced plants during the early stages of growth. But the plants at lower density later on had higher crop growth rate and net assimilation rate than plants at higher density probably as a result of less mutual shading of the leaves at the lower density than at the higher density. Crop growth rate and net assimilation rate were however, lower in this crop than in either beans or maize (Fisher 1975 b, Law and Fisher 1977). This is probably due to the lower leaf area index recorded in the crop as compared to either beans or maize (Fisher 1977). However, with higher rainfall the crop growth rate and net assimilation rate may be greater than was recorded in the rather dry season under discussion (see 4.3.1. and 5.1.).

Net assimilation rate at the higher density increased from 1.5 grams per m^2 per day during the first sampling to 3.3 grams per m^2 per day in week 15. From week 15 onwards net assimilation rate at the higher density declined and a value of -1.45 grams per m^2 per day was recorded on the final sampling date. Increase in leaf area index increased net assimilation rate until mutual shading of the leaves resulted in the decline of net assimilation rate after week 15. The mutual shading of leaves, possibly coupled with excessive leaf senescence caused the closely spaced plants to lose weight and thus show a negative net assimilation rate after week 26. Net assimilation rate at the widely spaced plants continued to increase up to the final harvest time. This was most likely due to the fact that no mutual shading of leaves was experienced at this density. Furthermore, by the time senescence started to occur in week 27, the proportion of total photosynthesis carried out by organs other than the leaves was on the increase. As only leaf area is taken into account in calculating net assimilation rate any increase in the proportion of total photosynthesis carried out by organs other than the leaves will progressively give more value of the total photosynthesis to the leaves than they have actually carried out. This has resulted in the sudden rise in net assimilation rate at the time when leaf area index was falling rapidly (Figures 4, 5 and 7). Similar results have been recorded by Narayanan and Sheldrake (1974/75). The sudden rise in net assimilation rate as from week 27 at 1 plant per m^2 but not at 8.2 plants per m^2 was probably due to the higher number of pods per plant at the former density than at the latter density (Narayanan and Sheldrake (1974/75 and 1975/76).

Shoot dry weight per plant, number of leaves per plant and plant height were the same at 1 and 8.2 plants per m^2 from the first sampling in week 3 up to about week 18 (Figures 1, 4 and 8). This suggests that plant to plant competition was not experienced until week 18 even at the higher density. After week 18 competitive stresses became greater at the higher density than at the lower density. This resulted in the closer spaced plants being smaller than the wider spaced plants at the final harvest (Figure 9). It is, therefore, possible to intercrop pigeon pea cv PP1 with a crop which matures in about 20 weeks as this will have no adverse effect on either of the crops. However, some work should be done in monitoring the soil moisture and nutrients at different plant densities over time. Such a study would help in the identification of the limiting factors and when they set into operation at different plant densities.

CHAPTER SIX

6. CONCLUSIONS

The cultivar PP1 readily adapts itself to the space available and as such most of its growth parameters were affected by different plant densities in both 1976 and 1976/77 experimental seasons. The more space available to the plants the bigger the plants grew. Shoot dry weight per hectare increased with increasing plant density and apparently, did not reach its maximum at the highest density used in the present study. Plant density affected plant height only in the first drier season when increasing plant density reduced plant height.

The plants were bigger and taller in the second season than in the first season. The seasonal growth differences were largely due to differences in the amount of rainfall between the experimental seasons.

Various phosphate fertilizer levels had no effect on the growth of the crop.

Plant density affected the numbers of flowers and of pods per plant, and flower - and pod-abscission. Increasing plant density reduced the numbers of flowers initiated and of pods which matured but increased flower - and pod-abscission.

Although phosphate fertilizer application increased the number of flower buds initiated per plant, most of these were shed before they even set pods and as such phosphate fertilizer application had no effect on the number of mature pods per plant and on percentage flower - and pod-abscission.

Seed yield per plant and per hectare were lower in the second season than in the first season. The yield differences between the seasons were attributed to pigeon pea leafspot incidence in the second year. The disease incidence was higher in the plots at the bottom of the valley which were also nearer stagnant water than the plots at the top of the valley.

Seed yield per hectare was not affected by different plant densities in the two years of experimentation. However, seed yield per plant decreased with increasing plant densities in both 1976 and 1976/77 seasons. Of the yield components, only the number of pods per plant was affected by plant density in both seasons. It followed the same trend as seed yield per plant. The number of seeds per pod was affected by plant density only in the drier 1976 season. This was due to the higher seed abortion at higher densities in the dry season resulting in fewer seeds per pod with increasing density. 100 seed weight was not affected by plant density treatments.

The reason for the lack of response in seed yield per hectare to plant density was due to the ability of the cultivar to adapt to and utilize space available to it. The adaptability of the cultivar was such that yield per plant decreased with increasing plant density at a rate sufficient to compensate for the increase in plant number per unit area. Hence, no difference occurred in seed yield per hectare when plant density ranged from 10,000 to 81,633 plants per hectare. The most sensitive yield component in pigeon pea was found to be the number of pods per plant which was adversely affected by increasing competitive stresses as the plant density increased.

Phosphate fertilizer application had no effect on any of the yield components or on seed yield both per plant and per hectare in both 1976 and 1976/77 seasons. The lack of response to phosphate fertilizer application in growth, flower-and pod-abscission, yield and yield components was probably due to the ability of the cultivar to effectively extract such phosphates as are found in the Kabete Field Station soil. Another reason may be that the experimental site had adequate fertilizer from previous applications.

Four phases of growth have been distinguished at 81,633 plants per hectare while only three were distinguished at 10,000 plants per hectare. The cultivar grows very slowly for the first seven weeks. This is followed by a grand growth period which lasts for about 10 weeks before another slow growth period sets in during the last few weeks before maturity. Higher plant density was found to favour vegetative growth at the expense of seed yield per plant and per hectare. Competitive stresses came into operation only after week 18 even at the higher plant density. Therefore, it is possible to intercrop the cultivar with a crop which would mature in about 20 weeks without adverse effects on either of the crops. A density of 10,000 pigeon pea plants per hectare is recommended for the mixed cropping situation since there were no differences in seed yield per hectare between 10,000 and 81,633 plants per hectare. A number of problems have been posed which may only be answered by further research in the following areas:

(i) Effects of season, rainfall and date of planting on the growth and yield of various pigeon pea cultivars.

(ii) Effects of plant density and phosphate fertilizer on the growth, yield and yield components of different pigeon pea cultivars. Soil moisture and nutrients should be monitored at different densities over time. Such experiments should be carried out in areas where no phosphate fertilizer has been used before.

(iii) Evaluation of the extent of flower - and pod-abscission in a number of pigeon pea cultivars.

CHAPTER SEVEN

7. REFERENCES

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APPENDICES

Appendix 1.

Effects of plant density and phosphate fertilizer on the growth of pigeon pea cv PP1 at Kabete: Table 12-22.

Table 12. <u>Analysis of Variance Table for the heights of pigeon pea observed a week before harvest, at Kabete in 1976</u>

Source	df	SS	MSS	F-ratio
Block	3	24.07	8.02	0.65^{ns}
Density	2	2186.63	1093.32	86.18**
P fertilizer	2	10.91	5.46	0.45^{ns}
Density x P fertilizer	4	93.58	23.40	1.91^{ns}
Error	24	294.12	12.26	
Total	35	2609.31		

ns = not significant

** = significant at 1%

Table 13. Plot averages for plant height (in cm) observed a week before harvesting the experiment on the effects of plant density and phosphate fertilizer on pigeon pea at Kabete.in 1976.

TREATMENTS	BLOCKS 1	2	3	4	TOTAL	MEAN
D_1P_o	83.88	90.69	88.90	90.59	345.06	88.52
D_1P_1	91.38	91.25	88.98	84.93	356.54	89.14
D_1P_2	81.26	86.62	92.05	80.07	340.00	85.00
D_2P_o	77.02	72.14	72.61	82.25	304.02	76.01
D_2P_1	75.58	76.69	75.69	70.32	298.28	74.57
D_2P_2	75.90	81.71	75.44	76.08	309.13	77.28
D_3P_o	65.89	65.43	66.16	65.78	263.26	65.82
D_3P_1	73.51	69.96	68.74	70.24	282.45	70.61
D_3P_2	72.89	70.28	70.24	64.31	277.72	69.43
TOTAL	697.30	704.77	698.81	684.57	2785.46	
MEAN	77.44	78.31	77.65	76.06		77.37

Table 14. Plot averages for plant height (in cm) observed a week before harvesting the experiment on the effects of plant density and phosphate fertilizer on pigeon pea at Kabete in 1976/77

TREATMENTS	BLOCKS				TOTAL	MEAN
	1	2	3	4		
D_1	180.8	166.3	176.1	193.0	716.2	179.05
D_1P_1	184.3	174.3	179.2	177.4	715.2	178.80
D_1P_2	186.3	173.1	176.9	171.3	707.6	176.90
D_2P_o	169.5	172.4	175.9	185.7	703.5	175.88
D_2P_1	176.4	186.4	174.0	187.7	724.5	181.13
D_2P_2	165.1	174.7	179.7	193.8	713.3	178.33
D_3P_o	168.7	161.2	191.9	193.7	715.5	178.88
D_3P_1	191.9	184.3	197.9	197.0	771.1	192.78
D_3P_2	168.2	186.4	193.4	191.0	739.0	184.75
TOTAL	1591.2	1579.1	1645.0	1690.6	6505.9	
MEAN	176.80	175.46	182.78	187.84		180.72

Table 15. Plot averages for the maximum number of leaves recorded per plant in the experiment on the effects of plant density and phosphate fertilizer on pigeon pea at Kabete in 1976

TREATMENTS	BLOCKS					
	1	2	3	4	TOTAL	MEAN
D_1P_o	373.3	286.7	400.7	241.7	1302.4	325.6
D_1P_1	419.3	506.3	389.3	285.3	1600.2	400.1
D_1P_2	277.0	496.8	411.2	397.2	1582.2	395.6
D_2P_o	184.2	209.0	253.0	172.8	819.0	204.8
D_2P_1	201.7	185.0	191.5	167.3	745.5	186.4
D_2P_2	251.5	181.3	242.7	206.3	881.8	220.5
D_3P_o	157.8	55.3	141.5	87.7	442.3	110.6
D_3P_1	143.0	139.2	122.5	120.2	524.9	131.2
D_3P_2	147.0	130.5	147.8	100.5	525.8	131.5
TOTAL	2154.8	2190.1	2300.2	1779.0	8424.1	
MEAN	239.4	243.3	255.6	197.7		234.0

Table 16. Plot averages for the maximum number of leaves recorded per plant in the experiment on the effects of plant density and phosphate fertilizer on pigeon pea at Kabete in 1976/77.

TREATMENTS	B L O C K S					
	1	2	3	4	TOTAL	MEAN
D_1P_o	821.3	739.8	1096.0	1010.2	3667.4	916.9
D_1P_1	815.5	653.0	857.5	1013.5	3339.5	834.9
D_1P_2	639.3	772.3	1151.8	918.3	3481.7	870.4
D_2P_0	573.3	763.0	685.3	672.0	2693.6	673.4
D_2P_1	553.5	612.5	626.0	632.8	2424.8	606.2
D_2P_3	396.3	702.3	659.0	771.5	2529.1	632.3
D_3P_o	664.3	734.8	627.0	553.0	2579.1	644.8
D_3P_1	518.3	543.3	437.5	663.3	2162.4	540.6
D_3P_2	515.5	588.0	585.3	795.0	2483.0	621.0
TOTAL	5497.3	6109.0	6725.4	7029.7	25361.4	
MEAN	610.8	678.8	747.3	781.1		704.5

Table 17. Plot averages for the number of primary branches per plant at harvest of the experiment on the effects of plant density and phosphate fertilizer on pigeon pea at Kabete in 1976

TREATMENTS	BLOCKS					
	1	2	3	4	TOTAL	MEAN
D_1P_o	12.3	9.7	10.7	11.1	43.8	11.0
D_1P_1	9.9	14.2	10.6	9.1	43.8	11.0
D_1P_2	12.5	11.2	11.9	11.3	46.9	11.7
D_2P_o	9.6	6.3	10.8	10.6	37.3	9.3
D_2P_1	7.3	7.0	10.3	9.4	34.0	8.5
D_2P_2	9.8	8.4	12.8	9.8	40.8	10.2
D_3P_o	7.3	7.2	4.7	4.7	23.9	6.0
D_3P_1	9.0	7.7	6.3	5.8	29.3	7.3
D_3P_2	6.5	7.1	5.5	7.2	26.3	6.6
TOTAL	84.7	78.8	83.6	79.0	326.1	
MEAN	9.4	8.8	9.3	8.8		9.1

Table 18. Plot averages for the number of primary branches per plant at harvest of the experiment on the effects of plant density and phosphate fertilizer on pigeon pea at Kabete in 1976/77

TREATMENTS	BLOCKS 1	2	3	4	TOTAL	MEAN
D_1P_o	20.6	32.0	27.4	25.4	105.4	26.4
D_1P_1	29.0	26.0	29.0	24.6	108.6	27.2
D_1P_2	27.0	25.2	28.0	25.0	105.2	26.3
D_2P_o	17.8	19.1	13.7	18.9	69.5	17.4
D_2P_1	12.0	14.2	16.3	16.1	58.6	14.7
D_2P_2	16.5	15.9	17.3	17.5	67.2	16.8
D_3P_o	18.8	20.0	22.6	20.1	81.5	20.4
D_3P_1	19.2	21.8	17.2	16.4	74.6	18.7
D_3P_2	23.8	18.1	17.5	18.8	78.2	19.6
TOTAL	184.7	192.3	189.0	182.8	748.8	
MEAN	20.5	21.4	21.0	20.3		20.8

Table 19. Plot averages for shoot dry weight in grams per plant at harvest of the experiment on the effects of plant density and phosphate fertilizer on pigeon pea at Kabete in 1976.

TREATMENTS	BLOCKS					
	1	2	3	4	TOTAL	MEAN
D_1P_o	146.65	177.63	171.29	148.41	643.98	161.00
D_1P_1	188.26	151.60	137.02	145.78	622,66	155.67
D_1P_2	124.23	166.64	186.19	171.14	648.20	162.05
D_2P_o	52.58	57.16	59.74	56.07	225.55	56.39
D_2P_1	58.18	47.48	62.83	72.67	241.16	60.29
D_2P_2	52.80	59.57	62.83	71.40	246.60	61.63
D_3P_o	24.74	27.19	25.00	27.60	104.53	26.13
D_3P_1	29.92	28.20	27.67	34.38	120.17	30.04
D_3P_2	28.85	38.47	29.23	34.83	131.38	32.85
TOTAL	706.21	753.94	761.80	762.28	2984.23	
MEAN	78.47	83.77	84.64	84.70		82.90

Table 20. Plot averages for shoot dry weight in grams per plant at harvest of the experiment on the effects of plant density and phosphate fertilizer on pigeon pea at Kabete in 1976/77.

TREATMENTS	BLOCKS					
	1	2	3	4	TOTAL	MEAN
D_1P_o	797.12	553.91	666.73	551.58	2589.34	647.34
D_1P_1	749.23	554.28	687.71	544.78	2536.00	634.00
D_1P_2	381.06	588.11	623.32	693.41	2285.90	571.48
D_2P_o	374.24	317.11	171.17	283.11	1145.63	286.41
D_2P_1	287.86	356.18	354.42	305.02	1303.48	325.87
D_2P_2	457.33	389.10	309.45	373.90	1529.78	382.45
D_3P_o	318.41	310.07	291.61	305.28	1225.37	306.34
D_3P_1	173.84	343.08	222.72	175.14	914.78	228.70
D_3P_2	283.86	301.38	320.20	228.20	1133.62	283.41
TOTAL	3822.95	3713.22	3647.31	3480.42	14663.90	
MEAN	424.77	412.58	405.26	386.71		407.33

Table 21. Plot averages for shoot dry weight in quintals per hectare at harvest of the experiment on the effects of plant density and phosphate fertilizer on pigeon pea at Kabete in 1976.

	BLOCKS					
TREATMENTS	1	2	3	4	TOTAL	MEAN
D_1P_o	14.67	17.76	17.13	14.84	64.40	16.10
D_1P_1	18.83	15.16	13.70	14.58	62.27	15.57
D_1P_2	12.42	16.66	18.62	17.11	64.81	16.20
D_2P_o	21.03	22.86	23.90	22.43	90.22	22.56
D_2P_1	23.27	18.99	25.13	29.07	96.46	24.12
D_2P_2	21.12	23.83	25.13	28.56	98.64	24.66
D_3P_o	20.20	22.20	20.41	22.53	85.34	21.34
D_3P_1	24.43	23.02	22.59	28.07	98.11	24.53
D_3P_2	23.55	31.40	23.86	28.44	107.25	26.81
TOTAL	179.52	191.88	190.47	205.63	767.50	
MEAN	19.95	21.32	21.16	22.85		21.32

Table 22. Plot averages for shoot dry weight in quintals per hectare at harvest of the experiment on the effects of plant density and phosphate fertilizer on pigeon pea at Kabete in 1976/77.

TREATMENTS	BLOCKS 1	2	3	4	TOTAL	MEAN
D_1P_o	79.71	55.39	66.67	57.16	258.93	64.73
D_1P_1	74.92	55.43	68.77	54.48	253.60	63.40
D_1P_2	38.11	58.81	62.33	69.34	228.59	57.15
D_2P_o	149.70	126.84	68.47	113.24	458.25	114.56
D_2P_1	115.15	142.47	141.77	122.01	521.40	130.35
D_2P_2	182.93	155.64	123.78	149.56	611.91	152.98
D_3P_o	259.12	253.12	238.05	249.21	1000.31	250.08
D_3P_1	141.91	280.07	181.81	142.97	746.76	186.69
D_3P_2	231.72	246.03	261.37	186.29	925.41	231.35
TOTAL	1274.08	1373.80	1213.02	1144.26	5005.16	
MEAN	141.56	152.64	134.78	127.14		139.03

Appendix 2. Effects of plant density and phosphate fertilizer on flower - and pod-abscission in pigeon pea cv PP1 at Kabete: Tables 23-27.

Table 23. Plot averages for the number of flower buds initiated per plant in the experiment on the effects of plant density and phosphate fertilizer on pigeon pea at Kabete in 1976.

TREATMENTS	BLOCKS					
	1	2	3	4	TOTAL	MEAN
D_1P_o	499.0	653.5	656.0	635.0	2443.5	610.9
D_1P_1	833.0	1045.0	816.0	627.5	2321.5	830.4
D_1P_2	626.5	1149.0	933.5	739.5	2448.5	862.1
D_2P_o	301.5	344.0	410.0	231.5	1287.0	321.8
D_2P_1	441.0	460.0	364.0	433.0	1698.0	424.5
D_2P_2	383.0	424.0	439.0	365.0	1611.0	402.8
D_3P_o	228.5	137.0	207.5	165.0	738.0	184.5
D_3P_1	325.5	279.5	190.0	212.0	1007.0	251.8
D_3P_2	261.5	178.0	253.0	212.5	905.0	226.3
TOTAL	3899.5	4670.0	4269.0	3621.0	16459.5	
MEAN	433.3	518.9	474.3	402.3		457.2

Table 24. Plot averages for the number of open flowers per plant in the experiment on the effects of plant density and phosphate fertilizer on pigeon pea at Kabete in 1976.

TREATMENTS	BLOCKS					
	1	2	3	4	TOTAL	MEAN
D_1P_o	196.5	329.0	237.0	305.0	1067.5	266.9
D_1P_1	355.0	553.5	455.5	297.0	1661.0	415.3
D_1P_2	246.0	614.5	505.5	368.0	1734.0	433.5
D_2P_o	143.5	160.5	252.5	113.5	670.0	167.5
D_2P_1	229.0	219.0	176.5	177.0	801.5	200.4
D_2P_2	176.0	269.5	254.0	172.0	871.5	217.9
D_3P_o	87.0	61.0	89.0	73.0	310.0	77.5
D_3P_1	118.5	123.0	78.5	94.0	414.0	103.5
D_3P_2	107.5	96.5	87.0	121.5	412.5	103.1
TOTAL	1659.0	2426.5	2135.5	1721.0	7942.0	
MEAN	184.3	269.6	237.3	191.2		220.6

Table 25. Plot averages for the number of pods set per plant in the experiment on the effects of plant density and phosphate fertilizer on pigeon pea at Kabete in 1976.

TREATMENTS	BLOCKS 1	2	3	4	TOTAL	MEAN
D_1P_o	164.5	202.5	151.0	194.5	712.5	178.1
D_1P_1	194.0	340.5	270.0	175.5	986.0	245.0
D_1P_2	135.5	337.0	280.0	251.0	1003.5	250.9
D_2P_o	68.0	89.0	139.5	67.5	364.0	91.0
D_2P_1	108.5	120.5	81.0	106.5	416.5	104.1
D_2P_2	83.0	101.5	130.0	122.0	436.5	109.1
D_3P_o	56.5	21.0	45.5	31.0	154.0	38.5
D_3P_1	36.5	62.0	39.5	45.5	183.5	45.9
D_3P_2	53.5	48.5	51.5	50.0	203.5	50.9
TOTAL	900.0	1322.5	1188.0	1043.5	4454.0	
MEAN	100.0	146.9	132.0	115.9		123.7

Table 26. <u>Plot averages for the number of mature pods per plant in the experiment on the effects of plant density and phosphate fertilizer on pigeon pea at Kabete in 1976.</u>

	B L O C K S					
TREATMENTS	1	2	3	4	TOTAL	MEAN
D_1P_o	118.0	115.0	141.5	136.0	510.5	127.6
D_1P_1	137.5	219.0	254.0	148.0	758.0	189.6
D_1P_2	114.0	269.0	249.5	188.5	821.0	205.3
D_2P_o	48.0	65.5	113.0	55.0	281.5	70.4
D_2P_1	83.5	106.0	56.0	68.5	314.0	78.5
D_2P_2	68.5	84.0	99.0	61.0	312.5	78.1
D_3P_o	42.0	18.5	41.0	22.0	123.5	30.9
D_3P_1	23.5	44.5	33.5	28.5	130.0	32.5
D_3P_2	42.0	39.5	48.0	37.0	166.5	41.6
TOTAL	677.0	961.0	1035.5	744.5	3418.0	
MEAN	75.2	106.8	115.1	82.7		94.9

Table 27. Plot averages for flower- and pod-abscission (in percentage) per plant in the experiment on the effects of plant density and phosphate fertilizer on pigeon pea at Kabete in 1976.

TREATMENTS	BLOCKS 1	2	3	4	TOTAL	MEAN
D_1P_o	76.4	82.4	78.4	78.6	315.8	78.95
D_1P_1	83.5	79.0	68.9	76.4	307.8	76.95
D_1P_2	81.8	76.6	73.3	74.5	306.2	76.55
D_2P_o	84.1	81.0	72.4	76.2	313.7	78.43
D_2P_1	81.1	77.0	84.6	84.2	326.9	81.73
D_2P_2	82.1	80.2	77.4	83.3	323.0	80.75
D_3P_o	81.6	86.5	80.2	86.7	335.0	83.75
D_3P_1	92.8	84.1	82.4	86.6	345.9	86.48
D_3P_2	83.9	77.8	81.0	82.6	325.3	81.33
TOTAL	747.3	724.6	698.6	729.1	2899.6	
MEAN	83.03	80.51	77.62	81.01		80.5

Appendix 3. Effects of plant density and phosphate fertilizer on yield and yield components of pigeon pea cv PP1 at Kabete: Tables 28-37.

Table 28. Plot averages for the number of pods per plant in the experiment on the effects of plant density and phosphate fertilizer on pigeon pea at Kabete in 1976.

TREATMENTS	BLOCKS 1	2	3	4	TOTAL	MEAN
D_1P_o	160.2	199.8	148.0	151.9	659.9	165.0
D_1P_1	199.1	186.1	145.2	150.2	680.6	170.2
D_1P_2	127.4	187.7	217.3	173.4	705.8	176.5
D_2P_o	56.7	65.3	67.9	54.1	244.0	61.0
D_2P_1	64.5	51.6	61.1	68.2	245.4	61.4
D_2P_2	54.8	57.1	57.0	69.0	237.9	59.5
D_3P_o	24.4	30.3	22.9	28.7	106.3	26.6
D_3P_1	19.5	27.8	25.9	32.5	105.7	26.4
D_3P_2	30.1	39.9	21.6	37.9	129.5	32.4
TOTAL	736.7	845.6	766.9	765.9	3115.1	
MEAN	81.9	94.0	85.2	85.1		86.5

Table 29. Plot averages for the number of pods per plant in the experiment on the effects of plant density and phosphate fertilizer on pigeon pea at Kabete in 1976/77.

	BLOCKS					
TREATMENTS	1	2	3	4	TOTAL	MEAN
D_1P_o	346.0	136.6	92.6	24.0	599.2	149.8
D_1P_1	675.4	162.2	103.8	18.2	959.6	239.9
D_1P_2	113.6	294.0	250.0	14.0	671.6	167.9
D_2P_o	170.3	46.8	47.7	36.5	301.3	75.3
D_2P_1	108.3	114.0	38.7	19.4	280.4	70.1
D_2P_2	106.7	69.7	37.3	19.1	232.8	58.2
D_3P_o	39.7	93.9	27.5	7.6	168.7	42.2
D_3P_1	50.6	22.9	12.4	4.8	90.7	22.7
D_3P_2	36.0	70.9	21.1	14.7	143.3	35.8
TOTAL	1646.6	1011.0	631.70	158.30	3447.6	
MEAN	183.0	112.3	70.2	17.6		95.8

Table 30. Plot averages for the number of seeds per pod in the experiment on the effects of plant density and phosphate fertilizer on pigeon pea at Kabete in 1976.

TREATMENTS	BLOCKS					
	1	2	3	4	TOTAL	MEAN
D_1P_o	3.5	3.3	4.6	3.9	15.3	3.8
D_1P_1	3.8	4.3	3.5	4.2	15.8	4.0
D_1P_2	4.5	4.2	3.3	3.7	15.7	3.9
D_2P_o	2.2	3.0	2.6	3.3	11.1	2.8
D_2P_1	3.2	3.1	3.8	2.9	13.0	3.3
D_2P_2	4.0	2.6	3.4	3.2	13.2	3.3
D_3P_o	1.6	3.6	2.0	3.5	10.7	2.7
D_3P_1	2.0	3.0	2.6	3.1	10.7	2.7
D_3P_2	2.8	2.9	2.4	2.7	10.8	2.7
TOTAL	27.6	30.0	28.2	30.5	116.3	
MEAN	3.1	3.3	3.1	3.4		3.2

Table 31. Plot averages for the number of seeds per pod in the experiment on the effects of plant density and phosphate fertilizer on pigeon pea at Kabete in 1976/77.

TREATMENTS	BLOCKS 1	2	3	4	TOTAL	MEAN
D_1P_o	4.0	2.9	2.9	2.7	12.5	3.1
D_1P_1	3.2	3.7	3.4	1.7	12.0	3.0
D_1P_2	3.9	3.3	4.0	2.2	13.4	3.4
D_2P_o	3.2	3.0	3.4	2.9	12.5	3.1
D_2P_1	2.8	2.7	2.7	2.5	10.7	2.7
D_2P_2	3.3	3.0	2.7	2.8	11.8	3.0
D_3P_o	2.8	3.5	2.8	3.1	12.2	3.1
D_3P_1	3.2	2.7	3.3	2.4	11.6	2.9
D_3P_2	3.0	3.2	2.7	2.8	11.7	2.9
TOTAL	29.4	28.0	27.9	23.1	108.4	
MEAN	3.3	3.1	3.1	1.9		3.0

Table 32. Plot averages for 100 seed weight (in grams) in the experiment on the effects of plant density and phosphate fertilizer on pigeon pea at Kabete in 1976.

TREATMENTS	BLOCKS 1	2	3	4	TOTAL	MEAN
D_1P_o	12.24	13.30	11.66	12.35	49.55	12.39
D_1P_1	11.62	11.68	13.11	11.04	46.85	11.71
D_1P_2	10.47	10.09	11.54	11.65	43.75	10.94
D_2P_o	14.43	12.79	12.75	12.43	52.40	13.10
D_2P_1	11.01	11.72	9.61	11.71	44.05	11.01
D_2P_2	10.79	11.36	11.22	10.00	43.37	10.84
D_3P_o	20.33	8.30	8.99	9.97	47.59	11.90
D_3P_1	10.44	12.00	12.20	10.91	45.55	11.39
D_3P_2	9.92	11.79	9.90	11.40	43.01	10.75
TOTAL	111.25	102.43	100.98	101.46	416.12	
MEAN	12.36	11.38	11.22	11.27		11.56

Table 33. Plot averages for 100 seed weight (in grams) in the experiment on the effects of plant density and phosphate fertilizer on pigeon pea at Kabete in 1976/77.

TREATMENTS	BLOCKS					
	1	2	3	4	TOTAL	MEAN
D_1P_o	11.66	10.63	11.82	10.09	44.20	11.05
D_1P_1	12.95	11.47	11.47	8.39	44.28	11.07
D_1P_2	11.18	12.00	12.47	12.15	47.80	11.95
D_2P_o	12.78	10.89	11.99	11.83	47.49	11.87
D_2P_1	11.99	11.73	10.80	10.16	44.68	11.17
D_2P_2	11.74	11.22	10.93	11.44	45.33	11.33
D_3P_o	10.57	12.41	11.06	10.86	44.90	11.23
D_3P_1	11.61	11.82	10.49	10.58	44.50	11.13
D_3P_2	11.23	11.57	11.10	10.66	44.56	11.14
TOTAL	105.71	103.74	102.13	96.16	407.74	
MEAN	11.75	11.53	11.35	10.68		11.33

Table 34. Plot averages for seed yield (in grams per plant) in the experiment on the effects of plant density and phosphate fertilizer on pigeon pea at Kabete in 1976.

TREATMENTS	BLOCKS 1	2	3	4	TOTAL	MEAN
D_1P_o	68.32	87.71	78.68	73.40	308.11	77.03
D_1P_1	88.69	89.47	66.60	69.38	314.14	78.54
D_1P_2	59.98	79.00	81.95	74.86	295.79	73.95
D_2P_o	17.64	25.18	22.51	21.91	87.24	21.81
D_2P_1	22.47	18.43	24.22	23.15	88.27	22.07
D_2P_2	23.54	16.57	21.65	22.71	85.47	21.37
D_3P_o	7.93	9.15	4.11	9.95	31.14	7.79
D_3P_1	4.04	9.84	8.31	10.96	33.15	8.29
D_3P_2	8.34	13.68	5.13	11.78	38.93	9.73
TOTAL	300.95	349.03	313.16	319.10	1282.24	
MEAN	33.44	38.78	34.80	35.46		35.62

Table 34. Plot averages for seed yield (in grams per plant) in the experiment on the effects of plant density and phosphate fertilizer on pigeon pea at Kabete in 1976.

	BLOCKS					
TREATMENTS	1	2	3	4	TOTAL	MEAN
D_1P_o	68.32	87.71	78.68	73.40	308.11	77.03
D_1P_1	88.69	89.47	66.60	69.38	314.14	78.54
D_1P_2	59.98	79.00	81.95	74.86	295.79	73.95
D_2P_o	17.64	25.18	22.51	21.91	87.24	21.81
D_2P_1	22.47	18.43	24.22	23.15	88.27	22.07
D_2P_2	23.54	16.57	21.65	22.71	85.47	21.37
D_3P_o	7.93	9.15	4.11	9.95	31.14	7.79
D_3P_1	4.04	9.84	8.31	10.96	33.15	8.29
D_3P_2	8.34	13.68	5.13	11.78	38.93	9.73
TOTAL	300.95	349.03	313.16	319.10	1282.24	
MEAN	33.44	38.78	34.80	35.46		35.62

Table 35. Plot averages for seed yield (in grams per plant) in the experiment on the effects of plant density and phosphate fertilizer on pigeon pea at Kabete in 1976/77.

TREATMENTS	BLOCKS 1	2	3	4	TOTAL	MEAN
D_1P_o	74.75	43.14	27.77	10.72	156.38	39.10
D_1P_1	123.75	27.87	32.67	4.74	189.03	47.26
D_1P_2	21.43	75.41	82.10	13.19	192.13	48.03
D_2P_o	44.15	13.47	13.48	8.06	79.16	19.79
D_2P_1	29.13	29.03	11.69	4.21	74.06	18.52
D_2P_2	31.23	13.62	9.67	5.89	60.41	15.10
D_3P_o	10.03	25.73	6.80	2.37	44.93	11.23
D_3P_1	11.02	7.25	3.56	1.12	22.95	5.74
D_3P_2	7.58	13.39	5.06	3.32	29.35	7.30
TOTAL	353.07	248.91	192.80	53.62	848.40	
MEAN	39.23	27.66	21.42	5.96		23.57

Table 36. Plot averages for seed yield (in quintals per hectare) in the experiment on the effects of plant density and phosphate fertilizer on pigeon pea at Kabete in 1976.

TREATMENTS	BLOCKS					
	1	2	3	4	TOTAL	MEAN
D_1P_o	6.83	8.77	7.87	7.34	30.81	7.70
D_1P_1	8.87	8.95	6.66	6.93	31.41	7.85
D_1P_2	6.00	7.90	8.20	7.49	29.58	7.40
D_2P_o	7.06	10.07	9.00	8.76	34.90	8.72
D_2P_1	8.99	7.37	9.69	9.26	35.31	8.83
D_2P_2	9.42	6.63	8.66	9.48	34.19	8.55
D_3P_o	6.47	7.47	3.36	8.12	25.42	6.36
D_3P_1	3.30	8.03	6.78	8.95	27.06	6.77
D_3P_2	6.81	11.17	4.19	9.62	31.78	7.95
TOTAL	63.75	76.36	64.40	75.95	280.46	
MEAN	7.08	8.48	7.16	8.44		7.79

Table 37. Plot averages for seed yield (in quintals per hectare) in the experiment on the effects of plant density and phosphate fertilizer on pigeon pea at Kabete in 1976/77.

TREATMENTS	BLOCKS 1	2	3	4	TOTAL	MEAN
D_1P_o	7.48	4.31	2.78	1.07	15.64	3.91
D_1P_1	12.38	2.79	3.27	0.47	18.91	4.73
D_1P_2	2.14	7.54	8.21	1.32	19.21	4.80
D_2P_o	17.66	5.39	5.39	3.22	31.66	7.92
D_2P_1	11.65	11.61	4.68	1.68	29.62	7.41
D_2P_2	12.49	5.45	3.87	2.36	24.17	6.04
D_3P_o	8.19	21.00	5.55	1.93	36.67	9.17
D_3P_1	9.00	5.92	2.91	0.91	18.74	4.69
D_3P_2	6.19	10.93	4.13	2.71	23.96	5.99
TOTAL	87.18	74.94	40.79	15.67	218.58	
MEAN	9.69	8.33	4.53	1.74		6.07

Appendix 4. Growth and development study of pigeon pea cv PP1 at Kabete: Tables 28-41.

Table 38. Pigeon pea shoot dry weight production and its distribution in grams per plant at 1 plant per M^2 at Kabete in 1976.

TIME FROM SOWING IN WEEKS	SHOOT DRY WEIGHT IN GRAMS PER PLANT			
	Leaves	Stems	Reproductive parts	Total
3	0.06	0.02	0	0.08
4	0.11	0.05	0	0.16
7	0.39	0.17	0	0.56
9	1.37	0.68	0	2.05
11	2.60	1.55	0	4.15
13	4.99	3.41	0	8.40
15	7.11	4.50	0	11.61
17	11.52	8.47	0.08	20.07
19	22.78	17.89	0.47	41.13
21	33.47	28.88	1.14	63.49
22	27.45	23.63	2.22	53.30
23	31.08	29.09	3.78	63.96
24	29.68	31.34	8.27	69.29
25	39.85	40.23	11.99	92.07
26	38.20	35.53	11.31	85.03
27	36.41	36.85	31.54	104.80
28	42.37	46.70	36.76	125.83
29	33.29	39.59	47.62	120.50
30	27.28	35.85	86.35	149.46
31	11.95	32.24	95.16	139.34
32	11.11	40.06	103.55	154.74

Table 39. Pigeon pea shoot dry weight production and its distribution in grams per plant at 8.2 plants per M^2 at Kabete in 1976.

Time from sowing in weeks	Shoot dry weight in grams per plant			
	Leaves	Stems	Reproductive parts	Total
3	0.06	0.02	0	0.08
4	0.13	0.06	0	0.19
7	0.51	0.21	0	0.72
9	1.37	0.67	0	2.04
11	3.08	1.72	0	4.80
13	4.10	2.55	0	6.65
15	10.04	6.97	0	17.01
17	11.74	9.54	0.60	21.88
19	13.77	14.59	0.47	28.83
21	15.14	15.98	1.16	32.28
22	16.54	22.78	0.88	40.20
23	12.20	14.70	2.68	29.93
24	12.17	15.62	2.14	29.93
25	11.22	16.74	6.89	34.85
26	12.82	18.10	3.68	34.60
27	12.11	17.89	8.30	38.30
28	11.01	15.13	10.39	36.53
29	9.38	17.31	11.73	38.42
30	7.58	13.53	10.87	31.98
31	6.42	13.39	10.96	30.77
32	6.45	13.02	11.31	30.78

Table 40. Pigeon pea height, number of leaves per plant and leaf area index at 1 plant per m^2 at Kabete in 1976.

Time from sowing in weeks	Plant in cm	Number of leaves per plant	Leaf area index
3	6.95	2	0.001
4	10.10	3	0.002
7	22.48	5.3	0.008
9	35.76	10.7	0.025
11	41.90	25.3	0.048
13	52.03	41.0	0.088
15	53.25	61.3	0.108
17	64.05	108.0	0.166
19	70.83	166.3	0.314
21	86.15	276.0	0.432
22	82.00	230.7	0.328
23	79.45	257.3	0.373
24	79.80	240.3	0.351
25	81.85	285.7	0.446
26	79.70	342.7	0.494
27	81.05	301.3	0.458
28	93.10	367.7	0.516
29	93.86	309.7	0.384
30	86.20	272.3	0.358
31	86.25	159.0	0.164
32	92.00	119.0	0.151

Table 41. Pigeon pea height in cm, number of leaves per plant and leaf area index at 8.2 plants per m^2 at Kabete in 1976.

Time from sowing in weeks	Plant height in cm	Number of leaves per plant	Leaf area index
3	6.65	2	0.012
4	10.10	3	0.020
7	26.48	6	0.080
9	37.13	10.7	0.205
11	44.03	25.3	0.455
13	49.03	33.3	0.593
15	60.53	75.0	1.225
17	66.65	100.0	1.339
19	69.83	116.7	1.345
21	68.78	138.0	1.562
22	71.88	122.3	1.707
23	67.43	104.7	1.161
24	74.85	106.7	1.183
25	71.03	123.3	1.104
26	68.73	144.0	1.344
27	69.38	127.3	1.205
28	68.10	114.0	1.187
29	62.40	89.0	0.881
30	67.15	85.7	0.837
31	61.40	77.7	0.646
32	58.33	89.7	0.665