EFFECTS OF PLANT DENSITY AND PHOSPHATE LEVELS ON GROWTH, YIELD AND YIELD COMPONENTS OF FIELD BEANS PHASEOLUS VULGARIS L.

by

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1983

DECLARAT ION

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

Signed
Grace Wangari Mbugua

Date April 26, 1983

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

Signed
Dr. D.R. Basiime

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DEDICATION

To Mrs Leah N. Ngini, my teacher and friend, whose assistance, encouragement and inspiration during my High School days enabled me to pursue education up to the University.

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ABSTRACT

Field bean (*Phaseolus vulgaris*) grown mainly for its protein rich dry bean seeds, is the most important legume and the second most important crop in Kenya. Bean yields have been shown to be increased by phosphate fertilizers particularly in areas which are low in available phosphorus which is the case in most farming areas of Kenya. Increasing bean plant populations under optimal growth conditions has resulted in increase in bean yields mainly due to the increase in number of pods per unit area. The objective of this study was to investigate the effects of phosphate fertilizer, plant population density, and population density x fertilizer interaction on growth and yield of *Phaseolus vulgaris*.

Two experiments were conducted at the University of Nairobi, Kabete in 1979 and 1980. Kabete has an annual average rainfall of 950 mm and mean maximum and minimum temperatures of 23°C and 13°C respectively. The soils are deep red friable loams.

Bean seeds (cultivar Rose Coco) were planted at 25 x 25 cm, 20 x 20 cm, 15 x 15 cm and 10 x 10 cm to give population densities of 160,000, 250,000,

444,444 and 1,000,000 plants/ha respectively. Triple superphosphate fertilizer (46% P_2O_5) was applied at the rates of 0 (control), 50, 100 and 150 kg P/ha. The 4 x 4 treatment combinations were replicated four times in a randomized complete block design. The crop was grown following the recommended agronomic practices.

Six sequential harvests, each of which comprised 10 and 5 plants per plot in 1979 and 1980 respectively, were harvested at 2 week-intervals. From the samples, leaf, stem, pod and root dry weights, nodule number and nodule weight per plant were determined. Leaf Area Index (LAI) was also determined using the disc method. Seed yield, pods/plant, seeds/pod, 100 seed weight, total dry matter and Harvest Index (HI) were determined at the final harvest. Growth rate was also monitored throughout the growing seasons.

Phosphate fertilizer increased LAI, plant growth rate, rate of plant senescence, and number and weight of nodules. Pod number per plant, seeds/pod, and 100-seed weight in 1980, were also higher in the fertilized than in the control plants. There was 13% and 9% increase in seed yield over the control in 1979 and 1980 respectively at the 150 kg P/ha treatment and this increase could be attributed to the increase in the number of pods per plant.

Yield differences resulting from the different fertilizer rates (50-150 kg P/ha) were insignificant, consequently application of 50 kg P/ha appeared the best.

With increase in plant population, growth rate, dry matter yield and rate of senescence per plant, pods/plant and seeds per pod all decreased, while LAI, rates of growth, dry matter yield, rate of senescence and number of pods per hectare increased. 100-seed weight was apparently unaffected. Seed yield decreased with increase in plant density hence this did not reflect increases in vegetative dry matter with rise in plant population. High populations favoured vegetative rather than reproductive growth as indicated by decreasing HI values with increase in plant density. Therefore no yield benefit was obtained by increasing plant population of this particular variety beyond 160,000 plants/ha.

Population density x fertilizer interactions were largely insignificant. Where the interactions were significant, responses in growth and yield to the different plant densities occurred mainly where fertilizer was applied. This seemed to indicate that phosphorus can be limiting in Kabete soils.

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CHAPTER ONE

INTRODUCTION

1.1. Importance of Legumes in Kenya

In developing countries such as Kenya, where animal protein is in short supply and therefore expensive for the low income groups, beans and other pulses containing considerable amount of protein of high nutritional quality assume an emminent role as a potential source of low cost readily obtainable protein. The importance of legumes mainly lies in their actual and potential value as a source of plant protein for human consumption.

Phaseolus vulgaris is by far the most important legume in Kenya, and is second only to maize as a major food crop. Beans are grown in all agricultural areas except at the Coast, in an area of about 320,000 hectares. Most of this area is in the medium potential region of Central and Eastern Provinces with a bimodal rainfall pattern of 700 to 900 millimeters, (Schonher and Mbugua, 1976). The hectarage under beans in Uganda and Tanzania is about 270,000 and 120,000 hectares respectively (Acland, 1971).

1.2. Effect of Phosphate Fertilizer on Yield of Field Beans

Phosphatic fertilizers have been shown to raise dry bean yields and dry matter production particularly in areas where soils are low in available phosphorus. Most soils in the farming areas of Kenya have very low phosphate reserves, hence responses to phosphate fertilizers are often obtained.

1.3. Effect of Plant Population Density on Yield of Field Beans

Many population density studies with field beans[1], (Vicia faba) (*P. vulgaris*), have resulted in higher plant densities producing higher yields, as shown by, among others, Almeida (1965), Mascarenhas (1966), Enyi (1975), Edje and Mughogho (1975), and Westermann and Crothers (1977). At closer spacing, Leaf Area Index (LAI) is increased which results in more complete ground cover with consequent increase in interception of photosynthetically active radiation and increased carbon dioxide fixation per unit area (Enyi, 1975; Immer et al., 1977). Increased yields with increase in plant population was positively correlated with LAI (Mosley, 1972).

In P. vulgaris, higher yields obtained from higher plant densities have been shown to be mainly due to the increase in the number of pods per unit area (Mosley, 1972, Leakey, 1972, Rojas et al., 1975, Immer et al., 1977). The number of pods produced per plant decreases as plant population density is raised due to interplant competition, but the decrease is more than compensated for by the increase in the number of plants per unit area.

Additional advantage of high plant densities is the uniform maturation of the crop. If a crop of even maturity is desired in mechanical harvesting for example, this may be achieved by increasing plant population and restricting the duration of the fruiting season (Smartt, 1976). At high plant densities of snap beans (P. vulgaris), the range of pod maturity appeared to be smaller and duration of flowering shorter than at low plant densities (Mosley, 1972).

1.4. Population Density-fertilizer Interaction

At higher levels of nutrient supply, more plants per unit area are required to exploit fully the higher soil fertility potential and thereby produce maximum yields. Conversely, as plant density increases up to a certain limit, the crop will continue to respond to added nutrients (Arnon, 1972). Leakey (1972) reported that bean yield response to plant population and increased fertilizer levels appeared to be additive in effect. Chagas *et al.* (1975) did not find any interaction between *P. vulgaris* population density and fertilizer.

The objective of this study was therefore to:

1) determine the effect of population density of field beans on:
   - i) the rate of growth
   - ii) grain yield and yield components

2) examine the effect of different phosphate fertilizer levels on the above (i) and (ii)

3) investigate the interaction between plant population density and phosphate fertilizer on yield and yield components of _P. vulgaris_

4) determine the effect of phosphate fertilizer on nodulation of P. vulgaris.

CHAPTER TWO

LITERATURE REVIEW

2.1. Effect of Plant Density on Bean Yield

Many population density studies with field beans P. vulgaris have shown that higher plant densities produce higher yields. Mascarenhas et al. (1966) compared an early maturing dry bean variety at all combinations of between row spacings of 40, 30 and 20 cm and within row spacings of 30, 20 and 10 cm. Yields per unit area were still rising at the highest population of 500,000 plants per hectare (given by the closest spacing of 20 x 10 cm). Yields varied from 870 kg/ha at 40 x 30 cm to 1650 kg/ha at 20 x 10 cm at one site; and from 1010 to 1360 kg/ha at another site averaged over two seasons. Almeida (1965) had similarly found increases in yield of 'Rico-23' an erect bean variety, by progressively decreasing distances between rows from 60 to 30 cm and within rows from 30 to 10 cm. Grain yield per hectare was increased by 27, 50 and 48% when P. vulgaris plant population was increased from 74,000 to 111,000, 222,000 and 444,000 plants per hectare respectively (Enyi, 1975). Edje et al. (1975) in Malawi obtained yield increases of 19 and 13% on increasing plant population from 111,000 to 222,000 and from 222,000 to 444,000 plants per hectare respectively. Goulden (1975) working with navy beans, obtained 57% increase in yield by raising plant population from 250,000 to 1,040,000 plants per hectare.

2.2. Effect of Plant Arrangement on Yield

Square planting is the theoretical optimum arrangement for crops as suggested by Donald (1963). It would be reasonable to expect that square arrangement would be more efficient in the utilisation of light, water and nutrients available to the individual plant than would be a rectangular arrangement, as the former arrangement would reduce to a minimum the competitive effects of neighbouring plants to one another (Arnon, 1972). When field beans were planted at a spacing of 25 x 25 cm and 76 x 8 cm, both spacings, giving the same population density, plants spaced at 25 x 25 cm yielded 13½ more than those spaced at 76 x 8 cm; plants spaced at 20 x 20 cm yielded 12% more than those spaced at 76 x 5 cm (Kuenemann *et al*., 1979). Plant arrangement experiments at Kakamega in Kenya resulted in square arrangement outyielding rectangular arrangement by 23%, though in four other sites at Katumani, Embu, Thika and Kisii, plant arrangement did not significantly affect yield (Grain Legume Project, 1975-6).

2.3. Effect of Plant Density on Yield Components

The yield component most sensitive to changes in plant population density is the number of pods per plant, followed by seeds per pod and weight per seed. This order of stress responsiveness has been observed in dry beans by, among others Mathews (1933), Adams (1967), Appadural *et al*. (1967), Camacho *et al*. (1968), and Wiley and Osiru (1972).

Mosley (1972) reported that increased yield with increase in plant density from 2.62 to 9.6 plants per foot square (29.11 to 106.6 plants per m^2) was due to the increase in the number of pods per unit area. Leakey (1972) and Rojas *et al*. (1975) found that the number of pods per plant decreased, but the number of pods per unit area increased with increase in plant population. Yield was determined to the extent of 85.7 and 86.1% by the product of pods per plant and plants surviving to harvest (Leakey, 1972). Plant density and thinning experiments showed that pod number per plant was sensitive to interplant competition between 36 and 78 days after sowing, while number of seeds per pod and seed weight were not sensitive (Immer et al., 1977).

Among the components of pods per plant, i.e. pods per raceme, racemes per node, nodes per branch and branches per plant, analysed by Bennet, Adams and Burga (1977), only racemes per node and branches per plant were significantly reduced by higher planting densities and this accounted for the observed decrease in pods per plant.

Though no regular changes in the number of seeds per pod with changes in plant population were observed, the lowest numbers were obtained at the highest plant densities and vice versa in *P. vulgaris* (Leakey, 1972). Edje et al. (1975); Immer et al. (1975), and Goulden (1975) did not obtain any significant effect of spacing on the number of seeds per pod in *P. vulgaris*.

Among the highly plastic components of plant yield, the weight of the individual seed is only rarely influenced by changes in plant density (Arnon, 1972). Carvalho (1974), Rojas et al. (1975) and Goulden (1975) did not obtain any significant effect of spacing on seed weight.

2.4. Some Problems Encountered with High Plant Densities

High plant population densities may prevent light penetration into the canopy and may also result in creation of humid microclimate that favours growth of plant pathogens. Beans planted at the higher plant densities, for example, were more severely attacked by white mould (*Whetzelinia sclerotiorum*) than those planted at lower densities (Nichols, 1973). In two experiments conducted with *P. vulgaris*, it was found that it was possible to control white mould (reflected in yield increase) by changing the distance between rows. At 95 cm the bean variety yielded 1333 kg/ha as compared to 796 kg/ha when sown at 50 cm between rows (Agric. Teh. Mex., 1977). Cultivars with open canopies that permit light penetration and exchange of gases throughout the canopy are more suited for high plant densities. Appropriate disease and pest control measures should also be employed where necessary.

Leakey (1972) observed a clear trend towards increasing mortality of plants during growth with increased density of stands. He reports that highest densities although giving the highest grain yield, are wasteful of seed in that plants surviving to contribute yield are much reduced. This may occur at very high densities when competition among the plants may be so severe and plant survival takes precedence over total seed production per unit area (Donald, 1963).

Excessively high plant populations are disadvantageous where water availability is low at the period of final maturation, but if supplementary irrigation is available, higher plant populations may be used with advantage (Smartt, 1976).

2.5. Effect of Phosphatic Fertilizer on Yield

Various types of fertilizers, fertilizer rates and methods of application have been studied to determine their benefit to field bean

(*P. vulgaris*) production. Most of this work, however has been done outside Eastern Africa.

Where soils are poor in available phosphorus, phosphatic fertilizers have been shown to increase dry bean yields and dry matter production. Fertilizer work by Mitchel (1964) in Australia resulted in the highest yields being obtained where 57 kg P and 80 kg N per hectare were given as basal application at planting followed by 57 kg N per hectare three weeks later. Average seed yields of 444 kg/ha without fertilizer were raised to 1307 kg/ha by application of 120 kg P_2O_5/ha and 30 kg N/ha (Miyasaka *et al.*, 1965). Application of 80 kg P_2O_5 and 160 kg P_2O_5 per hectare gave 36.5% and 35.1% increase in bean yield over no fertilizer (Almeida, 1973). Edje *et al.* (1975) obtained 25% and 10% bean yield increase on increasing NPK from zero to 400 to 800 kg per hectare respectively.

In Uganda, *P. vulgaris* bean yields were significantly increased by superphosphate, agricultural lime and ammonium sulphate. Phosphate was found to be the main requirement and it was probable that the effect of lime was due in part to its own P content (2% P_2O_5) and to its action in making soil phosphate more available (Stephens, 1967). In further fertilizer work in Uganda by Leakey (1972), 0, 5, 10, 20 cwt per acre (0, 254, 508 and 1016 kg/ha) of 2:2:1 compound fertilizer containing 46 N, 19 P, 46 K, 28 S and 70 Ca pounds per acre (52.2 N, 21.6 P, 52.2 K, 31.8 S and 79.5 Ca kg per hectare) in every cwt (50.8 kg) was used on beans. Higher fertilizer levels raised bean yields. The largest yield increment was obtained by using 5 cwt NPK per acre (254 kg per ha). There was no apparent advantage in yield from increasing fertilizer level from 10 to 20 cwt per acre (508 to 1016 kg per ha).

* Most soils in the farming areas of Kenya have very low phosphate reserves, hence responses to phosphatic fertilizers are commonly obtained. In bean-growing areas of Central and Eastern Provinces of Kenya, FAO work (1971-72) showed that application of phosphorus and potassium resulted in economical yield increases, where 40 kg per hectare for both P and K proved to be highly effective. In Muranga and Kiambu districts the yields were raised from 952 and 878 kg/ha with no fertilizer

to 1536 and 1504 kg/ha respectively when 40 kg P and 40 kg of K was given to the crop.

Grain Legume Project (GLP) work (1977) in Katumani, Thika, Embu, Kisii and Kakamega showed that bean yields were significantly increased by Diammonium phosphate; 200 kg/ha of the fertilizer applied in furrows at planting time gave the highest bean yield of 2276 kg/ha. Double superphosphate did not give any response.

Kabete area represents soils with an acid pH of about 6, and a high capacity to fix phosphorus, hence addition of this nutrient seems important in the improvement of bean yields (Keya and Mukunya, 1979). Yields of Canadian Wonder beans (*P. vulgaris*) were progressively increased by raising fertilizer rates from 0 to 30 to 60 kg P_2O_5 per hectare at Kabete (Mahatanya, 1976). More recent work by Keya and Mukunya (1979) resulted in phosphatic fertilizers increasing dry matter and seed yield of *Phaseolus vulgaris*.

2.6. Effect of Phosphate Fertilizer on Yield Components

Since phosphorus influences total yield it would be expected to have an effect on the yield components as well. Hiroce *et al*. (1970) found a positive, linear and highly significant increases in seed yield per plant by phosphorus application, and the seed yield was positively and significantly correlated with pod number. GLP (1979) work in Kenya also showed that increased yields due to phosphate fertilizer application was mainly due to the increase in the number of pods per plant.

2.7. Effect of Phosphate Fertilizer on Nodulation

Several studies have shown that application of phosphatic fertilizers to field beans can improve nodulation and nitrogen fixation with consequent increase in yield (Anderson, 1973; Keya, 1977; Keya and Mukunya, 1979).

2.8. Population Density-fertilizer Interaction

At higher levels of nutrient supply, more plants per unit area are required to exploit fully the higher soil fertility potential and thereby produce maximum yields. Conversely, as plant density increases up to a certain limit, the crop will continue to respond to higher levels of added nutrients (Arnon, 1972).

In a study of maize concerning the relationship between population density and different levels of nitrogen supply, it was found that the higher the level of nitrogen was, the greater would be the plant population required for achieving maximum yields (Lang *et al*., 1956). Different populations of *P. vulgaris* can probably be expected to respond to phosphate levels in a similar manner. Leakey (1972) reported that bean yield response to population and increased fertilizer levels appeared to be additive in effect. Chagas *et al*. (1975) did not find any interaction between *P. vulgaris* population density and fertilizer.

CHAPTER THREE

MATERIALS AND METHODS

3.1. The Experimental Site

Two experiments identical in design and layout were established at the University of Nairobi Field Station, Kabete. Kabete is situated at latitude 1° 15' South and longitude 36° 44' East. It has an altitude of 1820 meters with mean maximum and minimum temperatures of 23°C and 13°C respectively. The coolest months are May, June, July and early August with the lowest temperatures being recorded in July. December, January and February are among the hottest months (see Appendix table I).

The area has a bimodal rainfall regime with annual average rainfall of 950 mm. The first or the long rains fall in the months of March, April, May and the first part of June. 494 mm of rain, about 52% of the annual average, falls in these months. These rains are more reliable and heavier than the second or the short rains which fall in late October, November and December. Only about 269 mm, 28% of the annual average total, is received in this season. Appendix I shows the temperatures and the rainfall received in 1979 and 1980, the period during which the experiments were carried out.

3.2. Soils

Kabete soils have been described as Kikuyu friable loams (Keya and Mukunya, 1979). The soils are deep-red clays with a stable microstructure. Laboratory analysis of the soils revealed the following nutrient content:

Table 1: Nutrient Content of Soils Sampled from Fields 14 and 19.

	Field 14	Field 19
pH in water and in 0.01 m calcium chloride, respectively	6.1; 5.2	6; 5.6
Total nitrogen	0.28%	0.28%
Available phosphorus, ppm	4.1	3.6
Echangeable potassium me/100 g of soil	4.4	2.7
Carbon/nitrogen ratio	12 :1	10:1
Organic matter	6.0	4.8%

Analytical methods used in the Department of Soil Science (Ahn, 1973 and 1975) were used in determining the above, except for phosphorus which was determined by Murphy and Riley Method (1962).

Note: Response to phosphorus is expected if soil phosphorus is less than 5 ppm.

5 - 10 ppm (P) - response to phosphorus is probable.

>10 ppm (P) - response to phosphorus is unlikely.

3.3. The Bean Variety Used in the Experiment

Phaseolus vulgaris cultivar Rosecoco which resembles GLP x-98 was used in the experiment. The cultivar is medium to late maturing, with an indeterminate growth habit, and is quite popular in the medium rainfall areas of Kenya's Central Province. It is also quite common in Western and Eastern Provinces.

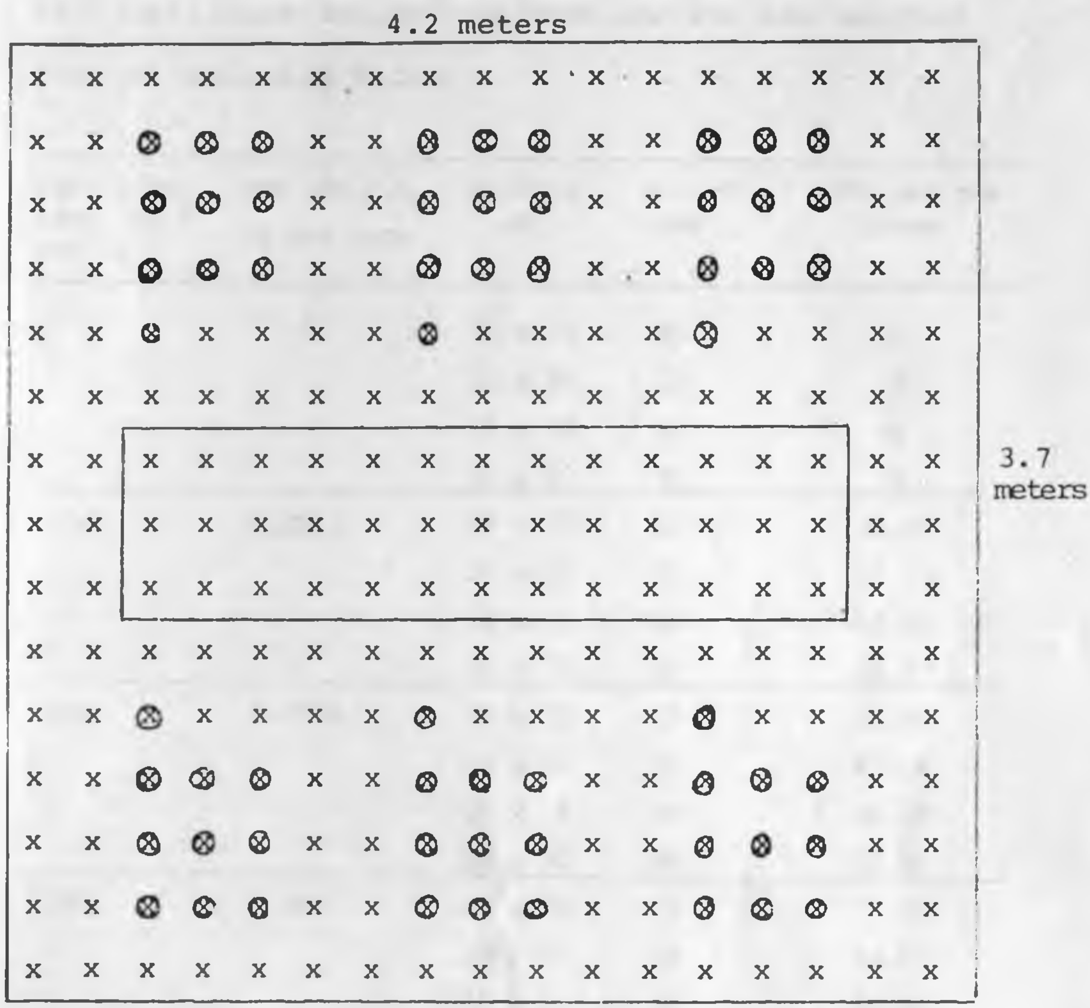
3.4. Planting methods

Rosecoco seeds were dressed with aldrin at the rate of 5 grams per kilogram of seed to control pests especially bean fly (*Melanargromyza* phaseoli). The seeds were then planted in four different spacings to give four different population densities as follows:

Spacing in cm	Number of plants per hectare	
25 x 25	160,000	(P_1)
20 x 20	250,000	(P_2)
15 x 15	444 ,444	(P_3)
10 x 10	1,111,000	(P_4)

Triple superphosphate fertilizer containing 46% phosphorus pentoxide (P_2O_5) was applied at four different rates to give four levels of phosphorus per hectare. These levels were 0, 50, 100 and 150 kg P/ha. Hence there were 4 x 4 treatment combinations. These 16 treatments were replicated four times to give a total of 64 plots, each plot being 4.2m x 3.7m. A randomised complete block design was used (see Fig. 2 for plot layout).

Fig. 1. Plot Layout (not to scale), spacing:(25 x 25 cm)



Key: ⊗ Plants for sequential harvest

x Guard plants

The net plot (enclosed area in the centre) was 325 x 75 cm for second rains 1979, and 1 x 1 m for first rains 1980 for all spacings from which final harvest was taken. Plants for sequential harvests were obtained from similar positions in their respective plots.

Depending on the plot size and spacing, the number of rows per plot were determined, then the fertilizer amount required per row was weighed out as indicated below:

Fertilizer rate, kg P per ha	TSP 46% P_2O_5 kg per plot	Spacing cm	No. of rows	TSP per row (grams)
0	0	25 x 25	15	0
		20 x 20	18	0
		15 x 15	24	0
		10 x 10	35	0
50	0.3911	25 x 25	15	26.07
		20 x 20	18	21.73
		15 x 15	24	16.30
		10 x 10	35	11.17
100	0.7748	25 x 25	15	51.65
		20 x 20	18	43.04
		15 x 15	24	32.28
		10 x 10	35	22.14
150	1.1622	25 x 25	15	77.48
		20 x 20	18	64.57
		15 x 15	24	48.43
		10 x 10	35	33.21

(Conversion factors for P:

$\% P = \% P_2O_5 \times 0.436$

$\% P_2O_5 = \% P \times 2.29$) (Ahn, 1970)

The fertilizer was applied in furrows at planting time and mixed with the soil. The seeds were then placed singly in the furrows and covered with the soil to a depth of about 2 to 3 cm.

The first experiment's crop was planted on 5 November 1979. The first weeding was carried out on 22 November, three weeks after planting when the plants had about 2 to 3 leaves. The second weeding was done three weeks later, i.e. six weeks after planting.

Soon after the first weeding calcium ammonium nitrate (CAN: 26% N) was applied at the rate of 13 kg N per hectare. The fertilizer was top-dressed between the rows.

Due to the drought that persisted throughout most of the season, the crop was irrigated twice: in December 1979 and again in January 1980.

The crop was sprayed twice, on 7 January, 1980 and again on 17 January 1980 with Dithane M 45 (40% emulsifiable concentrate) at the rate of 4 litres in 600 litres of water/hectare using Knapsack sprayers.

3.5. Sampling Techniques

Sequential harvests were carried out on 4th, 6th, 8th, 9th, 11th and 13th week after planting. At flowering and pod-forming stage, changes in plant growth were expected to be rapid and so only one week interval was allowed between the 3rd and the 4th sequential harvests. Ten plants were uprooted from a pre-determined area in each plot (see Fig. 2), making sure that most of the tap root and main lateral roots and most of the root nodules were recovered. The plant samples were then put in plastic bags to preserve their water content, then taken to the laboratory for weighing and measurement.

Leaf area was determined using the disc method and the cross-sectional area of the punch was 2.43 cm^2. Twenty whole discs were taken to calculate the area/weight relationship of the sample.

Total fresh weight of the plants, excluding the roots, was taken. Then the plant was separated into stem, leaves and pods and the fresh weight of these parts was recorded. The number of pods per plant was recorded at 4th, 5th and 6th harvests, i.e. 9, 11 and 13 weeks after planting, respectively.

During the first, third and fourth harvests, root nodules from each plant were counted. Nodule weight from the ten plants per sample per harvest was also recorded. During subsequent harvests the nodules were shrivelled and very few, making it difficult to separate them from the soil, to count or to weigh them.

The final harvest was taken on 5th March 1980 from an area of 75 x 325 cm^2 per plot (see Fig. 2). The number of the harvested plants differed with the varying plant population densities and this was achieved by harvesting as indicated below:

Spacing in cm	Number of rows harvested per plot
25 x 25	3 centre rows, omitting two plants at each end of every row.
20 x 20	4 centre rows, omitting two plants at each end of every row.
15 x 15	6 centre rows, omitting three plants at each end of every row.
10 x 10	8 centre rows, omitting four plants at each end of every row.

From the final harvest, the following data were obtained.

- seed yield in grams per plot
- number of pods per plant
- number of seeds per pod
- Weight of 100 seeds which were randomly selected from each sample. The 100-seed weight was taken after drying the seeds in the oven at 100°C for 24 hours.
- total dry matter
- harvest index. This was the ratio of seed yield to total dry matter:

$$\text{Harvest index} = 100 \times \frac{\text{seed yield in kg/ha}}{\text{total dry matter in kg/ha}}$$

Field 14 was used for the second experiment. The land was ploughed in early April 1980 then harrowed twice to a fine tilth just before planting. The crop was planted on 23rd April 1980, using the same procedure as in the first experiment. The first weeding was done during the third week after planting at two to three leaf-stage. The second weeding was carried out one month later.

The crop was top-dressed with CAN (26% N) 31 days after planting, i.e. on 26 May 1980 at the rate of 13 kg of nitrogen per hectare.

The rainfall received during the season was satisfactory hence the plants were not irrigated.

Samples were taken on 4th, 6th, 9th, 11th, 13th and 15th week after planting. The third sequential harvesting was done on the 9th rather than the 8th week after planting due to unavailability of workers during the latter period). The growing season was expected to be longer and the crop to remain green in the field for a longer time than in the previous season hence the interval between sequential harvests remained a constant two weeks. Five plants per plot (and not ten as in the previous season) were sampled in each harvest. This was to ensure that sufficient number of plants were left for final harvest since poor germination due to the very heavy rain that fell two days after planting resulted in fewer plants per plot than expected. As in the first experiment, total leaf, stem and pod fresh and dry weights were determined. Root fresh and dry weights were also determined. The number and weight of root nodules were recorded in the first, second and third and fourth harvests.

Final harvest was carried out on 21st and 22nd August 1980. Plants for final harvest were taken from an area of 1 x 1 meter square. Seed yield in grams per plot, number of pods per plant, number of seeds per pod and harvest index were determined as in the first experiment.

3.6. Statistical Analysis

Separation of means was done using Duncan's New Multiple Range Test.

Quantitative data so = trend analysis's
Orthogonal contrasts-

C H A P T E R   F O U R

RESULTS

4.1. Seasonal Differences

Tables 2 and 3 show the dry matter accumulation and growth rate* averaged over all the fertilizer levels and all the plant populations. In the 1979 crop total dry matter per plant increased at an increasing rate up to the 9th week after planting. The highest growth rate of 2.17 gm/plant per week was attained in the 9th week when the average dry weight per plant was 7.2 gm. After the 9th week, the rate of growth dropped to 0.56 gm/plant/week.

The rate of dry matter accumulation in the leaves increased from 0.70 gm/plant/week in the 6th week to 0.97 gm/plant/week in the 8th week. During the two weeks that followed,the rate dropped to 0.45 gm/plant/week, after which negative growth rate set in. The leaves attained their maximum dry matter in the 9th week.

In the 6th week stem dry matter increased at the rate of 0.25 gm/plant/week.

*Growth rate refers to absolute growth rate in the text and tables.

Table 2. Change in dry matter (gm/plant) with time:

	Second rains 1979					First rains 1980				
Weeks after planting	leaf	stem	pod	total	Weeks after planting	leaf	stem	root	pod	total
4	0.73	0.19		0.92	4	1.80	0.48	0.36		2.64
6	2.14	0.69		2.83	6	4.86	1.90	0.58		7.34
8	3.66	1.46		5.12	9	7.05	3.86	0.86	1.57	13.34
9	4.11	2.35	0.75	7.21	11	6.29	4.61	0.71	7.71	19.32
11	2.77	2.38	3.30	8.45	13	4.58	4.50	0.63	16.22	25.93
13	1.57	2.29	5.67	9.53	15	0.97	3.86	0.65	18.44	23.92

Table 3. Growth rate. grams/plant/week

Weeks after planting	leaf	stem	pod	total	Weeks after planting	leaf	stem	root	pod	total
6	0.7	0.25		0.95	6	1.53	0.71	0.11		2.36
8	0.76	0.39		1.15	9	0.73	0.65	0.09		2.80
9	0.45	0.89		2.09	11	-0.38	0.38	-0.08	3.07	2.99
11	-0.67	+0.02	1.28	0.62	13	-0.86	-0.06	-0.04	4.26	3.31
13	-0.60	-0.05	1.19	0.54	15	-1.81	-0.32	-0.01	1.11	-1.01

(NB. In the text, Second rains, 1979 and First rains, 1980 are referred to as 1979 crop or 1979 and 1980 crop or 1980 respectively).

The rate reached a peak of 0.90 gm/plant/week in the 9th week when the total stem dry matter per plant was 2.35 grams. After the 9th week, negative stem growth rate commenced.

After pod initiation in the 7th week, pod dry matter increased from 0.75 gm/plant in the 9th week to 5.67 gm/plant in the 13th week. The rate of increase dropped from 1.37 gm/plant/week in the 11th week to 1.11 gm/plant/week in the 13th week.

In the 1980 crop, total dry matter per plant increased from 2.64 grams in the 4th week to a peak of 25.41 grams in the 13th week, after which it dropped to 23.86 grams in the 15th week. The rate of growth increased from 2.36 gm/plant/week in the 6th week to 3.04 gm/plant/week in the 13th week, after which negative growth rate was observed.

Leaf dry matter increased from 1.8 gm/plant in the 4th week to a peak of 7.05 gm/plant in the 9th week after which negative growth rate commenced. Highest leaf growth rate was recorded in the 6th week.

The rate of dry matter increase in the stems rose from 0.71 gm/plant/week in the 6th week to 0.91 gm/plant/week in the 9th week. After this, the rate declined to 0.28 gm/plant/week in the 11th week. Maximum stem dry matter of 4.61 gm/plant was observed in the 11th week.

The rate of dry matter increase in the roots was 0.11 gm/plant/week in the 6th week at which time root dry matter per plant was 0.58 gms. The rate increased to 0.13 gm/plant/week in the 9th week when the root dry matter attained a peak of 0.86 gms per plant. After the 9th week, negative growth was observed.

Pod dry weight in the 9th week was 1.57 gm/plant. This increased at the rate of 2.26 gm/plant/week up to the 11th week. The rate had risen to 4.26 gm/plant/week in the 13th week when the maximum pod dry matter of 8.51 gm/plant was attained. After the 13th week, the rate of pod growth declined to 1.04 gm/plant/week.

Table 4. Effect of phosphate fertilizer on leaf growth rate gms/plant/week

Fertilizer level: kg P/ha	Weeks after planting				
2nd rains 1979	6	8	9	11	13
0	0.67a	0.96a	0.30a	-0.80ab	-0.44a
50	0.72a	1.16a	-1.16b	-1.16c	-0.56a
100	0.70a	0.82a	0.85a	-0.58a	-0.68a
150	0.73a	0.94a	0.95a	-0.96bc	-0.56a
S.E. mean	0.06	0.19	0.35	0.09	0.15
1st rains 1980	6	9	11	13	15
0	1.42a	0.89a	-0.39a	-0.50a	-1.67b
50	1.44a	0.77a	0.20a	-1.39a	-1.54b
100	1.71a	0.95a	-0.35a	-0.69a	-0.50a
150	1.55a	1.47a	-0.57a	-0.88a	-1.68b
S.E. mean	0.14	0.25	0.28	0.31	0.19

N.B. Figures with the same letter in each column do not differ significantly (Duncan's New Multiple Range test).

4.2. Effect of Phosphate Fertilizer on Growth Rate

4.2.1. Leaf Growth Rate

Table 4 shows the effect of phosphate fertilizer on the rate of leaf dry matter increase in the bean plant. The rate increased with increase in fertilizer level in both seasons. In 1979, the lowest leaf growth rate was obtained from plants which had received 50 kg P/ha during the 9th week. Growth rate at this fertilizer level had already negated in the 9th week, while at the other treatments, growth was still positive. In the 11th week, negative growth rate had commenced in all the treatments. Plants treated with 100 kg P/ha had the least rate of dry matter loss, while the highest rate of dry matter decline was obtained from 50 kg/ P/ha treatment plants, and the difference between this level and the control was significant. Negative growth rate at the highest fertilizer level was higher but not significantly different from the control.

In the first rains of 1980, the highest rate of leaf growth in the 6th week was obtained where 100 kg P/ha was applied, and at 150 kg P/ha in the 9th week. Up to the 9th week, the difference in leaf growth rate between the four fertilizer treatments was not significant. In the 11th week, negative growth had commenced in all the treatments except at the 50 kg P/ha treatment. The highest rate of leaf dry matter loss was recorded at the highest fertilizer level, though it was not significantly higher than the control and the 100 kg P/ha fertilizer level. In the 13th week, plants fertilized with 50 kg P/ha had the highest rate of leaf loss, while the control plants had the least, but no significant differences between the four fertilizer treatments were observed. In the 15th week, plants which had received 100 kg P/ha had significantly lower rate of dry matter decline than all the other treatments. Differences within the other treatments were not significant.

4.2.2. Stem Growth Rate

No significant differences in rates of stem dry matter increase were observed in the 1979 crop (Table 5), though in the 9th week of growth, stem growth rate increased slightly with increase in fertilizer level.

Table 5. Effect of phosphate fertilizer on stem growth rate gms/plant/week

Fertilier level: kg P/ha	Weeks after planting				
2nd rains 1979	6	8	9	11	13
0	0.25a	0.48a	0.74a	-0.04a	-0.07a
50	0.25a	0.59a	0.71a	-0.05a	0.00a
100	0.25a	0.40a	1.10a	0.18a	-0.13a
150	0.25a	0.49a	1.04a	-0.02a	0.02a
S.E. mean	0.03	0.08	0.18	0.12	0.11
1st rains 1980	6	9	11	13	15
0	0.68b	0.68b	0.21a	0.34a	-0.42ab
50	0.62b	0.84ab	0.49a	-0.52b	-0.02a
100	0.88a	0.95ab	0.24a	0.11a	-0.51b
150	0.68b	1.19a	0.18a	-0.16ab	-0.23ab
S.E. mean	0.06	0.13	0.17	0.20	0.15

N.B. Figures with the same letter in each column do not differ significantly.

In the 1980 crop, during the 6th week, 100 kg P/ha treatment plants had significantly higher stem growth rate than the other treatments. In the 9th week, 150 kg P/ha treatment plants had significatly higher stem growth rate than the control. The rate increased as the fertilizer level was raised, but these increases were not significant within the three fertilizer treatments. In the 13th week, negative stem growth had commenced at the 50 kg P/ha and 150 kg P/ha treatment plants but growth was still positive at the other two treatments. Plants which had received 50 kg P/ha had significantly lower rate of stem dry matter loss than plants at all the other treatments, these other treatments were not significantly different from each other. In the 15th week, negative growth had already commenced at all the treatments. The highest rate of stem dry matter decline occurred at the 100 kg P/ha treatment plants, and this was significantly different from that at the 50 kg P/ha treatment plants, but it was not significantly different from the other two treatments.

Table 6: Effect of phosphate fertilizer on pod growth rate (gms/plant/week)

Fertilizer level kg P/ha	Weeks after planting		
2nd rains 1979	11	13	15
0	1.11b	0.93a	
50	1.31b	1.12a	
100	1.78a	1.01a	
150	1.29b	1.36a	
S.E. mean	0.14	0.25	
1st rains 1980	11	13	15
0	2.35a	4.94a	1.07a
50	2.32a	3.56a	1.71a
100	2.35a	4.53a	0.41a
150	2.03a	4.00a	0.96a
S.E. mean	0.30	0.56	0.65

N.B. Figures with the same letter in each column do not differ significantly.

4.2.3. Pod Growth Rate

In 1979 the rate of pod dry matter increase tended to rise with increase in fertilizer level (Table 6). In the 11th week, the rate of pod growth increased as the fertilizer level was raised from 0 to 100 kg P/ha, then dropped slightly at the highest fertilizer level. However, the only significant difference was between the 100 kg P/ha treatment and all the other treatments. In the 13th week, pod growth rate increased from 0.93 grams/plant/week at the control, to 1.36 grams/plant/week at the highest fertilizer level with a small depression at the 100 kg P/ha fertilizer level. Differences between the four treatments were however not significant. In 1980 significant differences in pod growth rate were not obtained.

4.2.4. Root Growth Rate

During the 6th and the 9th weeks, 150 kg P/ha and 100 kg P/ha treatment plants respectively had higher rates of root growth than the control. In the 13th week, 50 and 100 kg P/ha treatment plants had higher rates of dry matter decline than the control. However, none of these differences were significant (Table 7).

4.2.5. Rate of Total Dry Matter Accumulation

In 1979, the different fertilizer treatments did not result in significantly different rates of

Table 7. Effect of phosphate fertilizer on root growth rate gms/plant/week

Fertilizer level kg P/ha	Weeks after planting				
2nd rains 1980	6	9	11	13	15
0	0.09a	0.09a	-0.06a	-0.03a	-0.01a
50	0.12a	0.13a	-0.04a	-0.09a	0.04a
100	0.12a	0.17a	- 0.06a	-0.07a	0.00a
150	0.13a	0.13a	-0.07a	-0.02a	-0.01a
S.E. mean	0.02	0.03	0.03	0.04	0.03

N.B. Figures with the same letter in each column do not differ significantly.

Table 8. <u>Effect of phosphate fertilizer on the rate of total dry matter increase: gms/plant/week</u>

Fertilizer level kg P/ha	Weeks after planting				
2nd rains 1979	6	8	9	11	13
0	0.92a	1.43a	1.71a	0.29a	0.42a
50	0.97a	1.76a	1.14a	0.59a	0.60a
100	0.95a	1.23a	2.68a	1.12a	0.43a
150	0.97a	1.43a	2.61a	0.37a	0.83a
S.E. Mean	0.08	0.26	0.54	0.36	0.33
2nd rains 1980	6	9	11	13	15
0	2.19a	2.19b	2.12a	4.32a	-0.54a
50	2.18a	2.44ab	2.97a	1.56a	0.02a
100	2.70a	2.94ab	2.17a	3.34a	-1.44a
150	2.35a	3.63a	1.56a	2.94a	-0.96a
S.E. Mean	0.19	0.40	0.64	1.00	0.90

N.B. Figures with the same letter in each column do not differ significantly.

total dry matter increase (Table 8). Peak rates of growth occurred in the 9th week, with the two highest fertilizer levels having higher peaks than the lower levels. From the 9th to the 11th week, 100 kg P/ha treatment plants had the highest rate of growth, and in the 13th week, the rate was highest at the highest fertilizer level.

In 1980, during the 6th week, 100 kg P/ha treatment plants had the highest rate of growth, followed by the 150 kg P/ha treatment plants, but the differences were not significant. During the 9th week, growth rate increased progressively as the fertilizer level was raised, with the highest growth rate occurring at the highest fertilizer level. Growth rate at the highest fertilizer level was significantly higher than the control. After the 9th week, growth rate was not consistent with the fertilizer levels, though in the 11th week, 50 kg P/ha treatment plants had the highest rate of growth, followed by the 100 kg P/ha treatment plants. These differences were, however, not significant.

Table 9. Effect of phosphate fertilizer on Leaf Area Index

Fertilizer level kg P/ha	Weeks after planting				
2nd rains 1979	4	8	9	11	13
0	0.60a	2.52a	2.69a	1.54b	0.98a
50	0.61a	3.30a	2.73a	1.94a	1.16a
100	0.64a	2.95a	2.58a	1.90ab	1.15a
150	0.64a	3.07a	3.05a	1.86ab	1.19a
C.V.%	29	39	29	28	38
S.E. Mean	0.04	0.29	0.20	0.13	0.11
1st rains 1980	4	6	9	11	
0	2.08a	4.33b	5.47b	3.71c	
50	2.27a	4.87ab	5.98ab	5.48a	
100	2.14a	5.22ab	6.93a	4.22bc	
150	2.45a	5.71a	6.80a	4.72ab	
C.V.%	29	30	28	27	
S.E. Mean	0.16	0.37	0.44	0.31	

N.B. Figures with the same letter in each column do not differ significantly.

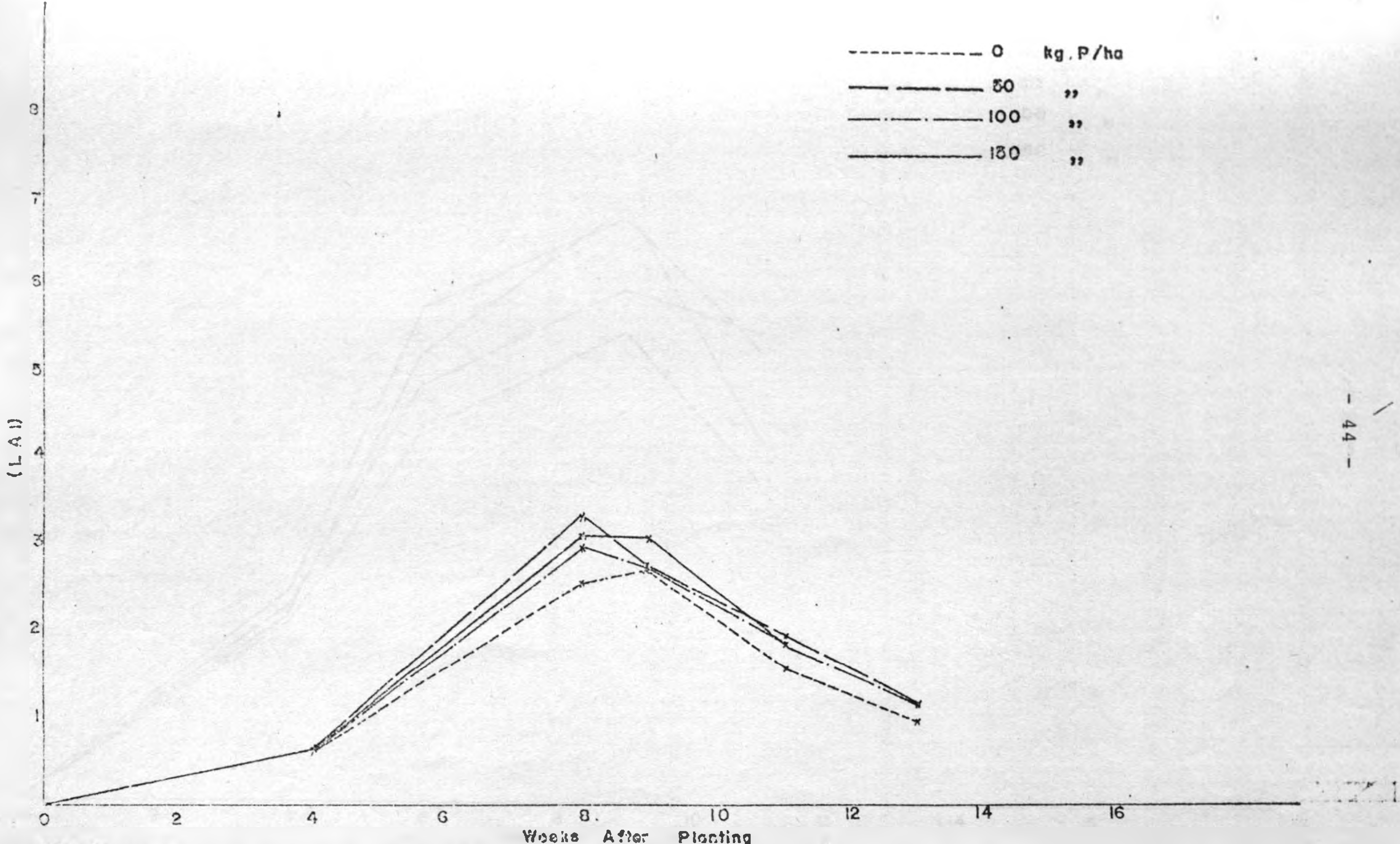


Fig.2a.... Effect Of Phosphate Fertilizer On Leaf Area Index (LAI): Second Rains 1979.

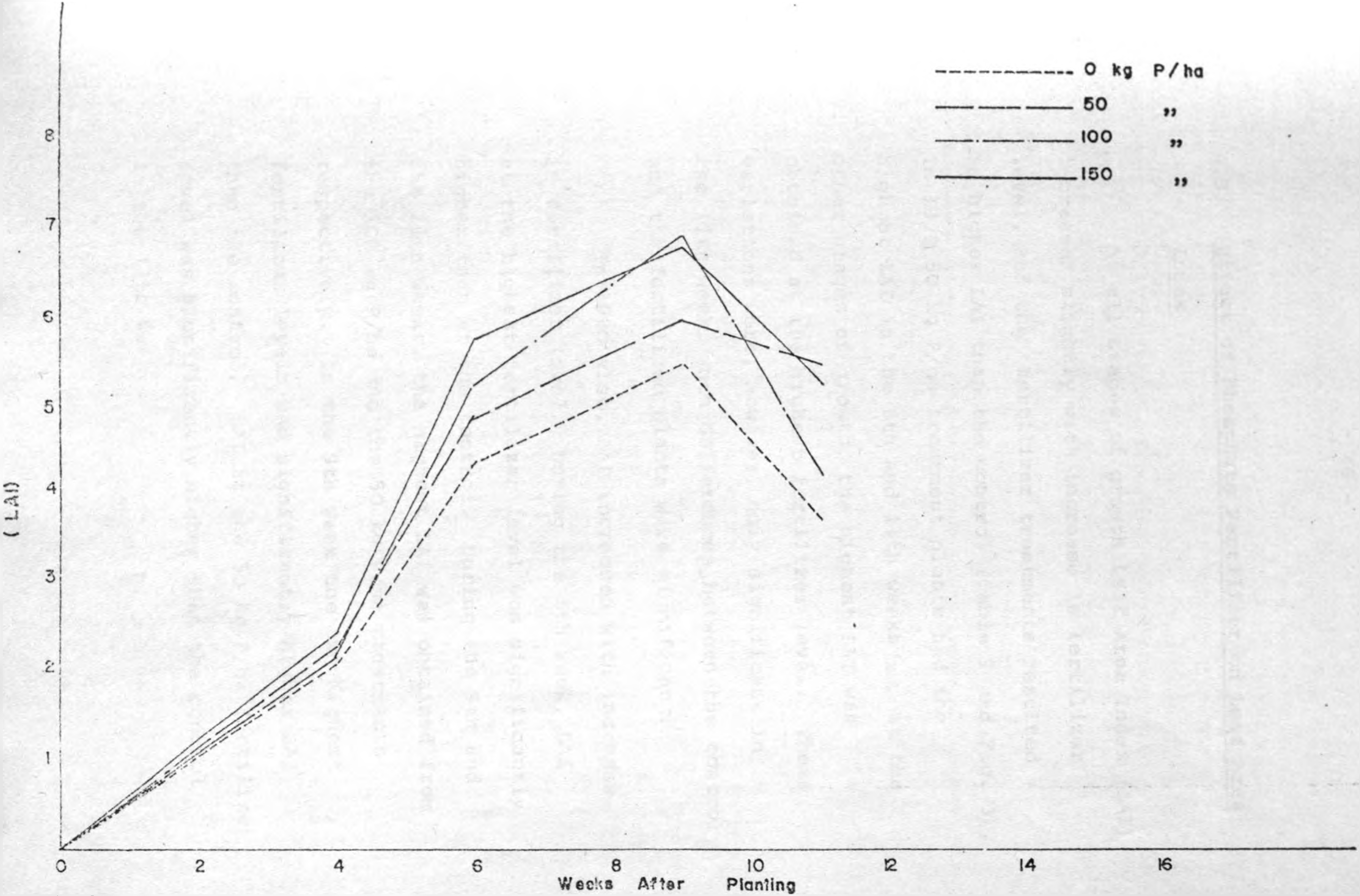


Fig 2b. Effect Of Phosphate Fertilizer On Leaf Area Index (L AI): First Rains 1980.

4.3. Effect of Phosphate Fertilizer on Leaf Area Index

At all stages of growth Leaf Area Index (LAI) increased slightly with increase in fertilizer level, and the fertilizer treatments resulted in higher LAI than the control (Table 9 and Fig. 3). In 1979 50 kg P/ha treatment plants had the highest LAI in the 8th and 11th weeks but at the other stages of growth, the highest LAI was obtained at the highest fertilizer level. These variations were, however, only significant in the 11th week, when differences between the control and the fertilized plants were significant.

In 1980 also, LAI increased with increase in fertilizer level. During the 6th week, LAI at the highest fertilizer level was significantly higher than at the control. During the 9th and the 11th weeks, the highest LAI was obtained from the 100 kg P/ha and the 50 kg P/ha treatments respectively. In the 9th week the two highest fertilizer levels had significantly higher LAI than the control. LAI at the 50 kg P/ha fertilizer level was significantly higher than the control in the 11th week.

4.4. Effect of Phosphate Fertilizer on Dry Matter

4.4.1. Leaf Dry Matter

Leaf dry matter increased with increase in fertilizer level (Table 10 and Fig. 4). In the 1979 crop, up to the 6th week, these dry matter increases were consistently higher at the highest fertilizer level but the variations among the treatments were not significant. Significant differences were obtained in the 8th and 11th weeks. In the 8th week 50 kg P/ha treatment plants had significantly higher dry matter than the control, but not significantly different from the other fertilizer treatments. In the 9th week, the highest fertilizer level had the highest leaf dry matter. In the 11th week, 100 kg P/ha treatment plants had the highest leaf dry matter. Difference in dry matter between this level and the control was significant. During the 6th, 11th and 13th weeks, leaf dry matter tended to decline at the highest fertilizer level.

In 1980, the trend of increasing leaf dry matter with rise in fertilizer level was

Table 10: Effect of Phosphate fertilizer on leaf dry matter: gms/plant

Fertilizer level: kg P/ha	Weeks after planting					
2nd rains 1979	4	6	8	9	11	13
0	0.69a	2.02a	3.03a	3.83a	2.34a	1.39a
50	0.71a	2.15a	3.98b	3.82a	2.68ab	1.47a
100	0.75a	2.14a	3.43ab	4.28a	3.20b	1.74a
150	0.78a	2.23a	3.71ab	4.66a	2.87ab	1.68a
C.V.%	19	23	32	28	27	43
S.E. mean	0.04	0.12	0.29	0.30	0.19	0.17
1st rains 1980	4	6	9	11	13	15
0	1.67a	4.51a	6.42a	5.35a	4.36a	0.79a
50	1.74a	4.64a	6.28a	6.82a	4.05a	0.76a
100	1.87a	5.29a	7.33ab	6.38a	5.04a	1.07b
150	1.91a	5.01a	8.17b	6.61a	4.85a	1.24b
C.V.%	22	27	33	35	39	35
S.E. Mean	0.10	0.33	0.58	0.55	0.49	0.09

N.B. Figures with the same letter in each column do not differ significantly.

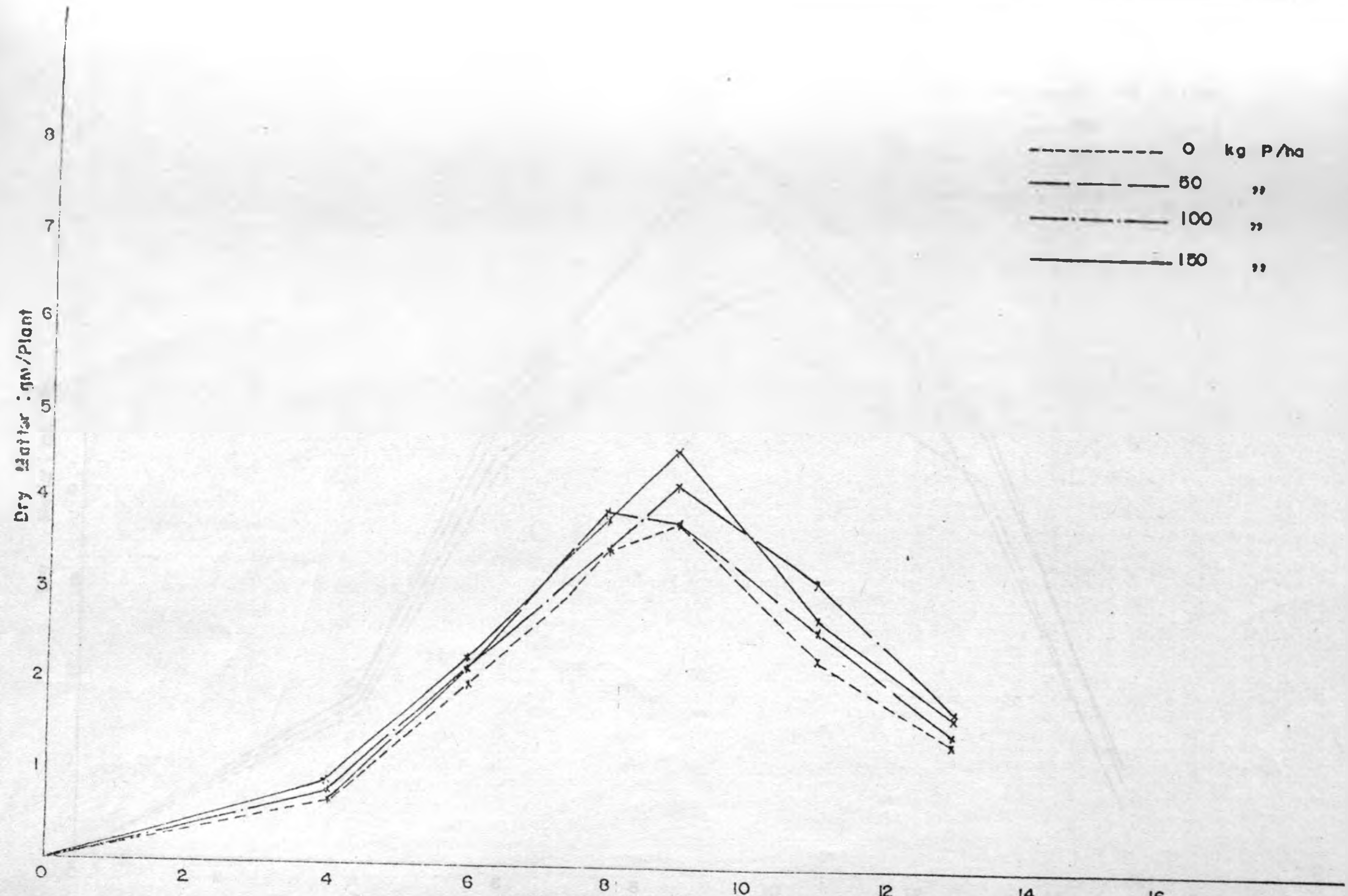


Fig 3a. Effect Of Phosphate Fertilizor On Leaf Dry Matter Per Plant : Second Rains 1979 .

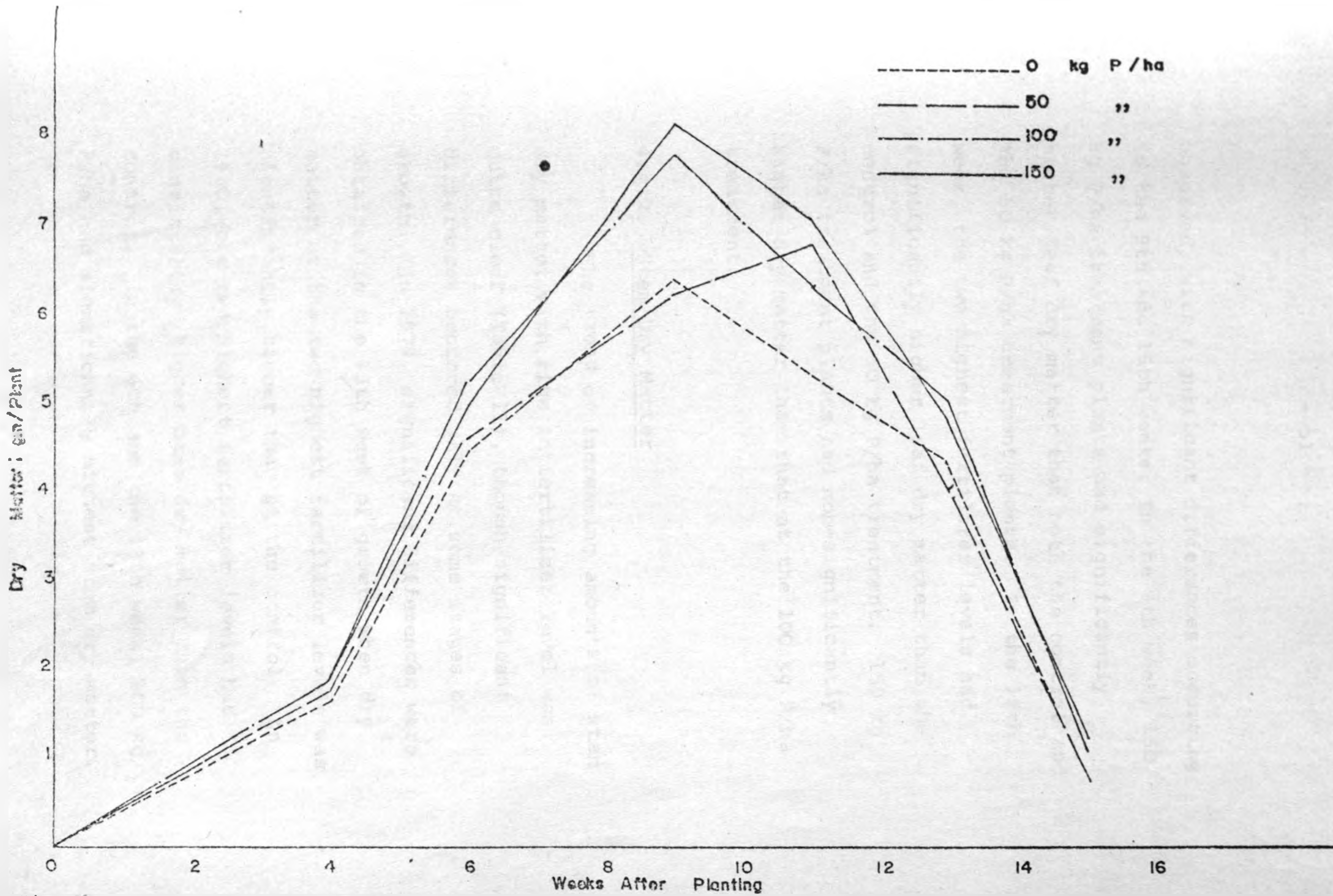


Fig 3b. Effect Of Phosphate Fetilizer On Leaf Dry Matter Per Plant I First Rains 1980 ·

observed, with significant differences occurring in the 9th and 15th weeks. In the 9th week, 150 kg P/ha treatment plants had significantly higher leaf dry matter than both the control and the 50 kg P/ha treatment plants. In the 15th week, the two highest fertilizer levels had significantly higher leaf dry matter than the control and the 50 kg P/ha treatment. 150 kg P/ha treatment plants had non-significantly higher dry matter than that at the 100 kg P/ha treatment.

4.4.2. Stem Dry Matter

The trend of increasing amounts of stem dry matter with rise in fertilizer level was quite clear (Table 11), though significant differences occurred only at some stages of growth. In 1979, significant differences were obtained in the 13th week of growth when dry matter at the two highest fertilizer levels was significantly higher than at the control. In 1980, the two highest fertilizer levels had consistently higher stem dry matter than the control. In the 6th and the 13th week, 100 kg P/ha had significantly highest stem dry matter.

Table 11. Effect of phosphate fertilizer on stem dry matter gms/plant

Fertilizer level kg P/ha	Weeks after planting					
2nd rains 1979	4	6	8	9	11	13
0	0.19a	0.68a	1.43a	2.17a	2.10a	1.95a
50	0.18a	0.68a	1.60a	2.31a	2.21a	2.22ab
100	0.20a	0.70a	1.33a	2.43a	2.76a	2.48b
150	0.20a	0.69a	1.46a	2.50a	2.46a	2.50b
C.V.%	17	25	32	31	33	28
S.E. Mean	0.01	0.04	0.12	0.19	0.19	0.17
1st rains 1980	4	6	9	11	13	15
0	0.46a	1.81a	3.27a	3.84a	4.51ab	3.61a
50	0.45a	1.68a	3.48ab	4.80a	3.76a	3.71a
100	0.50a	2.25b	4.28b	4.92a	5.15b	4.04a
150	0.51a	1.86ab	4.41b	4.89a	4.57ab	4.08a
C.V.%	25	29	32	35	27	27
S.E. Mean	0.03	0.14	0.31	0.40	0.31	0.26

N.B. Figures with the same letter in each column do not differ significantly.

Table 12: Effect of phosphate fertilizer on pod dry matter gms/plant

Fertilizer level: kg P/ha	Weeks after planting			
2nd rains 1979	9	11	13	15
0	0.67a	2.79a	4.73a	
50	0.83a	3.27ab	5.68a	
100	0.74a	4.06b	6.22a	
150	0.74a	3.12a	6.05a	
C.V. %	44	34	38	
S.E. Mean	0.08	0.28	0.56	
1st rains 1980	9	11	13	15
0	1.13a	7.50a	17.38a	19.67a
50	1.51ab	7.81a	14.92a	18.58a
100	1.86b	8.25a	17.29a	18.16a
150	1.77b	7.29a	15.29a	17.35a
C.V. %	39	44	22	29
S.E.	0.15	0.84	0.87	1.33

N.B. Figures with the same letter in each column do not differ significantly.

Table 12: Effect of phosphate fertilizer on pod dry matter gms/plant

Fertilizer level: kg P/ha	Weeks after planting			
2nd rains 1979	9	11	13	15
0	0.67a	2.79a	4.73a	
50	0.83a	3.27ab	5.68a	
100	0.74a	4.06b	6.22a	
150	0.74a	3.12a	6.05a	
C.V. %	44	34	38	
S.E. Mean	0.08	0.28	0.56	
1st rains 1980	9	11	13	15
0	1.13a	7.50a	17.38a	19.67a
50	1.51ab	7.81a	14.92a	18.58a
100	1.86b	8.25a	17.29a	18.16a
150	1.77b	7.29a	15.29a	17.35a
C.V. %	39	44	22	29
S.E.	0.15	0.84	0.87	1.33

N.B. Figures with the same letter in each column do not differ significantly.

4.4.3. Pod Dry Matter

In 1979, fertilized plants produced higher pod dry matter than the control plants (Table 12). In the 9th week, highest pod dry matter was produced at the 50 kg P/ha fertilizer level. From the 11th to 13th week, the highest pod dry matter was produced at the 100 kg P/ha fertilizer level, and in the 11th week, the difference between this level and the other three treatments was significant.

In 1980 during the 9th week, the two highest fertilizer levels resulted in significantly higher pod dry matter than the control. From the 9th to the 11th week, the highest pod dry matter was produced at the 100 kg P/ha fertilizer level. From the 13th to 15th week, pod dry matter tended to decrease as the fertilizer level was raised.

4.4.4. Root Dry Matter

Root dry matter increased with increase in fertilizer level, but these increases were only significant between the 9th and 11th weeks of growth (Table 13). During the 9th week, the two highest fertilizer levels had significantly

Table 13. Effect of phosphate fertilizer on root dry matter gms/plant

Fertilizer level kg P/ha	Weeks after planting					
2nd rains 1980	4	6	9	11	13	15
0	0.36a	0.54a	0.74a	0.57a	0.62a	0.61a
50	0.35a	0.59a	0.86ab	0.76b	0.58a	0.66a
100	0.36a	0.59a	0.95b	0.78b	0.64a	0.64a
150	0.37a	0.62a	0.90b	0.71b	0.68a	0.67a
C.V. %	17	22	21	23	27	26
S.E. Mean	0.02	0.33	0.05	0.04	0.04	0.04

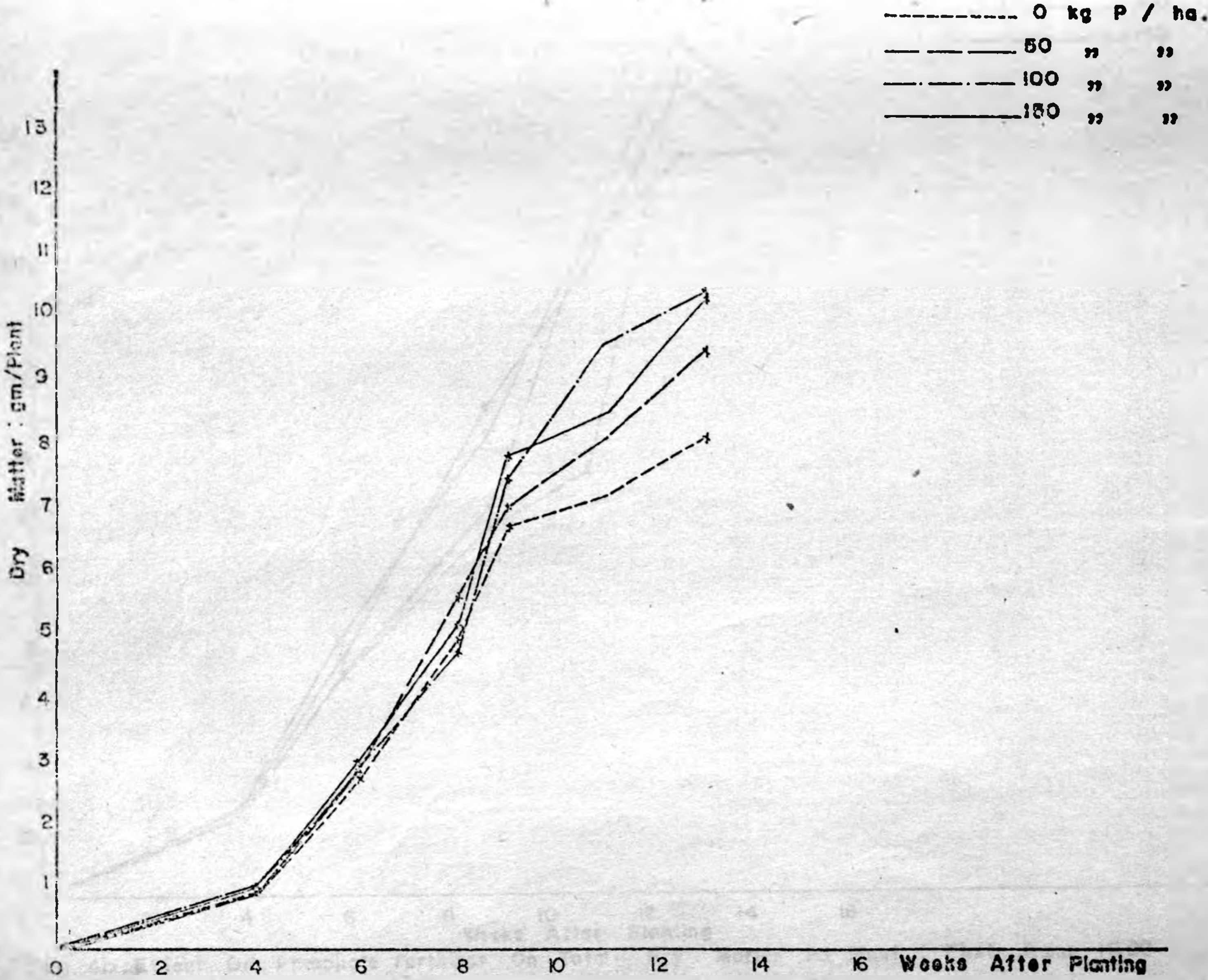
N.B. Figures with the same letter in each column do not differ significantly.

higher root dry matter than the control, but they were not significantly different from each other or from the lowest fertilizer level. The highest root dry matter occurred in the 100 kg P/ha treatment plants. In the 11th week, fertilizer-treated plants had significantly higher root dry matter than the control plants, but the three fertilizer levels did not result in significantly different root dry matter. 100 kg P/ha treatment plants produced the highest dry matter. From the 13th to 15th week, the 150 kg P/ha treatment plants produced the highest root dry matter followed by the 100 kg P/ha treatment plants in the 13th week, and by the 50 kg P/ha treatment plants in the 15th week, but these differences were not significant.

4.4.5. Total Dry Matter

In both seasons total dry matter increased with increase in fertilizer level (Table 14 and Fig. 5). In 1979, the increases were consistent except in the 8th week when the 50 kg P/ha treatment plants had the highest total dry matter followed by the 150 kg P/ha, treatment plants. However, significant differences were obtained only in the 11th and the 13th week. During these

Fig. 4a. Effect Of Phosphate Fertilizer On Total Dry Matter Per Plant : Second Rains 1979 .



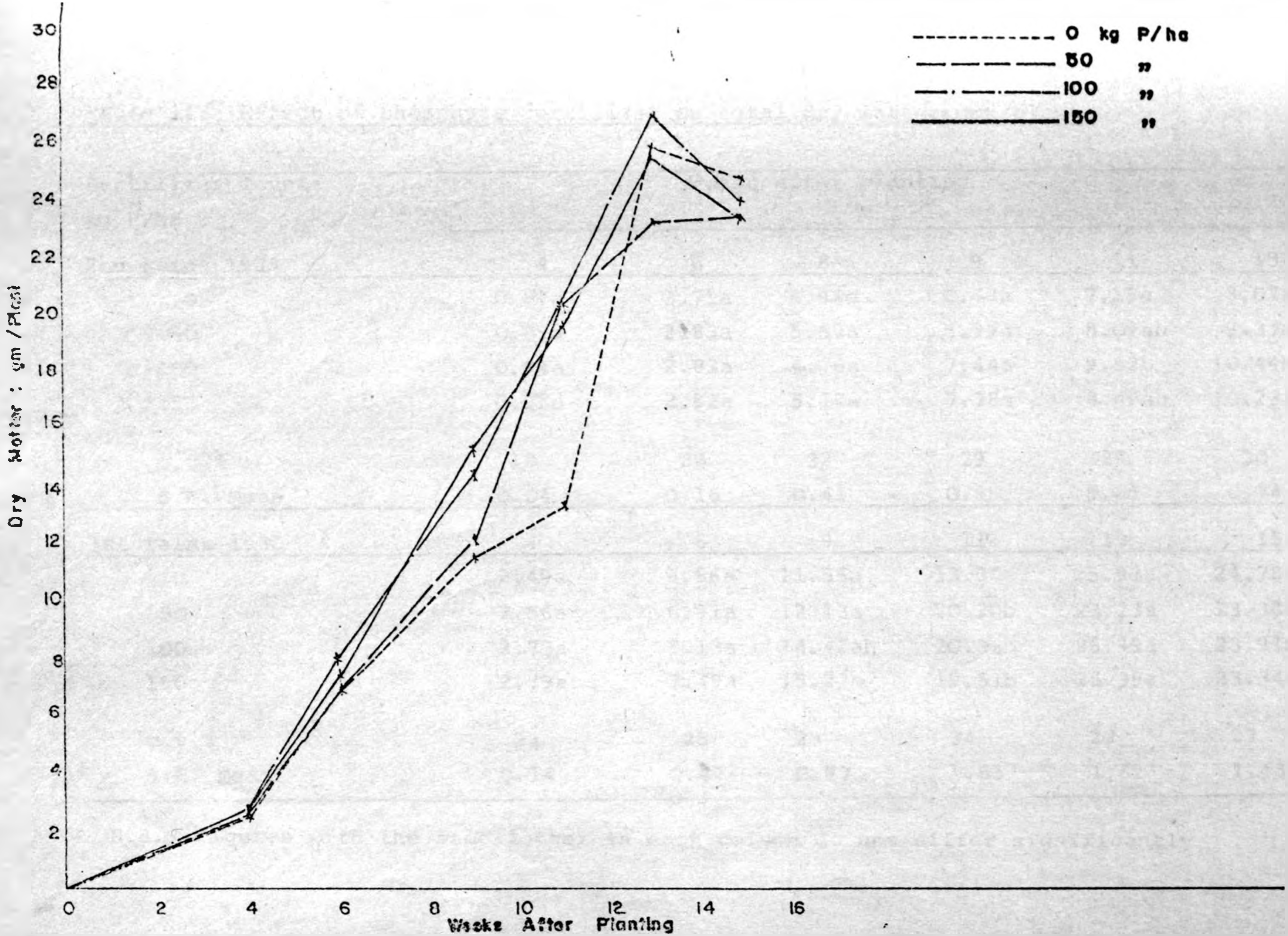


Fig. 4b: Effect Of Phosphate Fertilizer On Total Dry Matter Per Plant : First Rains 1980

Table 14. Effect of phosphate fertilizer on total dry matter: gms/plant

Fertilizer level: kg P/ha	Weeks after planting					
2nd rains 1979	4	6	8	9	11	13
0	0.87a	2.71a	4.96a	6.69a	7.17a	8.07a
50	0.89a	2.83a	5.59a	6.99a	8.09ab	9.37ab
100	0.94a	2.83a	4.76a	7.44a	9.52b	10.44b
150	0.98a	2.92a	5.17a	7.78a	8.46ab	10.23b
c.v.%	18	22	32	29	29	30
S.E. Mean	0.04	0.16	0.41	0.55	0.61	0.74
1st rains 1980	4	6	9	11	13	15
0	2.49a	6.86a	11.55a	13.30a	25.93a	24.78a
50	2.56a	6.91a	12.13a	20.20b	23.23a	23.36a
100	2.73a	8.13a	14.42ab	20.32b	26.99a	23.91a
150	2.79a	7.49a	15.27b	19.51b	25.39a	23.34a
c.v.%	21	25	29	34	22	27
S.E. Mean	0.14	0.47	0.97	1.65	1.62	1.43

N.B. Figures with the same letter in each column do not differ significantly last two weeks, 100 kg P/ha treatment plants had the highest total dry matter. In the 11th week, total dry matter at the 100 kg P/ha treatment was significantly higher than at the control but dry matter amounts at the three higher fertilizer treatments were not significantly different from each other. In the 13th week, both 100 kg P/ha and 150 kg P/ha treatments had significantly higher dry matter than the control, but not significantly different from that at the 50 kg P/ha treatment or from each other.

In 1980, total dry matter increased as fertilizer level was raised up to the 9th week, but during the 6th and 11th weeks the highest total dry matter occurred at the 100 kg P/ha treatment, decreasing slightly at the highest fertilizer level. These differences were, however, not significant. In the 9th week, the highest fertilizer level had significantly higher total dry matter than the control and the 50 kg P/ha fertilizer level. In the 11th week, fertilized plants had significantly higher dry matter than the control, but differences within the three fertilizer

Table 15. Effect of phosphate fertilizer on total dry matter (kg/ha) at harvest

	Fertilizer level in kg P/ha							
	2nd rains 1979				First rains 1980			
	0	50	100	150	0	50	100	150
	2804.6	3095.9	2925.0	3151.9	7849.3	7846.8	8026.4	8321.4
%increase over control	0	10.4	4.5	12.4	0	-0.03	2.3	6.0
Mean	2994.4				Mean	8010.9		
C.V.%	20.3%				c.v.	15.0%		
S.E. mean:	145.03				S.E. mean	319.95		

N.B. Figures with the same letter in each column do not differ significantly.

treatments were not significant. From the 13th to the 15th week, dry matter amounts were not consistent with the fertilizer level changes, though the highest dry matter occurred at the 100 kg P/ha fertilizer level in the 13th week.

4.4.6. Total Dry Matter at Harvest

There was a trend towards rising total dry matter production with increase in fertilizer level (Table 15). In 1979, plants which had received 150 kg P/ha produced about 3152 kg of dry matter per hectare and this was approximately 12% higher than dry matter production from the control which was only 2805 kg/ha. In 1980, the highest fertilizer level resulted in production of 8321 kg /ha of total dry matter, 6% more than the 7849 kg /ha produced from the control plants. None of these differences were, however, significant.

4.5. Effect of Phosphate Fertilizer on Yield Components

4.5.1. Number of Pods per Plant

The number of pods per plant increased

with increase in fertilizer level except at the final harvest in the 1980 crop when the number decreased from about 11 in the control plants to 9 at the highest fertilizer level (Table 16). Significant differences were, however, obtained in only a few stages of growth. In 1979 during the 11th week, 100 kg P/ha treatment plants had significantly higher number of pods per plant than at any other treatment. At other stages of growth and even at the final harvest, the highest pod number per plant occurred at the 150 kg P/ha treatment, though the difference between this and the other treatments was not significant.

In the 1980 crop, during the 11th week, plants at the 150 kg P/ha treatment had significantly higher number of pods per plant than the control. This number was also higher than at the two lower fertilizer levels but the difference was not statistically significant. In the 13th week 100 kg P/ha treatment plants had the highest number of pods per plant, but the number was not significantly higher than that at the other treatments. In the 15th week, the highest number of pods per plant was obtained

Table 16. Effect of phosphate fertilizer on the number of pods per plant

Fertilizer level kg P/ha	Weeks after planting				Final harvest
2nd rains 1979	9	11	13	15	
0	8.4a	7.3a	6.2a		5.7a
50	9.0a	7.0a	6.4a		5.6a
100	8.9a	8.8b	6.2a		6.3a
150	10.1a	7.2a	6.7a		6.5a
Mean	9.1	7.6	6.4		6.0
c.v. %	33	26	24		22
S.E. Mean	0.78	0.46	0.37		0.33
1st rains 1980		11	13	15	Final harvest
0		14.3a	13.8a	12.8a	10.6a
50		15.6ab	11.8a	13.3a	10.0a
100		15.6ab	13.9a	12.7a	10.1a
150		17.8b	13.6a	13.6a	9.3a
Mean		15.8	13.3	13.1	10.1
c.v. %		25	21	22	18
S.E. mean		0.99	0.68	0.59	0.56

N.B. Figures with the same letter in each column do not differ significantly.

Table 17. Effect of phosphate fertilizer on the number of seeds/pod and 100-seed weight (grams)

Fertilizer level kg P/ha	No. seed/pod	100-Seed weight
2nd rains 1979		
0	3.6a	33.13a
50	3.7a	32.15a
100	3.8a	31.92a
150	3.9a	32.94a
Mean	3.8	32.29
c.v.%	28.9	9.1
S.E. mean	0.11	0.71
1st rains 1980		
0	4.0a	40.97a
50	4.0a	41.55a
100	4.1a	41.43a
150	4.1a	41.73a
Mean	4.1	41.42
C.V.%	12.1	6.5
S.E. mean	0.12	0.68

N.B. Figures with the same letter in each column do not differ significantly.

from the highest fertilizer level, but the difference between this and the other treatments was not significant.

4.5.2. Number of Seeds Per Pod

In both seasons there was a slight increase in the number of seeds per pod with rise in fertilizer level but these increases were not significant, (Table 17).

4.5.3. 100 - Seed Weight

In the 1980 crop, the highest 100-seed weight of 41.73 grams was obtained from the 150 kg P/ha treatment plants, while the lowest seed weight was obtained from the control plants, but these differences were not significant. In 1979 fertilizer effects on 100-seed weight were inconsistent and insignificant (Table 17).

4.6. Effect of Phosphate Fertilizer on Seed Yield

Seed yield increased with increase in fertilizer level except in 1979 when the lowest yield was obtained at the 100 kg P/ha fertilizer level. In 1979, the highest fertilizer level

Table 18: Effect of phosphate fertilizer on:-

Fertilizer level: kg P/ha	Total dry matter at harvest		Seed yield		Harvest Index
	kg/ha,x	%increase over control	kg/ha,y	%increase over control	y/x x 100%
2nd rains 1979					
0	2804.6a	0	1131.5a	0	42a
50	3095.9a	10.4	1228.4a	8.6	37b
100	2925.0a	4.3	1112.7a	-1.8	42a
150	3151.9a	12.4	1280.0a	13.1	38c
Mean	2994.4		1188.2		
c.v.%	20.3		25.2		18.3
S.E. Mean	145.03		76.64		0.03
1st rains 1980					
0	7849.3a	0	2874.4a	0	37a
50	7846.8a	0	2931.6a	2	38b
100	8026.4a	2.3	3089.7a	7	39c
150	8321.4a	6.0	3140.0a	9	38b
Mean	8010.98		3008.9		
C.V. %	15.0		14.6		11.9
S.E. Mean	319.95		110.00		0.01

N.B. Figures with the same letter in each column do not differ significantly.

increased seed yield by 13% and in 1980 by 9%. However, none of these increases were significant (Table 18).

4.7. Effect of Phosphate Fertilizer on Harvest Index (HI)

In the 1979 crop, there was no definite response of HI to increased fertilizer level (Table 18). In 1980, HI at the 100 kg P/ha treatment was significantly higher than the other three treatments. Harvest indices at the lowest and the highest fertilizer treatments were also significantly higher than the control, but not significantly different from each other.

4.8. Effect of Phosphate Fertilizer on Number and Weight of Nodules

4.8.1. Number of Nodules per Plant

In all the treatments, the highest number of nodules was obtained in the fourth week and gradually decreased in subsequent weeks (Table 19).

In 1979 during the 8th week of growth, plants at the 150 kg P/ha and 100 kg P/ha fertilizer treatments had higher number of nodules per plant

Table 19. Effect of phosphate fertilizer on number of nodules per plant

Fertilizer level kg P/ha	Weeks after planting			
2nd rains 1979	4	8	9	11
0	18a	7a	4ab	
50	17a	7a	3a	
100	15a	8a	4ab	
150	14a	8a	5b	
C.V.%	43	47	54	
S.E. mean	1.67	0.86	0.55	
1st rains 1980	4	6	9	11
0	28a	29a	16a	8a
50	45b	41c	20c	12b
100	40ab	36b	18b	12b
150	53b	48d	22d	13c
C.V.%	43	40	46	46
S.E. mean	4.40	0.76	0.44	0.25

N.B. Figures with the same letter in each column do not differ significantly.

than those at the control and the 50 kg P/ha fertilizer treatment, but the differences were not significant (Table 19). In the 9th week, the number of nodules increased significantly from 3 at the 50 kg P/ha fertilizer treatment to 5 at the 150 kg P/ha treatment. Nodule number at the 100 kg P/ha treatment was not significantly different from that at the control.

In 1980, there were highly significant phosphate fertilizer effects on the number of nodules per plant. At all stages of growth, the number increased significantly as the fertilizer level was raised from 0 to 50 kg P/ha. At all stages of growth, there was a drop in nodule number as the fertilizer level increased from 50 kg P/ha to 100 kg P/ha, but the drop was significant only in the 6th and 9th weeks. The nodule number rose again significantly as the fertilizer level was increased to 150 kg P/ha. Plants treated with the higher fertilizer level had the largest nodule number. The differences between tne effect of this level and the effect of all other levels was significant at P = 0.05. From the 9th to the 11th week, the difference was significant also at the 1% level.

Table 20. Effect of phosphate fertilizer on the weight of nodules: mgs/plant

Fertilizer level kg P/ha	Weeks after planting			
2nd rains, 1979	4	8	9	11
0	175.6d	232.5a	144.4c	
50	133.8b	293.1b	82.5a	
100	158.8c	335.0c	117.5b	
150	115.6a	328.8c	191.3d	
c.v.%	55	68	79	
S.E. mean	2.08	5.06	2.50	
1st rains 1980	4	6	9	11
0	176.9a	205.0a	136.0a	47.6a
50	325.8b	335.5b	256.5ab	76.9ab
100	320.6b	290.8ab	332.0b	89.7bc
150	410.8b	463.4c	377.0b	119.1c
c.v.%	47	45	73	63
S.E. mean	36.40	36.74	50.25	13.23

N.B. Figures with the same letter in each column do not differ significantly.

4.8.2. Nodule Weight

In 1979, up to the 4th week consistent fertilizer effects were not obtained (Table 20). During the 8th week, nodule weight increased significantly with increase in fertilizer level, with the highest weight occurring at the 100 kg P/ha fertilizer level. During the 9th week, nodule weight difference between 50 kg P/ha and 150 kg P/ha fertilizer levels was significant.

In 1980, nodule weight increased significantly as the fertilizer level was raised from 50 kg P/ha to 150 kg P/ha, with a small depression at the 100 kg P/ha fertilizer level from the 4th to the 6th weeks. In the 4th week, nodule weight at each of the three fertilizer levels was significantly higher than the control, but the difference among the three levels were not significant. In the 6th week, nodule weights at the 150 kg P/ha treatment was significantly higher than at the other treatments. Nodule weights at the 50 kg P/ha and 100 kg P/ha treatments were higher than the control but were not significantly different from each other. In the 9th and 11th weeks the two highest fertilizer levels had significantly higher nodule weight than the contol, but were not significantly different from each other.

4.9. Plant Population Effects on the Rate of Growth

4.9.1. Leaf Growth Rate

Up to the 9th week of growth in the 1979 crop, leaf growth rate per plant decreased with increase in plant population. Up to the 8th week, the two highest plant populations had significantly lower leaf growth rate than the two lower populations, but differences within P_1 and P_2, and within P_2 and P_3 were not significant (Table 21). In the 9th week, negative leaf growth had already commenced at the highest population (P_4). Negative leaf growth at all the other populations commenced in the 11th week. Lower plant populations lost dry matter (per plant) at a greater rate than the higher populations. From the 11th to the 13th week, the two higher populations had significantly lower rates of leaf dry matter decline per plant than P_1, but these rates were not significantly different from each other.

Table 21. Plant population effects on leaf growth rate

No. plants/ha		Weeks after planting									
2nd rains 1979		6		8		9		11		13	
		gm/plant/ week	kg/ha week	gm/plant week	kg/ha week	gm/plant week	kg/ha week	gm/plant week	kg/ha week	gm/plant week	kg/ha week
P_1	160000	0.91a	145.6	1.44a	230.4	1.30a	208.0	-0.96a	-153.6	-0.99a	-158.4
P_2	250000	0.80a	200.0	1.22a	305.0	0.38ab	95.0	-0.87ab	-217.5	-0.56ab	-140.0
P_3	444444	0.59b	262.2	0.64b	284.4	0.37ab	164.4	-0.64b	-284.4	-0.38b	-168.9
P_4	1000000	0.52b	520.0	0.59b	590.0	-0.25b	-250.0	-0.41b	-410.0	-0.29b	-290.0
s.e. mean		0.06		0.19		0.35		0.09		0.15	
1st rains 1980		6		9		11		13		15	
P_1	160000	2.46a	393.6	1.68a	268.8	-1.33a	-212.8	-1.48a	-236.8	-2.30a	-368.0
P_2	250000	1.66b	415.0	1.47a	367.5	-0.06b	-15.0	-0.58bc	-120.0	-2.55a	-637.5
P_3	444444	1.33b	591.1	0.66b	293.3	-0.40b	-177.8	-0.98ac	-435.6	-1.04b	-462.2
P_4	1000000	0.70c	700.0	0.27b	270.0	-0.34b	-340.0	-0.15c	-150.0	-0.85b	-850.0
s.e. mean		0.14		0.25		0.28		0.31		0.19	

N.B. In all the subsequent tables, the letters P_1, P_2, P_3 and P_4 are used to refer to the plant populations 160000, 250000, 444444 and 1000000 respectively.

N.B. Figures with the same letter in each column do not differ significantly.

In the 1980 crop, leaf growth rate per plant decreased with increase in plant population up to the 9th week. In the 6th week, P_4 had significantly lower leaf growth rate than all the other populations. In the 9th week, P_3 and P_4 had significnantly lower leaf growth rates than P_1 and P_2. Negative growth rate at all the populations had commenced by the 11th week. The rate of dry matter decline tended to decrease with increase in plant population. From the 11th to the 13th week P_1 had significantly higher rate of leaf dry matter decline than the three higher populations. In the 15th week, P_3 and P_4 had significantly lower rate of leaf dry matter decline than P_1 and P_2.

Up to the 8th week in the 1979 crop, the rate of leaf dry matter accumulation per hectare increased with increase in plant population. In the 9th week, leaf growth per hectare decreased with increase in plant population, and had even negated at the highest population. In the 9th week of the 1980 crop, the highest rate of leaf growth per hectare was obtained at P_2 followed by P_3. With the onset of negative growth in both seasons after the 9th week, the rate of leaf dry matter decline per hectare tended to increase with increase in plant population.

4.9.2. Stem Growth Rate

Stem growth rate per plant decreased with increase in plant population up to the 9th week in the 1979 crop (Table 22). Up to the 8th week, P_1 and P_2 had significantly higher stem growth rates than P_3 and P_4, but differences within P_1 and P_2, and within P_3 and P_4 were not significant. In the 9th week, P_4 had lower growth rate than the three lower populations. After the 9th week, stem growth rates per plant did not appear to vary with changes in plant population.

In the 1980 crop, P_4 had significantly lower stem growth rate per plant than the three lower populations up to the 9th week. In the 6th week, P_2 and P_3 had significantly lower stem growth rate per plant than the control, but were not significantly different from each other. In the 11th week, the highest stem growth rate per plant occurred at P_2, then decreased with increase in plant population, but differences within the four populations were not significant.

Table 22. Effect of plant population on stem growth rate

Plant population density	Weeks after planting									
2nd rains 1979	6		8		9		11		13	
	gm/plant week	kg/ha week	gm/plant week	kg/ha week	gm/plant week	kg/ha week	gm/plant week	kg/ha week	gm/plant week	kg/ha week
P_1	0.33a	52.8	0.68a	108.8	0.69ab	110.4	0.03a	4.8	-0.17a	-27.2
P_2	0.29a	72.5	0.61a	152.5	0.91a	227.5	0.01a	2.5	0.00a	0.0
P_3	0.20ab	88.9	0.32b	142.2	0.78ab	346.7	-0.05a	-22.2	0.02a	8.9
P_4	0.18b	180.0	0.34.b	340.0	0.27b	270.0	0.09a	90.0	-0.03a	-30.0
s.e. mean	0.03		0.08		0.18		0.12		0.11	
1st rains 1980	6		9		11		13		15	
P_1	1.08a	172.8	1.26a	201.6	0.41a	65.6	0.02a	3.2	-0.35ab	-56.0
P_2	0.71b	177.5	1.17a	292.5	0.49a	122.5	-0.08a	-20.0	-0.67	-167.5
P_3	0.67b	297.8	0.73b	324.4	0.20a	88.9	-0.23a	-102.2	0.05b	-22.2
P_4	0.39c	390.0	0.49b	490.0	o.01a	10.0	0.06a	60.0	-0.12b	-120.0
s.e.	0.06		0.13		0.17		0.20		0.15	

N.B. Figures with the same letter in each column do not differ significantly.

Stem growth rate per hectare increased with increase in plant population up to the 8th week in the 1979 crop, and up to the 9th week in the 1980 crop. In the 9th week of the 1979 crop, the rate of stem dry matter accumulation per hectare increased up to P_3, then decreased at the highest population. At later stages of growth, stem growth rate per hectare did not appear to be influenced by changes in plant population.

4.9.3. Pod Growth Rate

The rate of pod growth per plant increased with decrease in plant population in both seasons (Table 23). In the 1979 crop, and during the 11th week of the 1980 crop, the rate of pod growth per plant at P_3 and P_4 was significantly lower than at the lower populations, but differences within P_3 and P_4 were not significant. In the 13th week of the 1980 crop, pod growth rate per plant at P_4 was significantly lower than in P_1 and P_2. During the 15th week, pod growth rate at P_1 was significantly higher than at the three higher populations but differences within the latter populations were not significant.

In the 1979 crop, pod growth rate per hectare increased with increase in plant population

Table 23. Effects of plant population on pod growth rate

Plant population density	Weeks after planting					
2nd rains 1979	11		13		15	
	gm/plant/wk	kg/ha/wk	gm/plant/wk	kg/ha/wk	gm/plant/wk	kg/ha/wk
P_1	2.48a	396.8	1.26ab	201.6		
P_2	1.43b	357.5	1.62a	405.0		
P_3	0.97c	431.1	0.42c	186.7		
P_4	0.61c	610.0	0.65bc	650.0		
s.e. mean	0.14		0.25			
1st rains 1980						
P_1	3.86a	617.6	6.12a	979.2	3.64a	582.4
P_2	3.13a	782.5	5.10ab	1275.0	0.22b	55.0
P_3	1.34b	595.6	3.66bc	1626.7	0.19b	84.4
P_4	0.72.b	720.0	2.15c	2150.0	0.10b	100.0
s.e. mean	0.30		0.56		0.65	

N.B. Figures with the same letter in each column do not differ significantly.

but there was a sharp drop at P_3 in the 13th week. In the 1980 crop, pod growth rate per hectare increased with increase in plant population up to the 13th week. In the 11th week, the highest pod growth rate per hectare occurred at P_2. In the 15th week pod growth rate per hectare was higher at the lowest population than at the other three populations.

4.9.4. Root Growth Rate

Up to the 9th week of the 1980 crop, the rate of root dry matter accumulation per plant increased with decrease in plant population (Table 24). In the 6th week, P_3 and P_4 had significantly lower rates of root growth than the lower populations, but differences within the two populations were not significant. In the 9th week, the highest rate of root growth occurred at P_2. After the 9th week, clear trend of root growth changes with changes in plant population was not observed.

Up to the 9th week, root dry matter increase rate per hectare increased as plant population rose, with a depression at P_3. In the 11th week, the rate but there was a sharp drop at P_3 in the 13th week. In the 1980 crop, pod growth rate per hectare increased with increase in plant population up to the 13th week. In the 11th week, the highest pod growth rate per hectare occurred at P_2. In the 15th week pod growth rate per hectare was higher at the lowest population than at the other three populations.

4.9.4. Root Growth Rate

Up to the 9th week of the 1980 crop, the rate of root dry matter accumulation per plant increased with decrease in plant population (Table 24). In the 6th week, P_3 and P_4 had significantly lower rates of root growth than the lower populations, but differences within the two populations were not significant. In the 9th week, the highest rate of root growth occurred at P_2. After the 9th week, clear trend of root growth changes with changes in plant population was not observed.

Up to the 9th week, root dry matter increase rate per hectare increased as plant population rose, with a depression at P_3. In the 11th week, the rate

Table 24. Effect of plant population on root growth rate

Plant population density	Weeks after planting									
1st rains 1979	6		9		11		13		15	
	gm/plant/wk	kg/ha wk	gm/plant/wk	kg/ha wk	gm/plant/wk	kg/ha/wk	gm/plant/wk	kg/ha/wk	gm/plant/wk	kg/ha/wk
P_1	0.23a	36.8	0.13b	20.8	0.01a	1.6	-0.11a	-17.6	0.05a	8.0
P_2	0.13b	32.5	0.23a	57.5	-0.10b	-25.0	-0.02a	-5.0	-0.04a	-10.0
P_3	0.05c	22.2	0.11b	48.9	-0.07b	-31.1	-0.01a	-4.4	0.01a	4.4
P_4	0.04c	40.0	0.06b	60.0	-0.06b	-60.0	-0.02a	-20.0	0.01a	10.0
s.e. mean	0.02		0.03		0.03		0.04		0.03	

N.B. Figures with the same letter in each column do not differ significantly.

of root dry matter decline per hectare was highest at the highest plant population, and decreased as plant population was lowered. After the 11th week, root dry matter changes with variations in plant population were irregular.

4.9.5. Rate of Total Dry Matter Increase

As was the case with the individual plant organs, the rate of total dry matter accumulation per plant decreased with increase in plant population (Table 25). In the 1979 crop, rates of dry matter increase at P_3 and P_4 were significantly lower than at P_1 and P_2 up to the 8th week of growth, but growth rate differences within the two populations were not significant. In the 9th week plants at P_1 had significantly higher rate of growth, and those at P_4 had significantly lower rate of growth than at the other populations. After the 9th week, significant differences did not occur.

In the 6th week of the 1980 crop P_4 had significantly lower rate of growth per plant than all the other populations. From the 9th to the 11th week P_3 and P_4 had significantly lower rates of plant growth than the lower two populations, but differences within P_3 and P_4 were not significant. In the 13th week, growth rate per plant decreased insignificantly with increase in plant population. Plants at P_1 continued to accumulate dry matter up to the 15th week, but negative growth at P_2, P_3 and P_4 had already commenced by the 15th week. The rate of dry matter decline per plant decreased with increase in plant population.

The rate of dry matter accumulation per hectare increased with increase in plant population up to the 8th week in the 1979 crop, and up to the 9th week in the 1980 crop. During the 9th week of the 1979 crop, the highest growth rate per hectare was obtained at P_3. From the 11th to the 13th week, the highest growth rate per hectare occurred at P_4. During the 11th week of the 1980 crop the highest growth rate per hectare occurred at P_2, then the rate dropped with increase in plant population. During the 13th week, the rate increased with increase in plant population. In the 15th week, the highest rate of dry matter decline per hectare occurred at P_4.

Table 25: Effect of plant population on the rate of total dry matter increase

Plant population density	Weeks after planting									
	6		8		9		11		13	
2nd rains 1979	gm/plant/wk	kg/ha/wk	gm/plant/wk	kg/ha wk	gm/plant/wk	kg/ha/wk	gm/plant/wk	kg/plant wk	gm/plant/wk	kg/ha/wk
P_1	1.24a	198.4	2.13a	340.8	4.24a	678.4	1.27a	203.2	0.35a	56.0
P_2	1.09a	272.5	1.83a	457.5	2.15ab	537.5	0.55a	137.5	1.07a	267.5
P_3	0.80b	355.6	0.95b	422.2	1.68bc	746.7	0.25a	111.1	0.56a	248.9
P_4	0.71b	710.0	0.93b	930.0	0.33c	330.0	0.27a	270.0	0.33a	330.0
s.e. mean	0.08		0.26		0.54		0.36		0.33	
1st rains 1980	6		9		11		13		15	
P_1	3.76a	601.6	4.08a	652.8	3.96a	633.6	3.99a	638.4	1.40a	224.0
P_2	2.50b	625.0	3.57a	892.5	3.45a	862.5	3.83a	957.5	-2.67b	-667.5
P_3	2.04b	906.7	2.27b	1008.9	1.08b	480.0	2.30a	1022.2	-0.77ab	-342.2
P_4	1.12c	1120.0	1.27b	1270.0	0.34b	340.0	2.04a	2040.0	-0.87ab	-870.0
s.e.	0.19		0.40		0.64		1.00		0.90	

N.B. Figures with the same letter in each column do not differ significantly.

Table 26: Effect of plant population on Leaf Area Index

Plant population density	Weeks after planting				
2nd rains 1979	4	8	9	11	13
P_1	0.29a	1.56a	1.95a	1.34a	0.63a
P_2	0.41b	2.26ab	2.24ab	1.46ab	0.90ab
P_3	0.61c	2.89b	2.65b	1.75b	1.12b
P_4	1.19d	5.13c	4.20c	2.67c	1.83c
C.V.%	23	33	29	28	38
s.e. mean	0.04	0.29	0.20	0.13	0.11
1st rains 1980	4	6	9	11	
P_1	0.88a	3.15a	4.22a	3.37a	
P_2	1.19a	3.34a	5.05a	4.52b	
P_3	2.44b	5.41b	6.57b	4.42b	
P_4	4.43c	8.24c	9.34c	5.82c	
C.V.%	29	30	28	27	
s.e. mean	0.16	0.37	0.44	0.31	

N.B. Figures with the same letter in each column do not differ significantly.

4.10. Effect of Plant Population on Leaf Area Index

As plant population density was increased, L.A.I. increased progressively and significantly at all stages of growth and in both seasons (Table 26). Peak leaf area indices at the three higher populations were obtained in the 8th week, and in the 9th week at the lowest population in the 1979 crop. In the 1980 crop, peak leaf area indices occurred in the 9th week at all the plant populations.

4.11 Effect of Plant Population on Dry Matter

4.11.1 Leaf Dry Matter

In both seasons, leaf dry matter per plant decreased significantly with increase in plant population at all stages of growth (Table 27 and Fig. 6). Leaf dry matter per hectare increased consistently with increase in plant population at all stages of growth in the 1979 crop, and up to the 11th week in the 1980 crop. During the 13th week, leaf dry matter per hectare was lower at P_3 than at P_2. In the 15th week, the lowest leaf dry matter occurred at P_2, followed by that at P_3.

x : grams/plant
y : kilograms/hectare

Table 27. Effect of plant population on leaf dry matter

Plant population density	Weeks after planting											
	4		6		8		9		11		13	
2nd rains 1979	x	y	x	y	x	y	x	y	x	y	x	y
P_1	0.89a	142.4	2.71a	433.6	4.98a	796.8	6.28a	1004.8	4.49a	718.4	2.31a	369.6
P_2	0.76b	190.0	2.35b	587.5	4.26a	1065.0	4.64b	1160.0	3.02b	755.0	1.83a	457.5
P_3	0.69bc	306.7	1.87c	831.1	2.87b	1275.6	3.24c	1440.0	2.06c	915.6	1.25b	555.6
P_4	0.58c	580.0	1.62c	1620.0	2.54b	2540.0	2.29d	2290.0	1.52c	1520.0	0.90b	900.0
C.V.%	19		23		32		28		27		43	
s.e. mean	0.04		0.12		0.29		0.30		0.19		0.17	
1st rains 1980	4		6		9		11		13		15	
P_1	2.07a	331.2	6.98a	1116.80	10.59a	1694.4	9.75a	1560.0	6.80a	1088.0	1.87a	299.a
P_2	1.80a	450.0	5.12b	1280.0	8.27b	2067.5	8.10b	2025.0	6.43a	1607.5	0.97b	242.5
P_3	1.86a	826.7	4.51b	2004.4	5.92c	2631.1	4.84c	2151.1	2.89b	1284.4	0.66c	293.3
P_4	1.45b	1450.0	2.84c	2840.0	3.41d	3410.0	2.49d	2490.0	2.20b	2200.0	0.37d	370.0
C.V.%	22		27		33		35		39		35	
s.e. mean	0.10		0.33		0.58		0.55		0.45		0.09	

N.B. Figures with the same letter in each column do not differ significantly.

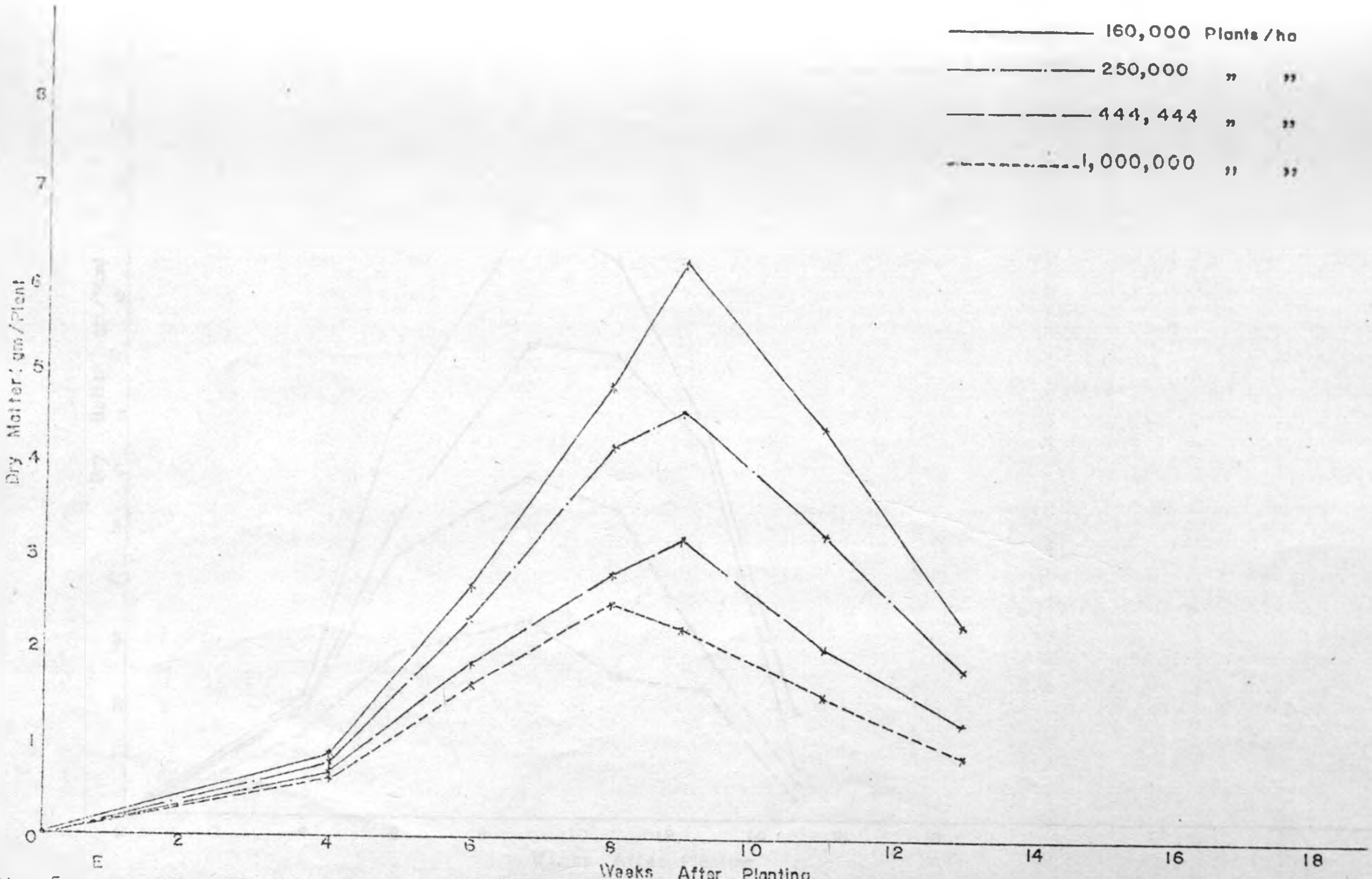


Fig. 5a . Effect Of Plant Population Density On Leaf Dry Matter Per Plant : Second Rains 1979.

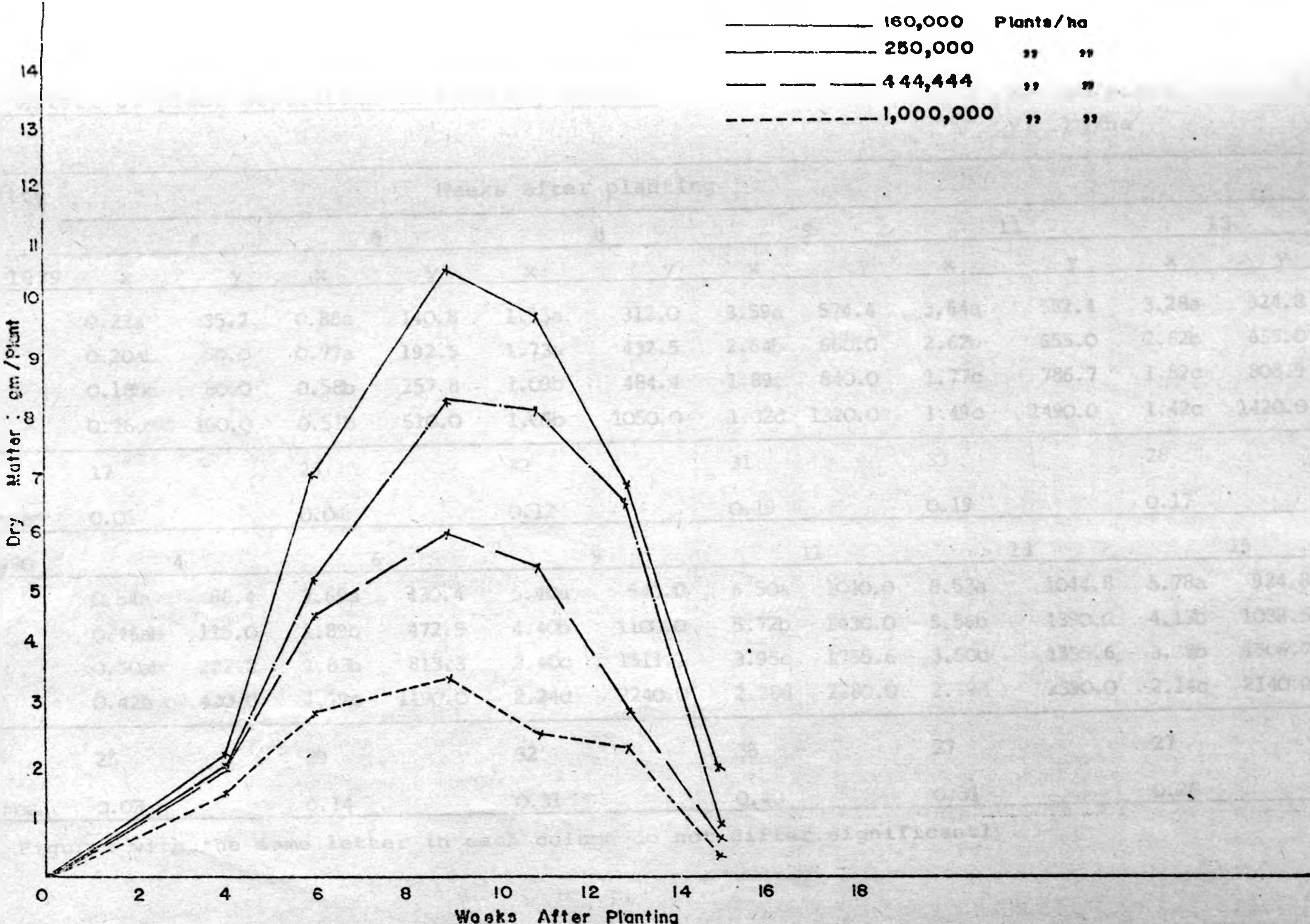


Fig 5b. Effect Of Plant Population Density On Leaf Dry Matter Per Plant : First Rains 1980.

Table 28: Effect of plant population on stem dry matter

x: gm/plant
y: kg/ha

Plant density density	Weeks after planting											
	4		6		8		9		11		13	
2nd rains 1979	x	y	x	y	x	y	x	y	x	y	x	y
P_1	0.22a	35.2	0.88a	140.8	1.95a	312.0	3.59a	574.4	3.64a	582.4	3.28a	524.8
P_2	0.20ab	50.0	0.77a	192.5	1.73a	432.5	2.64b	660.0	2.62b	655.0	2.62b	655.0
P_3	0.18bc	80.0	0.58b	257.8	1.09b	484.4	1.89c	840.0	1.77c	786.7	1.82c	808.9
P_4	0.16c	160.0	0.51b	510.0	1.05b	1050.0	1.32d	1320.0	1.49c	1490.0	1.42c	1420.0
C.V.%	17		25		32		31		33		28	
s.e. mean	0.01		0.04		0.12		0.19		0.19		0.17	
1st rains 1980	4		6		9		11		13		15	
P_1	0.54a	86.4	2.69a	430.4	5.40a	540.0	6.50a	1040.0	6.53a	1044.8	5.78a	924.8
P_2	0.46ab	115.0	1.89b	472.5	4.40b	1100.0	5.72b	1430.0	5.56b	1390.0	4.13b	1032.5
P_3	0.50ab	222.2	1.83b	813.3	3.40c	1511.1	3.95c	1755.6	3.50c	1555.6	3.39b	1506.7
P_4	0.42b	420.0	1.19c	1190.0	2.24d	2240.0	2.28d	2280.0	2.39d	2390.0	2.14c	2140.0
C.V.%	25		29		32		35		27		27	
s.e. mean	0.03		0.14		0.31		0.40		0.31		0.26	

N.B. Figures with the same letter in each column do not differ significantly.

4.11.2. Stem Dry Matter

Stem dry matter per plant decreased significantly with increase in plant population in both seasons (Table 28). From the 6th to the 8th week, differences between P_1 and P_2 were not significant. Except in the 9th week in 1979 crop, significant differences between P_3 and P_4 were not obtained. In 1980, significant differences in stem dry matter per plant between P_2 and P_3 during the 4th, 6th and 15th weeks were not obtained.

Stem dry matter per hectare increased with increase in plant population in both seasons at all stages of growth.

4.11.3. Pod Dry Matter

Pod dry matter per plant decreased significantly with increase in plant population at all stages of growth in both seasons (Table 29). During the 13th week of the 1979 crop, P_3 and P_4 were not significantly different in their pod dry matter. In 1980 P_2 and P_3 in the 9th week, and P_3 and P_4 in the 11th week, were also not significantly different.

Pod dry matter per hectare increased

Table 29. Effect of plant population on pod dry matter

x: gm/plant
y: kg/ha

Plant population density	Weeks after planting							
	9		11		13		15	
2nd rains 1979	x	y	x	y	x	y	x	y
P_1	1.30a	208	5.90a	944	8.61a	1377		
P_2	0.88b	221	3.54b	875	7.02a	1755		
P_3	0.53c	256	2.35c	1044	4.23b	1880		
P_4	0.28d	280	1.41d	1410	2.81b	2810		
C.V.%	44		34		38			
s.e. mean	0.08		0.28		0.56			
1st rains 1980								
P_1	2.15a	344	12.62a	2019	24.86a	3978	32.86a	5258
P_2	1.49b	373	9.99b	2498	20.19b	5048	20.67b	5168
P_3	1.64b	729	5.27c	2342	12.59c	5596	12.99c	5773
P_4	0.98c	980	2.94c	2940	7.23d	7230	7.44d	7440
C.V.%	39		44		22		29	
s.e. mean	0.15		0.84		0.87		1.33	

N.B. Figures with the same letter in each column do not differ significantly.

progressively with increase in plant population in both seasons except during the 11th and 15th weeks of the 1980 crop. In the 11th week, pod dry matter per hectare at P_2 was slightly higher than at P_3 and in the 15th week, dry matter at P_2 was slightly lower than at P_1. In both seasons and at all stages of growth, the highest population had consistently highest pod dry matter per hectare.

4.11.4 Root Dry Matter

Root dry matter per plant decreased progressively and significantly as plant population density was increased (Table 30). Root dry matter per hectare increased progressively with increase in plant population at all stages of growth.

4.11.5 Total Dry Matter

Total dry matter per plant decreased progressively and significantly with increase in plant population in both seasons at all stages of growth (Table 31 and Fig. 7). In both seasons, total dry matter per hectare increased with rise in plant population at all stages of growth except

Table 30. Effect of plant population on root-dry matter

x: grams/plant
y: kilograms/hectare

Plant population density	Weeks after planting											
	4		6		9		11		13		15	
1st rains 1980	x	y	x	y	x	y	x	y	x	y	x	y
P_1	0.38a	60.0	0.84a	134.0	1.11a	177.6	1.13a	180.8	0.91a	145.6	1.02a	163.2
P_2	0.36ab	90.0	0.61b	152.5	1.10a	277.5	0.82b	205.0	0.79b	197.5	0.70b	175.0
P_3	0.41a	182.2	0.51c	226.7	0.74b	328.9	0.54c	240.0	0.52c	231.1	0.54c	240.0
P_4	0.30b	300.0	0.37d	370.0	0.50c	500.0	0.34d	340.0	0.30d	300.0	0.33d	330.0
C.V.%	17		22		21		23		27		26	
s.e. mean	0.02		0.03		0.05		0.04		0.04		0.04	

N.B. Figures with the same letter in each column do not differ significantly.

Table 31. Effect of plant population on total dry matter

Plant population density	Weeks after planting											
	4		6		8		9		11		13	
2nd rains 1979	gm/plant	kg/ha	gm/plant	kg/ha	gm/plant	kg/ha	gm/plant	kg/ha	gm/plant	kg/ha	gm/plant	kg/ha
P_1	1.11a	177.6	3.59a	574.4	6.93a	1108.8	11.17a	1787.2	13.53a	2164.8	14.28a	2284.8
P_2	0.95b	237.5	3.12b	780.0	6.00a	1500.0	8.15b	2037.5	9.18b	2295.0	11.47b	2867.5
P_3	0.87b	386.7	2.46c	1093.3	3.96b	1760.0	5.64c	2506.7	6.11c	2715.6	7.30c	3244.4
P_4	0.71c	710.0	2.13c	930.0	3.59b	3590.0	3.92d	3920.0	4.42c	4420.0	5.13d	5130.0
C.V.%	18		22		32		29		29		30	
s.e. mean	0.04		0.16		0.41		0.55		0.61		0.74	
1st rains 1980	4		6		9		11		13		15	
P_1	3.00a	480.0	10.51a	1681.6	19.25a	3080.0	29.99a	4798.4	37.97a	6075.2	40.98a	6556.8
P_2	2.62a	655.0	7.62b	1905.1	15.27b	3817.5	24.63b	6157.5	32.28b	8070.0	26.55b	6637.5
P_3	2.78a	1235.6	6.85b	3044.4	11.71c	5204.4	14.65c	6511.1	19.25c	8555.6	17.59c	7817.8
P_4	2.17b	2170.0	4.14c	4410.0	7.13d	7130.0	8.05d	8050.0	12.13d	12130.0	10.27d	10270.0
C.V.%	21		25		29		34		22		27	
s.e. mean	0.14		0.47		0.97		1.65		1.62		1.43	

N.B. Figures with the same letter in each column do not differ significantly.

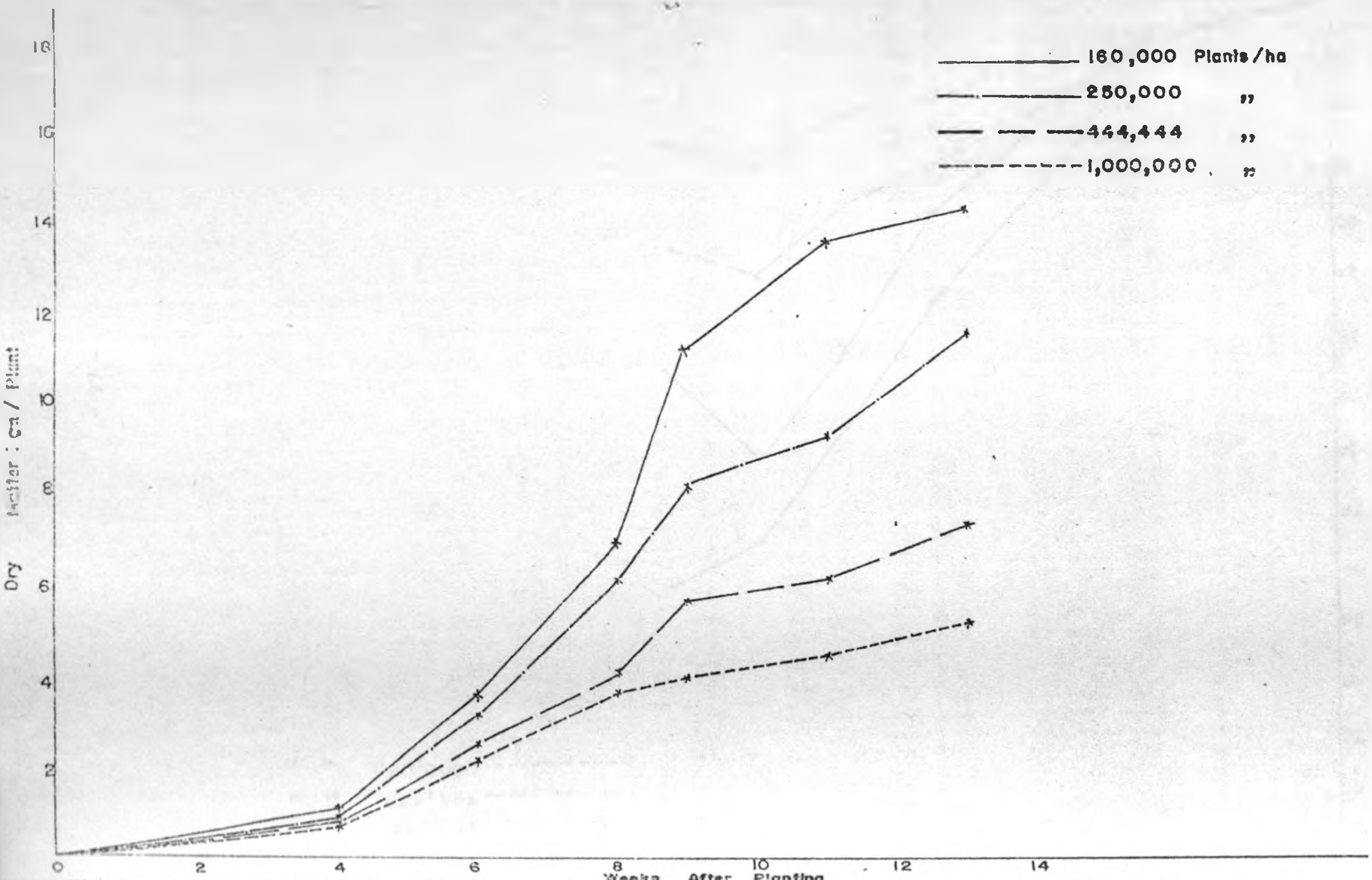


Fig. 6a. Effect Of Plant Population Density On Total Dry Matter Per Plant : Second Rains 1979.

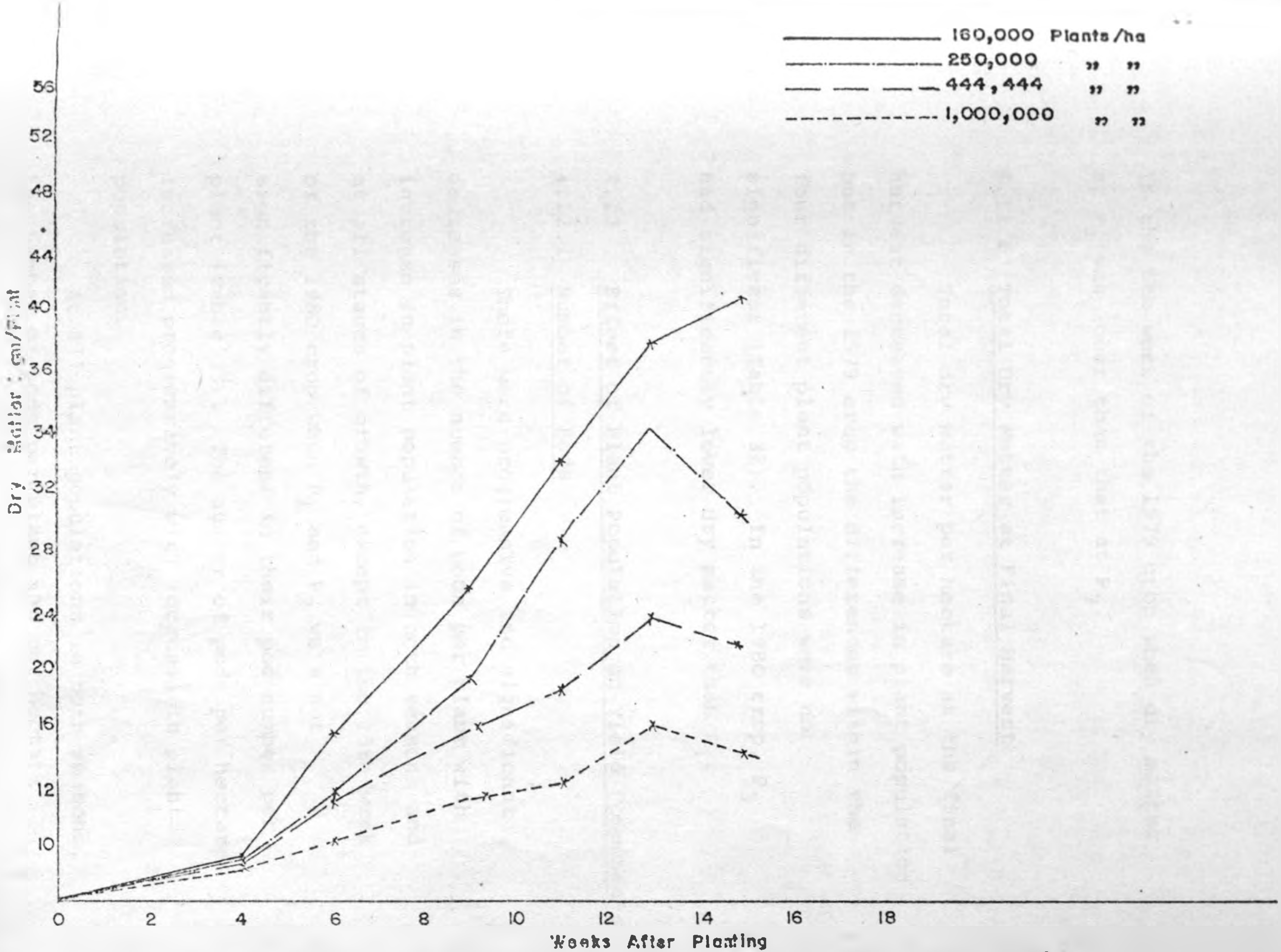


Fig.6b. Effect Of Plant Population Density On Total Dry Matter Per Plant : First Rains 1980.

in the 6th week of the 1979 crop when dry matter at P_4 was lower than that at P_3.

4.11.6 Total Dry Matter at Final Harvest

Total dry matter per hectare at the final harvest decreased with increase in plant population but in the 1979 crop the differences within the four different plant populations were not significant (Table 32). In the 1980 crop, P_3 had significantly lower dry matter than P_1.

4.12 Effect of Plant Population on Yield Components

4.12.1 Number of Pods

There were progressive and significant decreases in the number of pods per plant with increase in plant population in both seasons and at all stages of growth, except in the 13th week of the 1980 crop when P_1 and P_2 were not significantly different in their pod number per plant (Table 33). The number of pods per hectare increased progressively with increase in plant population.

At all plant populations in both seasons, the number of pods per plant and per hectare

Table 32. Effect of plant population on total dry matter at final harvest: kg/ha

2nd rains 1979		1st rains 1980	
Plant population density	Total dry matter: kg/ha	Plant population density	Total dry matter: kg/ha
160,000	3244.1a	160,000	8724.5a
250,000	2986.2a	250,000	7739.2ab
444,444	3063.9a	444,444	7534.3b
1000,000	2798.1a	1000,000	8045.9ab
mean	3023.1	mean	8011.0
C.V.%	20	c.v.%	16
s.e. mean	145.03	s.e. mean	319.95

N.B. Figures with the same letter in each column do not differ signigicantly.

Table 33. Effect of plant population on number of pods

x: Number of pods per plant
y: Number of pods per hectare x 1000.

Plant population density	Weeks after planting							
	9		11		13		FINAL HARVEST	
2nd rains 1979	x	y	x	y	x	y	x	y
P_1	13.6a	2176	11.3a	1808	10.2a	1632	9.9a	1584
P_2	10.1b	2525	7.9b	1975	6.7b	1675	6.7b	1675
P_3	7.6c	3378	6.4c	2844	5.3c	2356	5.1c	2268
P_4	5.3d	5300	4.7d	4700	4.1d	4100	3.5d	3500
C.V.%	33		26		24		22	
s.e. mean	0.78		0.46		0.37		0.33	
1st rains 1980	11		13		15		FINAL HARVEST	
P_1	22.7a	3632	17.3a	2768	19.7a	3152	15.6a	2496
P_2	19.4b	4850	17.0a	4250	15.9b	3975	11.6b	2900
P_3	13.4c	5956	12.0b	5333	10.9c	4844	7.9c	3511
P_4	7.8d	7800	6.8c	6800	5.9d	5900	4.9d	4900
C.V.%	25		21		22		18	
s.e. mean	0.99		0.68		0.59		0.56	

N.B. Figures with the same letter in each column do not differ significantly.

Table 34. Effect of plant population on number of seeds per pod and 100-seed weight

Plant population density	No. seeds/pod	100-seed weight (gm)
2nd rains 1979		
P_1	4.2a	34.71a
P_2	4.0a	33.41a
P_3	4.0a	34.85a
P_4	2.8b	29.36b
mean	3.8	33.08
C.V%	29	9
s.e. mean	0.11	0.71
1st rains 1980		
P_1	4.6a	42.11a
P_2	4.0b	41.62a
P_3	4.0b	40.47a
P_4	3.5c	41.46a
mean	4.0	41.42
C.V.%	12	7
s.e. mean	0.12	0.68

N.B. Figures with the same letter in each column do not differ significantly.

decreased as plant-maturity was approached due to pod shedding.

4.12.2 Number of Seeds Per Pod

In both seasons, plant population density significantly affected the number of seeds per pod. In the 1979 crop, the highest plant population had significantly lower number of seeds per pod than the lower three populations (Table 34). The highest seed number per pod was obtained at P_1, but P_1, P_2 and P_3 were not significantly different in their seed number per pod.

In the 1980 crop, P_1 had significantly higher number of seeds per pod while P_4 had significantly lower seed number than the other populations. There were no significant differences in seed number between P_2 and P_3.

4.12.3 100-Seed Weight

In both seasons, the highest 100-seed weight was obtained from the lowest plant population (Table 34). In the 1979 crop, P_4 had significantly lower 100-seed weight than the other three

Table 35. Effect of plant population on:-

Plant population density	Total dry matter at harvest kg/ha	Seed yield kg/ha	Harvest Index
2nd rains 1979	x	y	$^{y}/x \times 100$
P_1	3244.1a	1443.2a	45a
P_2	2986.2a	1148.4ab	38b
P_3	3063.9a	1254.2b	39c
P_4	2798.1a	906.9c	32d
mean	3023.1	1188.1	39
C.V.%	20	25	18
s.e. mean	145.03	76.64	0.03
1st rains 1980			
P_1	8724.5a	3789.7a	44a
P_2	7739.2ab	3166.9b	41b
P_3	7534.3b	2747.4c	37c
P_4	8045.9b	2348.6d	29d
mean	8011.0	3013.2	38
C.V.%	16	15	12
s.e. mean	319.95	110.00	0.01

N.B. Figures with the same letter in each column do not differ significantly.

populations. In the 1980 crop, significant differences were not obtained.

4.13 Effect of Plant Population on Seed Yield

In 1979, the lowest plant population had significantly higher seed yield (kg/ha) than the highest plant population (Table 35) which had the lowest seed yield.

In the 1980 crop, seed yield decreased progressively with increase in plant population, with significant differences between plant populations.

4.14 Effect of Plant Populations on Harvest Index

There were progressive and significant decreases in harvest index with increase in plant population in both seasons (Table 35).

4.15 Interaction between Plant Population Density and Fertilizer

4.15.1 Stem Growth Rate: 15th week of growth:1980

At 100 and 150 kg P/ha fertilizer levels, P_1 and P_2 respectively, had significantly higher

Table 36. Interaction between plant population and fertilizer on stem and leaf growth rate gm/plant/week. First rains 1980

No. plants/ha	kg P/ha					
Stem growth rate: 15th week of growth	0	50	100	150	mean	s.e. mean
P_1	-0.39abc	-0.61abc	-1.37c	-0.36abc	-0.50	0.31
P_2	-0.71abc	0.30a	-0.67abc	-1.01bc	-0.59	
P_3	0.17a	-0.27ab	-0.03ab	-0.43abc	-0.14	
P_4	-0.68abc	-0.03ab	0.05a	0.26a	-0.10	
mean	-0.40	-0.22	-0.51	-0.20		
s.e. mean	0.31					
Leaf growth rate: 15th week of growth:						
P_1	-1.97bcd	-2.41de	-2.66e	-1.12abc	-2.05	0.37
P_2	-2.05cde	-1.39abcd	-2.38de	-3.18e	-2.25	
P_3	-0.77ab	-0.97abc	-0.95abc	-0.98abc	-0.92	
P_4	-1.09abc	-0.73a	-0.54a	-0.67a	-0.76	
mean	-1.47	-1.38	-1.64	-1.49		
s.e.mean	0.37					

N.B. Figures with the same letter do not differ significantly.

rates of stem dry matter loss than the higher populations (Table 36). At the other fertilizer levels there were no significant differences in stem growth between the different populations. The lowest rate of dry matter loss occurred at P_4 with 100 kg P/ha fertilizer level.

4.15.2 Leaf Growth Rate: 15th Week of Growth: 1980

At the control, P_3 had significantly lower rate of leaf dry matter loss than P_1 and P_2 (Table 36). At 50 kg P/ha fertilizer level, P_3 and P_4 had significantly lower rates of leaf dry matter loss than P_1. At 100 kg P/ha level, P_3 and P_4 had significantly lower rates of leaf dry matter decline than P_1 and P_2.

4.15.3. Pod Growth Rate: 11th Week: 1979

P_1 resulted in the highest and P_4 in the lowest pod dry matter increase rate at all the fertilizer levels (Table 37). At 50, 100 and 150 kg P/ha fertilizer levels, the rate of pod dry matter increase at P_1 was significantly higher than at the higher populations. P_2 had significantly higher pod growth rate than P_4 at 0 and 100 kg P/ha

Table 37. Interaction between plant population and fertilizer on pod growth rate:gm/plant/week

No. plants/ha	kg P/ha					
11th week of growth: 1979	0	50	100	150	mean	s.e.mean
P_1	1.87 abc	2.25 b	3.36 a	2.44 b	2.48	0.27
P_2	1.40 cd	1.28 cde	1.87 bc	1.27 cde	1.46	
P_3	0.72 de	1.16 cde	1.29 cde	0.75 de	0.98	
P_4	0.45 e	0.57 de	0.47 e	0.48 e	0.49	
mean	1.11	1.32	1.75	1.24		
s.e. mean	0.27					
13th week of growth: 1980						
P_1	4.76 bcd	6.67 ab	9.01 a	4.05 cde	6.12	1.12
P_2	6.86 ab	2.18 de	4.22 bcde	7.14 ab	5.10	
P_3	3.96 bcde	3.63 bcde	3.99 bcde	3.07 cde	3.66	
P_4	4.16 bcde	1.74 b	0.92 e	1.75 b	2.14	
mean	4.94	3.56	4.54	4.00		
s.e. mean	1.12					
15th week of growth: 1980						
P_1	4.14 ab	4.89 a	-0.69 cd	4.51 a	3.22	1.30
P_2	0.90 abcd	1.33 abcd	0.67 abcd	-2.11 cd	0.20	
P_3	1.33 ac	-0.19 bcd	0.60 abcd	-1.08 cd	0.17	
P_4	-2.59 d	0.00 bcd	0.85 abcd	2.06 abc	0.08	
mean	0.95	1.51	0.36	0.85		
s.e. mean	1.30					

N.B. Figures with the same letter do not differ significantly.

levels. P_2 and P_3, and P_3 and P_4 did not have significantly different rates of pod growth.

4.15.4. Pod Growth Rate: 13th Week: 1980

Pod growth rate was significantly higher at P_1 than at the three higher populations in both 50 and 100 kg P/ha fertilizer levels (Table 37). At the highest fertilizer level, P_2 had significantly higher pod growth rate than P_3 and P_4.

4.15.5 Pod Growth Rate: 15th Week: 1980

At 0 kg P/ha fertilizer level, negative pod growth had occurred while at the higher fertilizer levels, growth was still positive at P_4 (Table 37). The highest pod growth rate occurred at P_1 where 50 kg P/ha was applied.

4.15.6. Leaf Area Index: 11th Week: 1980

At 50 kg P/ha fertilizer level, P_4 had significantly highest LAI than at the lower three populations; these lower populations were not significantly different in their LAI from each

Table 38. Interaction between plant population and fertilizer on Leaf Area Index: First rains 1980

No. plants/ha	kg P/ha						
	0	50	100	150	mean	s.e. mean	c.v.%
P_1	3.38cd	3.50cd	3.45cd	3.13d	3.37	0.62	27
P_2	3.88bcd	4.22bcd	5.60b	4.37cd	4.52		
P_3	3.21cd	5.28bc	3.39cd	5.81b	4.42		
P_4	4.36 bcd	8.91a	4.43 bcd	5.58b	5.82		
mean	3.71	5.48	4.22	4.72			
s.e. mean	0.62						

N.B. Figures with the same letter do not differ significantly.

other (Table 38). At 100 kg P/ha, LAI changes with increase in plant population were irregular. At 150 kg P/ha P_3 and P_4 had significantly higher LAI than P_1. The highest LAI occurred at P_4 where 50 kg P/ha was applied.

4.15.7 Stem Dry Matter: 13th Week: 1980

At 0 kg P/ha fertilizer level, P_1 and P_2 had significantly higher stem dry matter than P_3 and P_4 (Table 39). At 50 kg P/ha level, P_1 had significantly higher stem dry matter than any of the other three populations. At 100 kg P/ha level, P_1 produced the highest stem dry matter per plant followed by P_2. At 150 kg P/ha level the highest stem dry matter occurred at P_2, while P_4 had significantly lowest stem dry matter.

4.15.8. Leaf Dry Matter: 13th Week: 1980

At both 0 and 100 kg P/ha levels, P_1 and P_2 had significantly higher leaf dry matter than P_3 and P_4 (Table 39). At 50 kg P/ha level, P_1 had significantly higher leaf dry matter than each of the other populations. The highest leaf dry matter amounts occurred at P_2 and at the 150 kg P/ha level.

Table 39. Interaction between plant population and fertilizer on leaf, stem and root dry matter: gm/plant

No. plants/ha	kg P/ha						
Leaf dry matter: 13th week of growth: 1980	0	50	100	150	mean	s.e.mean	c.v.%
P_1	6.12abcd	7.70ab	8.57ab	4.79 cde	6.80	0.89	39
P_2	5.84bcd	3.83def	7.10abc	8.92a	6.42		
P_3	2.58ef	2.52ef	2.75ef	3.70ef	2.89		
P_4	2.90ef	2.16ef	1.75f	1.99ef	2.18		
mean	4.36	4.05	5.04	4.83			
s.e. mean	0.89						
Leaf dry matter: 15th week of growth: 1980							
P_1	1.35b	2.00a	2.05a	2.07a	1.87	0.17	35
P_2	0.86bcd	0.47de	1.34b	1.20bc	0.97		
P_3	0.71cde	0.19e	0.44de	1.32b	0.67		
P_4	0.25e	0.40de	0.45de	0.38de	0.37		
mean	0.79	0.77	1.07	1.24			
s.e. mean	0.17						
Stem dry matter: 13th week of growth: 1980							
P_1	6.53b	5.90bc	8.65a	5.02bcd	6.53	0.61	27
P_2	5.65bc	3.20def	6.77b	6.62b	5.56		
P_3	2.70ef	3.57def	3.16def	4.57cde	3.50		
P_4	3.14def	2.38f	1.98f	2.08f	2.40		
mean	4.51	3.76	5.15	4.57			
s.e. mean	0.61						
Root dry matter: 13th week of growth: 1980							
P_1	0.86abc	1.08a	0.95ab	0.75bc	0.91	0.08	27
P_2	0.86abc	0.49de	0.83abc	0.97ab	0.79		
P_3	0.45de	0.45de	0.49de	0.69cd	0.52		
P_4	0.31e	0.30e	0.28e	0.30e	0.30		
mean	0.62	0.58	0.64	0.68			
s.e. mean	0.08						

4.15.9 Leaf Dry Matter. 15th Week: 1980

At all the fertilizer levels, P_1 had significantly higher leaf dry matter than the other populations (Table 39). At 100 kg P/ha level, P_2 had significantly higher leaf dry matter than P_3 and P_4. At 150 kg P/ha level, P_2 and P_3 had significantly higher leaf dry matter than P_4. Otherwise P_2 and P_3, and P_3 and P_4 were not significantly different from each other. Highest leaf dry matter occurred at P_1 where 150 kg P/ha fertilizer was applied.

4.15.10 Root Dry Matter. 13th Week: 1980

P_1 and P_2 (Table 39) had significantly higher root dry matter than P_3 and P_4 at 0 and 100 kg P/ha levels. At 50 kg P/ha level, P_1 had significantly highest and at 150 kg P/ha level, P_4 had significantly lowest root dry matter. The highest root dry matter occurred at P_1 with 50 kg P/ha fertilizer level.

4.15.11. Pod Dry Matter. 9th Week: 1980

P_1 produced significantly highest pod dry matter at 50 and 100 kg P/ha levels than

Table 40. Interaction between plant population and fertilizer on pod dry matter: gm/plant: First rains 1980

No. plants/ha	kg P/ha						
9th week of growth:	0	50	100	150	Mean	S.E. Mean	c.v.%
P_1	1.00d	2.55ab	3.29a	1.75bcd	2.15	0.30	39
P_2	1.26b	1.28b	1.28cd	2.14bc	1.49		
P_3	1.45cd	1.44cd	1.53cd	2.16bc	1.65		
P_4	0.81d	0.75d	1.35cd	1.04d	0.99		
mean	1.13	1.51	1.86	1.77			
s.e. mean	0.30						
13th week of growth:							
P_1	24.24b	24.68b	30.25a	20.28b	24.86	1.75	22
P_2	22.37b	14.30c	21.89b	22.21b	20.19		
P_3	12.11cd	12.94cd	12.81cd	12.51cd	12.59		
P_4	10.80de	7.76def	4.22f	6.16ef	7.24		
mean	17.38	14.92	17.29	15.29			
s.e. mean	1.75						

N.B. Figures with the same letter do not differ significantly.

the other populations (Table 40). Pod dry matter differences within the highest populations were not significant.

The highest pod dry matter occurred at P_1 where 100 kg P/ha fertilizer was applied.

4.15.12 <u>Pod Dry Matter. 13th Week: 1980</u>

The highest pod dry matter was obtained at P_1 with 100 kg P/ha (Table 40). At this fertilizer level pod dry matter was significantly higher than at any other level. Pod dry matter at P_1 and P_2 with 0 kg P/ha, and at P_1 with 50 and 100 kg P/ha was significantly higher than at the other populations. At 100 kg P/ha level, pod dry matter decreased significantly with increase in plant population. At 150 kg P/ha level, P_4 had significantly lowest pod dry matter.

4.15.13 <u>Total Dry Matter: 13th Week: 1980</u>

P_1 and P_2 at 0, 100 and 150 kg P/ha had significantly higher total dry matter per plant than the higher populations, but dry matter differences between P_1 and P_2 were not significant

Table 41. Interaction between plant-population and fertilizer on total dry matter (gm/plant): First rains 1980

No. plants/ha 13th week of growth	kg P/ha						
	0	50	100	150	mean	s.e. mean	c.v.%
P_1	37.75b	39.36b	49.93a	30.84b	37.97	2.85	22
P_2	32.00b	21.82c	36.60b	38.72b	32.29		
P_3	16.83cd	19.48cd	19.20cd	21.48c	19.25		
P_4	19.48cd	12.60d	8.23e	10.52de	12.71		
mean	26.52	23.23	26.99	25.39			
s.e. mean	2.85						

N.B. Figures with the same letter do not differ significantly.

Table 42. Interaction between plant population and fertilizer on no. pods/plant: First rains 1980

No. plants/ha	kg P/ha						
13th week of growth:	0	50	100	150	mean	S.E. Mean	c.v.%
P_1	17.0 abc	16.3 bc	20.5a	15.3c	7.28	1.36	21
P_2	18.0 abc	14.3 cd	15.5 c	20.3ab	17.03		
P_3	10.3de	9.5ef	14.0cd	14.3cd	12.03		
P_4	9.8e	7.3efg	5.5fg	4.8g	6.85		
mean	13.78	11.85	13.88	13.68			
s.e. mean	1.36						

N.B. Figures with the same letter do not differ significantly.

(Table 41). At O and 50 kg P/ha level, P_3 and P_4 did not have significant differences in total dry matter. At 100 and 150 kg P/ha, P_4 had significantly lowest total dry matter. The highest total dry matter was recorded at P_1 where 100 kg P/ha was applied.

4.15.14. No. of Pods per Plant: 13th Week: 1980

P_1 and P_2 had significantly higher number of pods per plant than P_3 and P_4, but differences between P_1 and P_2 and between P_3 and P_4 were not significant (Table 42) at both O and 50 kg P/ha level. At 100 kg P/ha, P_1 had significantly highest and P_4 had significantly lowest pod number per plant. At 150 kg P/ha level P_2 had significantly highest, and P_4 had significantly lowest pod number per plant. The highest pod number occurred at P_1 with 100 kg P/ha.

4.15.15 Nodule Weight: 4th Week: 1980

Nodule weight per plant decreased insignificantly as population density was increased (Table 43). At each population density, nodule weight was lower at O kg P/ha level than at where fertilizer was applied. At P_1 and P_4, nodule weight was highest

Table 43. Interaction between plant population and fertilizer on nodule weight: mg/plant First rains 1980

No. plants/ha	kg P/ha					
4th week of growth	0	50	100	150	Mean	S.E.Mean
P_1	157.5e	316.5cde	508.5a	410.0abcd	348.13	72
P_2	214.0bcde	358.0bcde	201.5cde	441.0abc	303.63	
P_3	129.0e	444.0ab	215.5bcde	514.5a	325.75	
P_4	207.0bcde	184.5de	357.0abcde	278.0abcde	256.63	
Mean	176.88	325.75	320.63	410.85		
s.e. mean	72					

N.B. Figures with the same letter do not differ significantly.

at the 100 kg P/ha fertilizer level while at P_2 and P_3, the highest nodule weight occurred at the 150 kg P/ha level. The highest recorded nodule weight per plant was at P_1 with 100 kg P/ha fertilizer level.

CHAPTER FIVE

DISCUSSION

5.1. Seasonal Differences

The rate of growth, number of pods per plant, number of seeds per pod, 100-seed weight and consequently seed yields were higher in the first rains of 1980 than in the second rains of 1979. The differences could have been mainly due to the drier conditions in 1979 than in 1980. In the second rains of 1979 (October to December) only 242 mm of rain was received as compared to 443 mm received in the long rains of 1980 from March to May (see Appendix I). For the crop to be most successful, it must receive at least 300-380 mm of rainfall over a 10-week growing season (Kay, 1979) but the rainfall received in the 1979 season was well below this requirement. Though the crop was irrigated twice the moisture supplied could have been insufficient to fully meet the crops requirement for best performance hence subjecting the crop to water stress. Robins and Domingo (1956) showed that water stress prior to flowering reduced the number of pods per plant, and that water stress during flowering and early pod-fill stage reduced the number of seeds per pod and later on reduced the mean seed weight of _P. vulgaris_. Shibles and Weber (1966) found in soya beans that water stress during pod set was beneficial, but excessive water stress caused excessive pod and seed abortion which could lead to complete loss of yield.

5.2. Phosphate Fertilizer Effects

5.2.1. Effect of phosphate fertilier on the rate of growth and accumulated dry matter

The rates of dry matter increase in the leaves, stems, pods and roots were increased by the phosphate fertilizer before the onset of negative growth. Phosphorus is essential for cell development and division hence more satisfactory growth is expected in the phosphorus treated than in the control plants.

The rate of root growth was generally higher in the fertilized than in the control plants, resulting in higher root dry matter in the former than in the latter plants, although the differences were not significant. This indicated that phosphorus stimulated production of a stronger and more vigorous root system which could provide better anchorage of the plants in the soil, explore the soil for and absorb more nutrients including phosphorus, and water from the soil. This would lead to improved growth and development by the plant as a whole as compared to the unfertilized plants.

Improved growth rate and dry matter accumulation in the fertilized plants could also have been due to improved nitrogen uptake by these plants. Fertilized plants had higher number and weight of nodules than the control plants, hence the rate of nitrogen fixation and uptake could also have been higher in the fertilizer-treated than in the control plants. Sundara Rao (1971) found that phosphate application increased nitrogen uptake by lucerne crop by 26.4 kg N/ha.

The greater rate of leaf growth in the fertilized than in the control plants resulted in higher leaf area indices in these plants. Hence greater amounts of photosynthates could have been manufactured in the fertilized than in the control plants, resulting in greater rates of growth and higher dry matter quantities in the former than in the latter plants.

Higher stem dry matter amounts in the fertilizer-treated plants implied that phosphorus helped in producing stronger stems which had more resistance to lodging, or taller plants with consequent higher height to the first inflorescence hence the reproductive organs were carried further above the soil surface where they were less likely to be damaged by soil fungi.

Peak rates of dry matter production and peak dry matter amounts were higher in the fertilizer-treated than in the control plants. Peak growth rates in the leaves, stems, and roots were attained in the 9th week. Peak dry matter amounts were attained in the same week, except in the stems whose peaks were attained in the 11th week. The peaks were more sharply defined, and earlier, in the leaves than in the stems probably because of leaf senescence and abscission.

Negative leaf growth occurred earlier in the fertilizer-treated than in the control plants in the 1979 crop. Negative leaf growth at the 50 kg P/ha treatment commenced in the 9th week, and in the 11th week for all the other treatments. In the 1980 crop negative leaf growth commenced in the 11th week. The rates of leaf dry matter decline in the leaves and in the other plant organs were higher in the fertilizer-treated than in the control plants. This could probably be connected with the effect phosphorus has on enhancing plant maturity, particularly if the nutrient is in excess in relation to other nutrients (Gt. Brt. Min. Agric. 1964), nitrogen being one of the most important. When available phosphates are abundant in the rooting medium, the absorption of inorganic nitrogen compounds is depressed. The application of phosphatic fertilizers may therefore alter the nitrogen balance of the plant, resulting in the earlier maturation of plants when available phosphates are high, and the delay in reaching maturity occassioned by phosphorus deficiency (Meyer and Anderson, 1968). It is probable that the rates of phosphorus used in this work were in sufficient quantities to cause the nutrient imbalances which would result in the above effect. The quantity of fixed nitrogen in the fertilizer-treated plants could probably not match the amounts of available phosphates, and in the latter stages of growth small or no amounts of nitrogen could probably have been fixed due to decay and disintegration of the nodules. Hence the absorbed phosphorus might have accumulated in the plant tissues without improving growth or enhancing dry matter production. Parodi *et al.* (1977) reported that phosphorus applications to potted plants (*P. vulgaris*) increased the relative and absolute content of phosphorus in the plant but dry matter production did not increase. Martin (1976) also found that phosphorus, potassium and sulphur accumulated in the plant tissues (*P. vulgaris*) in the absence of nitrogen.

The greater rate of leaf dry matter decline in the fertilized plants implied higher rates of leaf senescence than in the control plants. This would lead to greater rates of reduction in photosynthetic surface. Consequently rates of dry matter production would also be lower than in the control plants. Since the rates of leaf dry matter decline were lower in the control than in the fertilized plants, the former plants retained their leaves and continued to produce plant dry matter for a longer time than the fertilized plants, hence the lower rates of plant dry matter decline in the control plants, and the small differences in dry matter between the fertilized and the control plants.

5.2.2. Effect of Phosphate Fertilizer on Leaf Area Index

Leaf Area Index (LAI) increased with increase in fertilizer level. The increase was significant between the control and the fertilized plants, but the difference within the fertilizer treatments was not significant. These results agree with Mahatanya's (1976) work in which he also obtained higher LAI in the phosphorus-treated than in the unfertilized plants but the LAI differences within the different fertilizer treatments were not significant. The higher the LAI the higher the photosynthetic potential of a crop up to a certain limit. Hence greater amounts of photosynthates are manufactured at higher leaf areas resulting in higher growth rates in the leaves, stems and roots, and the plant as a whole.

The corresponding increase in dry matter with increase in fertilizer level could therefore have been partly due to the corresponding increase in LAI. Watson (1956) concluded that leaf area and yield are closely related and that increasing the former will increase the latter.

It can be noted that at the two highest fertilizer levels the LAI was beyond 5 in the 6th week and beyond 6 in the 9th week in the 1980 crop (Table 9). An optimum LAI for every economic crop ranges from 2.5 to 5 (Mitchell, 1970). Probably, plants at the high fertilizer levels produced more leaves of which the lower ones were shaded by the upper ones, hence they could not intercept sufficient incoming radiation to photosynthesize efficiently. A condition of parasitism might therefore have occurred, the lower leaves using carbohydrates at a greater rate than they could photosynthesize. This could probably explain why, while the increase in LAI with increase in fertilizer level was significant from the 6th to the 11th week in the 1980 crop, the increases in seed yield and total dry matter at final harvest with the rise in fertilizer level were not significant.

5.2.3. Effect of Phosphate Fertilizer on Pod Dry Matter and Number of Pods per Plant

The number of pods per plant increased with increase in fertilizer level except at final harvest in the 1980 crop. Other researchers including Edje *et al*. (1975) and Haag *et al* (1978) also obtained increases in pod number per plant with increase in fertilizer level. It is noted, however, that the differences in pod number were not significant. The rate of dry matter decline was higher in the fertilizer-treated than in the control plants. The rate of pod abscission could also have been higher in the control than in the fertilizer-treated plants, making the number of pods more uniform at all the treatments. Also, LAI at the control and at the lowest fertilizer level was lower than at the two higher fertilizer levels. Hence at the former two treatments, the pods were less heavily shaded in the leaf canopy and greater photosynthesis by the pods could have occurred than at the two higher fertilizer levels. Greater rate of leaf fall which was indicated by the higher rate of negative leaf growth from the 11th week in the fertilized plants meant greater reduction in photosynthetic potential of these plants. This would mean reduction in dry matter that is partitioned to the pods. At the control and at the lower fertilizer level where the rates of leaf fall were lower, the leaves could have photosynthesised for a longer period, hence producing greater amounts of dry matter for their pods. The greater rate of pod abscission,the greater degree of pod shading, and the higher rate of leaf fall at the higher fertilizer levels would all tend to reduce the advantage the plants at these levels have of increased pod dry matter by the phosphate fertilizer, hence the insignificant increases in pod dry matter and pod number per plant with increase in fertilizer level. Duarte (1967) found that defoliation at flowering reduced the number of pods per plant but did not significantly affect the number of seeds per pod or 100-seed weight.

5.2.4. Effect of Phosphate Fertilizer on the Number of Seeds per Pod and 100-Seed Weight

In the 1979 crop, the number of seeds per pod at the 150 kg P/ha treatment was significantly higher than at the control, but the seed number differences within the three fertilizer treatments were not significant. In the 1980 crop, no significant changes in seed number per pod with changes in fertilizer level were observed. Mahatanya (1976) also reported increases in seed number per pod with increase in fertilizer level, but seed number differences within the fertilizer treatments were not significant. Haag *et al.* (1978) obtained significant increases in the number of seeds per pod with increase in fertility level. However, other researchers including Leakey (1972) and Edje *et al.*(1975) did not obtain significant effect of fertilizer on the number of seeds per pod.

In both seasons, 100-seed weight was not apparently affected by phosphate fertilizer application. Leakey (1972) also found that the mean seed weight was not altered by changes in fertility level. Gurnah (1979) also did not obtain any effect on Soybean weight by phosphate fertilizer, but Haag *et al.* (1978) reported an increase in bean seed weight with increase in fertility level.

Since there was an increase in seed yield with increase in fertility level, yet seed number per pod and 100-seed weight increases were only slight, the increase in seed yield could have been largely due to the increases in the number of pods per plant. Mujeeb and Greig (1973) found that bean yield of four mutants were significantly related to pod number which contributed more to yield than did number of seeds per pod or 100-seed weight.

5.2.5. Effect of Phosphate Fertilizer on Seed Yield

In 1979 the 13% increase in seed yield at the highest fertilizer level over the control could probably be attributed to the higher number of pods per plant and higher number of seeds per pod. These two components of yield increased with increase in fertilizer level, while the 100-seed weight was seemingly unaffected by fertilizer level changes. Haag _et al._ (1978) reported that the main effect of high fertility level was to enhance the role of "pods per plant" and "single seed weight" in influencing seed yield. Hodgson and Blackman (1955) and Goulden (1975) reported that seed yield production was solely governed by the number of mature pods formed.

In 1980, the 9% increase in seed yield at the highest fertilizer level over the control was probably due to the higher number of seeds per pod and 100-seed weight. These yield components increased, though insignificantly, with increase in fertilizer level, while pod number per plant at final harvest did not increase in fertilizer level.

Fertilized plants dried earlier than the untreated plants, but final harvest was taken at the same time for all the treatments when all the plants had dried. This implied that by final harvest greater seed loss through seed shattering could have occurred at the higher fertilizer levels where plants dried earlier than at the control and the lower fertilizer level. This might help to explain the non-significant difference in seed yield between the fertilized and the unfertilized plants.

5.2.6. Effect of Phosphate Fertilizer on Harvest Index

This is a measure of dry matter partitioning between economically useful parts and the rest of the plant. It is expressed as:-

$$\text{Harvest Index} = \frac{\text{Economic yield}}{\text{Total biological yield}} \times 100$$

(F.A.O., 1977)

When calculating harvest index (HI) in this study, the numerator was seed yield in kg/ha, and the denominator was total dry matter at harvest in kg/ha. These two components were not significantly affected by fertilizer level changes. Consequently, H.I. was also not significantly altered by fertilizer rates.

The average HI in 1979 crop was higher than in 1980 crop, being 40% and 38% respectively. It therefore appears that a greater proportion of dry matter was partitioned to the seeds in 1979 than in 1980. The more favourable rainfall regime in the first rains of 1980, and consequently better growth conditions than those of 1979, might have favoured production of greater proportion of vegetative growth.

In many food legumes there is a continuous senescence and fall of leaves during the growth of plants. These leaves are also part of the biological yield produced by the plant, hence harvest indices calculated from final harvest data may be higher than they actually should be because only sun-dried shoots without, or with very few, leaves, are used to determine the H.I. The figures therefore do not trully represent the H.I. (F.A.O. 1977).

5.2.7. Effect of Phosphate Fertilizer on Number and Weight of Nodules

In the second rains of 1979 the number and weight of nodules was lower than in the first rains of 1980. A possible explanation could be that the 1979 crop was planted in field 19 while the 1980 crop was grown in field 14; rhizobia strains capable of nodulating bean roots are lacking in field 19 (Keya and Mukunya, 1979). The poorer growth conditions in 1979 which adversely affected general plant growth including the roots, could also have interfered with nodule formation.

Phosphorus significantly increased the number and weight of the nodules formed. The phosphorus effect agrees with Keya's (1975) observation that the effect of superphosphates in legume nodulation was to increase the number of nodules formed per plant. Singh (1971) working with chickpeas, (*Cicer arietinum* L.) also obtained significant increases in nodule number and weight. Thus with 67.5 kg $P_2 O_5$/ha, a maximum of 138 nodules having 471 mg dry weight were produced. Most probably phosphorus stimulated nodulation more through its effect on bacteria than on the hosts. In the presence of adequate phosphorus, the bacterial cells become motile and flagellate, the pre-requisite for bacterial migration, whereas in the absence of phosphorus or with its inadequate supply, the infection remains latent, leading to the poor development of nodules (Singh, 1971).

The effect of increasing the rate of growth, plant dry matter and yield by phosphorus could partly be attributed to the increase in the number and weight of nodules by the phosphate fertilizer. The increase in the number and weight of nodules is associated with increase in nitrogen fixation. Nodule number and nodule mass can serve as reliable indicators of nitrogen fixation even as early as 3 weeks after emergence (Keya and Mukunya, 1979). During the late stages of growth, these indicators become less reliable because the nodules decay and disintegrate as the plant approaches maturity.

The number and weight of nodules increased significantly with increase in fertilizer level, yet the corresponding yield increase was not significant. This implied that the effect of phosphorus on the magnitude of nodulation was not the same for the dry matter production. This could mean that some or most of the nodules formed might have been partially or wholly ineffective in fixing nitrogen. Kintungulu Zake (1979) had found in groundnuts that, while phosphorus increased root number of nodules linearly, it increased the dry weight of groundnut tops in a quadratic manner, and the findings warned against equating nodulation with nitrogen fixation.

It can be noted that the number and weight of nodules decrease as plant maturity was approached. The same effect was observed by Keya and Mukunya (1979) who obtained peak nodulation between 30-40 days after plant emergence; one month later, the number of nodules decreased drastically irrespective of treatment. The maximum number of nodules is formed shortly before anthesis, and the nodules decay by the time the plants are mature. This is probably due to competition for photosynthates between the developing pods and the nodules. Since the developing pods provide a "sink" closer to the "source" leaves, the former become the recipients of photosynthates at the cost of the nodules (F.A.O. 1977).

5.2.8. Possible Reasons for Lack of Significant Phosphate Fertilizer Effects on Growth and Yield

1. Field beans (*P. vulgaris*) like other legumes have a well-developed tap root system with an extensive lateral root system concentrated largely in the top 25 cm of the soil (Smartt, 1976); the tap root grows deeper into the soil. Phosphorus was applied at a depth of about 3 cm in the furrows at planting time. Being one

of the less mobile elements, Phosphorus could have been out of reach of most of the bean roots. Dow *et al*. (1970) obtained little or no response of dry beans (*P. vulgaris*) to NPKS and Zn fertilizers and it was suggested that one of the reasons for lack of response was deep rooting,

2. Excess of phosphorus in relation to other nutrients can cause the too early maturation of a crop so that yields are decreased (Gt. Brt. Min. Agric. 1964). In this study, the high concentrations of phosphorus, ranging from 50 to 150 kg P/ha, which were used could have caused imbalances of the other essential nutrients particularly nitrogen, sulphur and the micro-nutrients zinc and molybdenum, causing the overall effect of depressed growth in the latter stages of growth and reduced yield. Excess phosphate has been found to induce zinc deficiency (Dow *et al*. 1970). Devarajan *et al*. (1980) working with red gram (*Cajanus cajan*), black gram (*Phaseolus*

reported antagonistic effect of phosphorus and zinc where high levels of phosphorus (50 kg P/ha) resulted in lower straw and grain yield, P content and uptake of nutrients. Anderson (1956) observed molybdenum deficiencies after the application of phosphorus in groundnuts.

3. Phosphorus fixation could also have occurred. Fixation refers to processes by which phosphorus is combined with soil constituents to form insoluble compounds which are largely unavailable to plants. Phosphorus may form insoluble compounds of calcium, magnesium, iron, aluminium and manganese. It may also combine with organic matter, or it may be adsorbed by the clay complex (Gt. Brt. Min. Agric. 1964). The pH range within which forms of phosphorus which the plants can absorb occur is between 5.5, - 7. Low pH soils have high concentrations of iron, aluminium and manganese. If the pH is below 5.5, insoluble compounds of iron and aluminium

immediate value for crops. Kaolinitic soils are high fixers of phosphorus, fixing it in the order of 500 to 1000 ppm added P, except for coarse-textured soils (Sanchez, 1976). Kabete soils are basically kaolinitic, with a low pH (5.2 - 5.6 as measured in 0.01 m calcium chloride solution), hence fixation of the applied phosphate could have occurred. Fixation capacity of the soils requires to be satisfied at least locally around the bands or spots where the fertilizer is applied, before crops would show a response.

4. The low response to phosphorus could also have been due to there being an adequate amount of phosphorus already present in the soils. Soil analysis indicated that the soil phosphorus was in the region of 4 ppm. This value is just below the margin above which phosphate fertilizer response is only probable (see Table 1 and the note below it).

5. In 1979, the limited phosphate fertilizer response could have been caused by lack of sufficient soil moisture due to the dry conditions that persisted throughout most of the growing season. Soil water must be adequate to keep the nutrient elements in solution from which they can be absorbed by the plants. This is particularly important for phosphorus because the diffusion rate of phosphate anion, which is slow enough even in moist soils, is drastically reduced due to lack of continuous moisture films as the soil dries up. Phosphate anions diffuse in short distances of not more than 1 mm. Root growth is also restricted during the dry season hence the root will not be able to explore the soil for phosphorus during this dry season. Where rainfall is marginal for crop production, no benefit from fertilizers may be obtained, and in other areas where cropping intensity and other yield potentials are limited by low or poorly distributed

rainfall, only relatively small dressings may prove economic (Webster and Wilson, 1966).

5.3. Plant Population Effects

5.3.1. Effect of plant population on growth rate

The rate of dry matter accumulation in each plant decreased with increase in plant population (Table 25). This indicated that the increase in plant numbers imposed a stress which restricted plant growth. This stress increased progressively from the lowest to the highest plant population. Supply of factors of production (nutrients, moisture, light etc) apparently became less and less as plant population was increased, hence competition for these factors increased as plant numbers per unit area increased. Among the vegetative organs, the leaves were the most affected by the competitional stress, as compared to the stems and roots; this was indicated by the more frequent significant differences in leaf than in stem and root growth rates between the various populations (Tables 21, 22 and 24).

On the "per unit area" basis, the rate of increase in total dry matter per hectare increased with increase in plant population (Table 25). Hence growth rate per plant decreased,but growth rate per unit area increased with increase in plant population. The decrease in the rate of growth per plant was therefore more than compensated for by the increase in plant numbers per unit area. This trend was similar to that observed in the rate of dry matter changes in the leaves up to the 8th and the 6th week in the 1979 and the 1980 crops respectively. In the stems and roots the trend was observed up to the 9th week in both seasons, while for pods it was observed up to the 13th week.

Negative growth in the leaves, stems and roots tended to commence earlier in the higher than in the lower plant populations, again due to the more severe inter- and intra-plant competition at the higher populations. The rate of negative growth per plant decreased with increase in plant population, but the rate of negative growth per hectare increased with increase in plant population. Hence the higher plant populations lost dry matter per hectare at a faster rate than the lower populations. Among the vegetative organs, this effect was again most obvious in the leaves. The rate of stem and root growth did not appear to be very much influenced by plant population changes.

In the 9th week of the 1979 crop, stem dry matter was still increasing at the rate of 270 kg/ha/week at the highest plant population, but leaf dry matter was decreasing at the rate of 250 kg/ha/week (Tables 21 and 22). In the 11th week of the 1980 crop stem dry matter was increasing at the rate of 88.9 and 10.0 kg/ha/week at the second highest and the highest populations respectively. In the same week, root dry matter was decreasing at the rate of 31.1 and 60.0 kg/ha/week at the respective plant populations (Table 24). Hence the sharp drop in the rate of total dry matter increase at the highest plant population in the 9th week of the 1979 crop and the 11th week of the 1980 crop could have been caused mainly by the drop in the rate of leaf dry matter production. Leaf dry matter decrease was caused mainly by leaf senescence and abscission as a result of translocation of nutrients from the leaves to the pods. The leaves withered faster in the high than in the low plant populations probably due to the mutual shading of the lower leaves, and the more severe inter- and intra-plant competition at the higher than at the lower plant populations.

Between the 11th and 13th weeks of growth, the rise in the rate of total dry matter production per unit area with increase in plant population was due mainly to the increase in the rate of pod dry matter accumulation with rise in plant population. At this stage, the rate of pod growth per hectare was positive, and increased with increase in plant population (Table 23), while the other plant parts i.e. leaves, stems and roots had negative growth rates. Hence after pod initiation, the available assimilates were translocated to the pods, rather than to the vegetative organs.

In the 15th week of the 1980 crop, the rate of growth was still positive at the lowest plant population, but negative at all the three higher populations. Hence the more sparsely spaced plants continued to accumulate dry matter for a longer time than the more densely packed plants. This was because of lack of competition between the low population plants, so that a positive continued growth was observed.

5.3.2. Effect of plant population on Leaf Area Index

Leaf Area Index (L.A.I.) increased progressively with increase in the number of plants per hectare (Table 26). Optimum L.A.I. for economic crops ranges from 2.5 to 5 (Mitchell, 1970) but leaf area indices at the two lower populations did not get beyond 2.3, and at the lowest population the L.A.I. was below 2 in the 1979 crop. At the lowest population in the 1980 crop, peak L.A.I. of 4.2 occurred in the 9th week, while at the highest population the peak was 9.3. This implied that more complete ground cover was attained at the higher than at the lower plant populations. Consequently, interception of photosynthetically active radiations would also be expected to be higher at the higher plant populations, resulting in higher rates of photosynthesis and dry matter accumulation than at the lower populations. The observed higher rates of growth and dry matter accumulation per hectare at the higher plant populations could therefore have been due to the higher L.A.I.

It was noted that L.A.I. at the highest plant population in the 8th week of the 1979 crop was higher than 5. In the 6th week of the 1980 crop also, the two highest, and in the 9th week the three highest populations had leaf area indices which were higher than 5. It was also observed that the rate of dry matter decline per hectare, particularly leaf dry matter was higher at the high than at the low plant populations. This could probably have been due to insufficient utilisation of all the available leaf area at the high plant populations because of excessive shading of the lower leaves. The lower leaves were therefore shed earlier and at a faster rate at the high than at the low plant populations.

After pod initiation in the 7th week, the developing pods at the lowest plant populations were not as heavily shaded in the leaf canopy as those at the higher populations, hence direct sunlight could have had access to these pods which could therefore have photosynthesised accumulation per hectare at the higher plant populations could therefore have been due to the higher L.A.I.

It was noted that L.A.I. at the highest plant population in the 8th week of the 1979 crop was higher than 5. In the 6th week of the 1980 crop also, the two highest, and in the 9th week the three highest populations had leaf area indices which were higher than 5. It was also observed that the rate of dry matter decline per hectare, particularly leaf dry matter was higher at the high than at the low plant populations. This could probably have been due to insufficient utilisation of all the available leaf area at the high plant populations because of excessive shading of the lower leaves. The lower leaves were therefore shed earlier and at a faster rate at the high than at the low plant populations.

After pod initiation in the 7th week, the developing pods at the lowest plant populations were not as heavily shaded in the leaf canopy as those at the higher populations, hence direct sunlight could have had access to these pods which could therefore have photosynthesised at a greater rate than those at the higher populations. The higher number of pods per plant, number of seeds per pod and seed weight at the lower than at the higher plant populations could have been partly due to this effect. Lucas and Milbourne (1970) reported that a reduction in leaf area after flowering and during the podding stage enhanced seed-weight as well as increasing the number of filled pods, and this provided evidence of the possible value of direct sunlight to the pods.

5.3.3. Effect of plant population on dry matter

The variations in dry matter accumulation rates caused by the various plant populations were reflected in total dry matter accumulated at various stages of growth (Table 30). As with the rate of growth, dry matter per plant decreased while dry matter per unit area increased with increase in plant population. Even at week 13 of both crops in the highest plant population total dry matter per unit area was still increasing. This indicated that the decrease in dry matter per plant with increase in plant population was still being more than compensated for by the increase in plant numbers per hectare even at the highest plant population. This implied an asymptotic relationship between plant density and dry matter yield. Similar effect has been reported in *P. vulgaris* by Leakey (1972) and Enyi (1975) among others.

In the 1980 crop, the three highest populations attained their peak dry matter per unit area in week 13 after which there occurred a rapid decline towards the 15th week of growth. At the lowest population, dry matter per unit area was still increasing even in week 15. The continued dry matter additions at the lowest plant population could have been due to the lower rate of leaf dry matter decline. The leaves at this population in the 15th week were being shed at the rate of 368 kg/ha/week as compared to the rate of 850 kg/ha/week at the highest population, a difference of about 57% (Table 21). The lower rate of leaf senescence at the lowest plant population also implied that there was a greater number of leaves which could photosynthesise, hence cause dry matter additions.

Lucas and Milbourne (1976) also reported slower senescence and prolonged photosynthetic activity in the more widely spaced plants.

In the 1979 crop, peak total dry matter was not attained and continued to increase up to the 13th week in all the plant populations. This was probably because sequential harvesting was terminated two weeks earlier in this season than in the 1980 crop. A similar effect as that observed in the 1980 crop could probably have been obtained had a further harvest been taken in the 15th week.

In the 1979 crop, peak leaf dry matter per plant was obtained in the 8th week at the highest plant population, but in the 9th week at all the other populations, (Table 27). In the 1980 crop, peak leaf dry matter was obtained in the 9th week in all the four populations. Peak stem and root dry matter per plant also tended to occur later at the lowest plant population (Tables 28 and 30). Hence peak dry matter per plant tended to occur later at the lower than at the higher plant populations indicating that at the lower population, dry matter production per plant, and hence per unit area, continued for a longer time than at the higher plant populations. The increase in plant numbers compensated for this effect by having higher peaks per unit area than at the lowest plant population, hence the advantage of longer period of dry matter production at the lowest plant population was offset when considering dry matter production per unit area.

5.3.4. Effect of plant population on total dry matter at harvest

As observed earlier plants at the higher populations lost their dry matter per unit area at a faster rate than those at the lower plant populations (Table 25). This had the effect of reducing the difference in dry matter between the lower and the higher plant populations caused by the higher dry matter accumulation rates per hectare at the higher populations during the earlier stages of growth. It was also observed that the leaves at the lower populations continued to produce dry matter for a longer period than those at the higher plant populations, hence dry plant, and hence per unit area, continued for a longer time than at the higher plant populations. The increase in plant numbers compensated for this effect by having higher peaks per unit area than at the lowest plant population, hence the advantage of longer period of dry matter production at the lowest plant population was offset when considering dry matter production per unit area.

5.3.4. Effect of plant population on total dry matter at harvest

As observed earlier plants at the higher populations lost their dry matter per unit area at a faster rate than those at the lower plant populations (Table 25). This had the effect of reducing the difference in dry matter between the lower and the higher plant populations caused by the higher dry matter accumulation rates per hectare at the higher populations during the earlier stages of growth. It was also observed that the leaves at the lower populations continued to produce dry matter for a longer period than those at the higher plant populations, hence dry matter production continued at the lower populations while production at the higher populations had already stopped. This might be attributed to less competition in lower populations and hence continued growth. This might probably account for the lack of significant differences in the final dry matter at harvest in the 1979 crop, and for the lowest population having higher final total dry matter than the higher plant populations.

5.3.5. Effect of Plant Population on Yield Components

5.3.5.1. Number of pods

As was the case with the vegetative dry matter, the number of pods per plant decreased with increase in plant populations and the number of pods per hectare increased with increase in plant population (Table 33). This is in agreement with the findings of Leakey, (1972), Rojas *et al*. (1975), and Westermann and Crothers (1977).

Though no data was collected on the number of branches it was observed that as plant population was increased, plants tended to grow taller due to increased internode length, and to have fewer branches than plants at the lowest population. Hodgson and Blackman (1956) reported an increase in the number of podless stems per plant with increase in plant density. Bennet *et al*. (1977) had found in *P. vulgaris* that the number of racemes per node and branches per plant were significantly reduced by increasing plant population density. Most of the variation in the number of pods per plant was attributed to changes in the number of branches and raceme development.

Edje and Mughogho (1975) also reported a decrease in the number of flowers setting mature pods, resulting from interplant competition at high plant densities. Leakey (1972) also reported that the number of pods produced per plant was actually much less than the number of flowers. Hodgson and Blackman (1956) found in broad beans (*Vicia faba*) that as plant density was increased, the number of nodes bearing pods diminished primarily due to the abscission of the inflorescences. Meadley and Milbourne (1970) reported that there was a 34% greater flower and pod wastage in vining peas planted at 172 plants per meter square than at a lower plant population. This reduction in the number of flowers with increase in plant density was due to competition between plants for environmental resources, and within plants for the available assimilates, which results in the reduction in the number of potential "sinks".

The observed reduction in the number of pods per plant with increasing plant population could therefore have been due to:

1. decrease in the number of branches per plant
2. decrease in the number of productive stems or decrease in the number of branches that bear flowers
3. greater flower wastage at high plant densities.

When plant population is increased, the resulting reduction in the number of pods per plant is relatively less, so that pods per unit area rises.

5.3.5.2. <u>Number of seeds per pod</u>

In both seasons, the highest plant population had significantly lower number of seeds per pod than the lower populations (Table 34). Leakey (1972), and Westermann and Crothers (1977) had also obtained a similar trend. Hence at the highest population competition was severe enough to affect the seed number per pod, but in the 1979 crop, competition was apparently not severe enough to result in significant differences in seed number per pod between the three lower plant populations.

5.3.5.3. 100-seed weight

No significant changes in 100-seed weight with variations in plant population were obtained in the 1980 crop, and in the 1979 crop the variations were irregular (Table 34). However, the lowest 100-seed weight was obtained at the highest population in the 1979 crop, and the difference in seed weight between this population and the other three was significant. This implied that competition between and within plants must have been quite severe in this season at the highest plant population, probably because of the less favourable rainfall regime in that season as compared to the 1980 season. Froussios (1970) had also found that the weight of seed decreased at plant densities higher than 100 plants/m^2, Enyi (1975) and Westermann and Crothers (1977) also reported that grams/seed increased as plant population decreased.

Among the highly plastic components of yield, that is, number of pods per plant, number of seeds per pod, and seed weight, the latter component is normally the last to be affected by competitional stress (Arnon, 1972). Harper (1961) considers this to be an internal or physiological homeostasis with respect to the organ that is essential for reproduction and dispersal.

5.3.6. Effect of plant population on seed yield

It was noted earlier that the rate of leaf senescence per hectare increased as plant population rose (Table 21). Consequently plants at the higher plant populations dried faster than those at the lower populations, hence seed loss through seed shattering could have been greater at the higher than at the lower plant populations. Leakey (1972) also reported a decline in seed yield at high plant densities due to seed shattering. Plants at the lower populations which had a lower rate of leaf senescence per hectare could also have produced more pod dry matter, hence greater number of pods and seeds after the plants at the high populations had already stopped to produce additional dry matter. The seeds at the highest plant populations were also significantly lighter than those at the lower populations. These factors might probably help to explain the decrease in seed yield with increase in plant population.

5.3.7. Effect of Plant Population on Harvest Index

Harvest index decreased significantly with increase in plant population, indicating that the proportion of vegetative dry matter increased as plant population rose (Table 35). This is in agreement with Nichols (1975) who suggested that with increasing plant density, a smaller proportion of assimilates is partitioned to the seeds, and more to the leaves and stems. Arnon (1972) reported that the internal competition within the individual plant between vegetative and reproductive parts becomes more severe as competition between plants increases, for example with increasing population pressure. As plant density is increased, changes may occur in the allocation of assimilates to different parts of the plant as a result of which greater proportion of the plants or of the reproductive parts of an individual plant may become barren. Grain production then shows a decline in yield whereas the total dry matter production may remain constant (Arnon, 1972).

5.4. Plant Population Density x Fertilizer Interaction

Significant interactions between plant population density and fertilizer were obtained at only a few stages of growth (Tables 36 to 43). Tables 36, 37, 39, 41 and 43 show that where fertilizer was not applied(control) significant differences in stem growth rate in the 15th week, pod growth rate in the 13th week, leaf area index in the 11th week, pod dry matter in the 9th week and nodule weight in the 4th week, between different populations were not obtained. Significant differences were obtained only where fertilizer was applied. Where significant differences at the control occurred, they were not as clearly marked as where the fertilizer was applied. During the 15th week of growth for example, significant differences in leaf growth rate (Table 36) between the four population densities were obtained but the clearest responses occurred at the 100 kg P/ha and 150 kg P/ha fertilizer levels. This tends to indicate that phosphorus is already a limiting factor in Kabete soils, and responses to plant population densities can only be obtained after phosphorus application. Different phosphate fertilizer levels did not influence the various population densities differently.

CHAPTER 6

CONCLUSION

In this study, significant phosphate fertilizer effects on growth and yield of beans were not obtained. However, fertilized plants showed improved growth, dry matter and seed yield over unfertilized plants. Fertilized plants had:-

1. More vigorous root systems which indicated improved water and nutrient absorption from the soil.

2. Higher leaf growth rate with consequent higher LAI resulting in manufacture of greater amounts of photosynthates.

3. Higher stem dry matter indicating production of stronger stems more resistant to lodging and higher height to the first inflorescence protecting the reproductive organs from possible soil pathogens.

4. Higher number of pods per plant and higher number of seeds per pod which resulted in 13% and 9% increase in seed yield in

1979 and 1980 respectively over unfertilized plants.

5. Significantly higher number and weight of nodules which could have resulted in higher rates of nitrogen fixation with consequent improvement in crop growth rate and yield.

6. Higher rate of plant senescence which exemplified the effect phosphorus has in enhancing plant maturity.

The non-significant differences in growth and yield due to the different fertilizer levels indicated that the bean plants did not substantially benefit from fertilizer rates higher than 50 kg P/ha. Higher fertilizer rates also tended to result in excessively high LAI in 1980 which did not result in corresponding increase in yield. Taking into account the improved performance of the fertilized plants and the non-significant yield differences due to the various fertilizer levels, application of 50 kg P/ha to the bean plants appears to be the best under Kabete conditions.

Rising rates of dry matter production with increase in plant population did not result in corresponding increase in seed yield. This indicated that vegetative rather than reproductive growth increased as plant population density was raised as shown by decrease in Harvest Index Values with increase in plant population. Thus vegetative growth appeared to have increased at the expense of reproductive growth. Since this particular crop is grown mainly for its seed, increasing plant population beyond 160,000 plants/ha does not appear to result in any advantage. Hence for this particular bean variety and under the Kabete conditions, population of 160,000 plants/ha appears to be the best.

Plant population density x fertilizer interactions were largely insignificant. In the few instances where significant interactions were obtained, significant differences in different plant densities occurred only where fertilizer was applied and not at the control. This seemed to indicate that phosphorus can be limiting in Kabete soils and responses to plant population densities can only be obtained after application of the element.

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APPENDIX I: Rainfall and Temperature Data: Kabete

	Rainfall (mm)		Mean Monthly Temperature: ^{o}C	
	1979	1980	1979	1980
January	61.3	159.1	18.1	18.2
February	205.1	63.5	18.7	18.9
March	120.6	61.2	19.0	19.7
April	209.3	154.2	18.7	19.8
May	187.5	423.5	17.9	18.7
June	40.0	24.9	16.6	15.8
July	33.4	3.4	15.6	15.5
August	12.7	18.8	16.2	15.7
September	15.6	28.9	17.6	17.6
October	26.4	25.9	19.0	18.8
November	133.1	255.2	18.2	18.1
December	82.2	73.7	18.3	18.0
Total	1127.2	1292.2		

APPENDIX II. Analysis of variance table showing mean squares for the studied variables

			1979					
Weeks after planting			4	6	8	9	11	13
Variable	Source of Variation	df						
Leaf Area Index	Total	63						
	Replications	3	0.09**		3.96*	2.22*	0.58	1.26**
	Fertilizer	3	0.01		1.71	0.64	0.53	0.14
	Spacing	3	2.57**		38.06**	16.07**	5.83**	4.28**
	Fertilizer x spacing	9	0.03		2.12	0.38	0.29	0.11
	Error	45	0.02		1.31	0.65	0.26	0.18
Leaf dry matter	Total	63						
	Replications	3	13.65**	256.34**	843.18**	726.50**	97.94	141.43*
	Fertilizer	3	2.06	8.60	114.52	123.35	156.86	29.92
	Spacing	3	30.63**	425.87**	2338.35**	5402.31**	2997.69**	700.18**
	Fertilizer x spacing	9	3.59	4.04	164.59	68.53	27.40	35.36
	Error	45	2.15	23.92	135.33	142.82	60.19	47.35
Stem dry matter	Total	63						
	Replications	3	1.22**	11.23*	210.79**	302.57**	109.35	145.82*
	Fertilizer	3	0.08	1.38	25.06	16.76	95.43	75.06
	Spacing	3	0.82**	47.10**	365.79**	1746.39**	1641.31**	1262.51**
	Fertilizer x spacing	9	0.04	1.83	18.06	19.57	68.69	23.00
	Error	45	0.12	2.98	22.53	59.85	58.37	48.26

APPENDIX II (CONTD...)

			1979					
Weeks after planting			4	6	8	9	11	13
Variable	Source of variation	df						
Pod dry matter	Total	63						
	Replications	3				81.01**	257.62	2004.44*
	Fertilizer	3				7.97	414.09*	519.51
	Spacing	3				354.08**	6659.91**	12489.92**
	Fertilizer x spacing	9				7.59	102.08	211.41
	Error	45				10.82	121.85	493.35
Root dry matter	Total	63						
	Replications	3						
	Fertilizer	3						
	Spacing	3						
	Fertilizer x spacing	9						
	Error	45						
Total dry matter	Total	63						
	Replications	3	22.97**	380.46**	1875.76**	2646.17**	780.82	4136.03*
	Fertilizer	3	2.81	7.55	245.08	206.52	1108.48	1332.46
	Spacing	3	41.16**	773.80**	4532.15**	17837.28**	28380.03**	29985.99**
	Fertilizer x spacing	9	1.55	29.16	280.03	166.08	330.72	409.96
	Error	45	3.10	38.45	262.78	480.37	603.61	870.22
No.pods/plant	Total							
	Replications					4820.06	635.08	687.87
	Fertilizer					502.40	937.03	69.83
	Spacing					24293.13**	13989.53**	14707.85**
	Fertilizer x spacing					391.01	545.39	141.16
	Error					965.50	336.35	215.71

APPENDIX II (CONTD....)

			1980					
Weeks after planting			4	6	9	11	13	15
Variable	Source of variation	df						
Leaf Area Index	Total	63						
	Replications	3	0.34	5.15	6.75	2.78		
	Fertilizer	3	0.43	5.37	7.61	9.12**		
	Spacing	3	41.45**	90.11**	81.31**	16.15**		
	Fertilizer x Spacing	9	0.33	2.38	3.44	6.12*		
	Error	45	0.41	2.22	3.09	1.53		
Leaf dry matter	Total	63						
	Replications	3	21.15**	211.91**	402.67**	108.01	180.40	7.75
	Fertilizer	3	4.80	50.90	310.81	172.12	81.55	21.21**
	Spacing	3	26.43	1164.66**	3814.94**	4237.98**	2245.03**	168.25**
	Fertilizer x Spacing	9	3.22	27.43	78.17	114.69	237.25**	10.12*
	Error	45	3.84	43.54	136.80	121.71	79.59	2.19
Stem dry matter	Total	63						
	Replications	3	1.74**	55.63**	182.11**	36.39	192.61**	36.52
	Fertilizer	3	0.37	24.16*	129.34*	107.50	127.75*	21.70
	Spacing	3	1.04*	149.76**	735.28**	1418.66**	1421.38**	925.29**
	Fertilizer x Spacing	9	0.29	4.64	11.75	43.37	158.27	30.39
	Error	45	0.35	7.71	37.99	64.94	37.71	27.28

APPENDIX II (CONTD.....)

			1980					
Weeks after planting			4	6	9	11	13	15
Variable	Source of variation	df						
Pod dry matter	Total	63						
	Replications	3			36.07*	756.39	44.39	239.19
	Fertilizer	3			43.59**	66.64	672.74	376.78
	Spacing	3			91.96**	7731.91**	24581.79**	47776.58**
	Fertilizer x Spacing	9			30.99*	308.13	1114.40*	1243.09
	Error	45			9.13	282.18	305.52	705.11
Root dry matter	Total	63						
	Replications	3	0.25	2.32**	6.60**	0.72	0.95	1.60
	Fertilizer	3	0.01	0.38	3.31*	3.67**	0.64	0.35
	Spacing	3	0.92**	15.88**	35.09**	47.06**	30.14**	33.54**
	Fertilizer x Spacing	9	0.06	0.47	0.99	0.83	2.36**	1.14
	Error	45	0.10	0.41	0.85	0.66	0.70	0.73
Total dry matter	Total	63						
	Replications	3	35.73**	534.50**	1633.75**	1301.00	704.20	477.04
	Fertilizer	3	7.83	141.29	1274.67*	787.99	954.17	180.87
	Spacing	3	48.97**	2524.60**	10652.45**	38790.34**	55923.42**	69913.31**
	Fertilizer x Spacing	9	5.68	50.47	243.75	1031.34	3149.24*	1565.18
	Error	45	7.40	87.68	375.99	1083.33	813.83	1054.30
No. pods/plant	Total	63						
	Replications	3				13.79	11.56	1.04
	Fertilizer	3				34.00	15.18	2.79
	Spacing	3				692.79**	389.68**	570.46**
	Fertilizer x Spacing	9				22.49	26.13*	5.50
	Error	45				15.55	7.42	5.50

APPENDIX II (CONTD...)

			1979			1980			
Weeks after Planting			4	8	9	4	6	9	11
Variable	Source of variation	df							
No. nodules	Total	63							
	Replications	3	37842.30	2942.23	112.22	6440.21	1417.23	170.44	5.02
	Fertilizer	3	5384.41**	571.47	536.93	44781.38**	1027.69**	134.10	86.81*
	Spacing	3	11467.55	2891.95	1164.79	6985.63	1163.52**	52.85	14.47
	Fertilizer x Spacing	9	4763.98	908.51	325.23	8514.67	195.65	130.95	12.99
	Error	45	4487.46	1192.91	488.69	7733.63	232.20	76.84	25.09
Weight of nodules	Total	63							
	Replications	3	0.01	0.06	0.03	1.13	1.36	0.71	0.05
	Fertilizer	3	0.01	0.04	0.03	3.77**	4.64**	4.44**	0.35**
	Spacing	3	0.01	0.13*	0.03	0.61	3.32**	2.34	0.06
	Fertilizer x Spacing	9	0.01	0.04	0.01	1.25	1.06	0.97	0.09
	Error	45	0.07	0.04	0.01	0.53	0.54	1.01	0.07

APPENDIX II (CONTD....)

	Source of variation	df	Total dry matter at harvest	Seed yield	No. pods/ plant	No. seeds/ pod	100-seed weight	Harvest Index
1979	Total	63						
	Replications	3	76182.18	21350.07	367.78	24.07	88.27	0.003
	Fertilizer	3	34357.17	5928.13	239.85	16.41	6.44	0.007
	Spacing	3	37657.10	55716.15**	5134.76**	539.81**	100.80**	0.062**
	Fertilizer x Spacing	9	33376.39	3574.75	231.74	15.55	10.93	0.003
	Error	45	19977.27	5583.86	175.91	18.71	8.16	0.005
1980	Total	63						
	Replications	3	3327.70	592.91	1.89	0.08	7.62	0.001
	Fertilizer	3	7982.63	2548.00	4.22	0.04	1.69	0.001
	Spacing	3	43277.78	59352.04**	343.27**	2.98**	7.53	0.067**
	Fertilizer x Spacing	9	20851.38	3324.57	9.58	0.17	6.76	0.002
	Error	45	16379.37	1936.14	4.99	0.24	7.31	0.002

* Significant at 5%

** Significant at 1%

APPENDIX III: Coefficient of Variation

The high coefficients of variation (CV over 15%) obtained in this work could have arisen because large quantities of bean material were handled during each havest. Errors could also have arisen because of working with different people each time. However, the CVS are within the range of those obtained from other work on field beans for example that of the Grain Legumes Project, Ministry of Agriculture. Beans, being an above-ground crop, are prone to many external factors such as pests and diseases the effects of which are reflected in the high CVS.