FFECT OF PHOSPHORUS FERTILIZER PLACEMENT AND SOIL MOISTURE REGIME ON YIELD OF PIGEONPEA (*Cajanus cajan* (*L.*) MILL.)

A THESIS SUBMITTED TO THE
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BY

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CERTIFICATE

This is to certify that this thesis entitled "Effect of phosphorus fertilizer placement and soil moisture regime on yield of pigeonpea (*Cajanus cajan* (*L.*)Mill.)" submitted for the degree of M.Sc. (Agriculture) in the major subject of Soil Science and Agriculture Chemistry of the Andhra Pradesh Agricultural University is a result of bonafide research work carried out by Mr. K. Veerabhadra Rao under our supervision and that the thesis has not formed in whole or in part the basis for the award of any degree, diploma or other similar distinction.

The assistance and help received during the course of this investigation have been fully acknowledged.

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I. INTRODUCTION

Pigeonpea (Cajanus cajan (L) Mill.) is one of the main grain legume crops of India. It is grown on 2.7 million hectares, or 11% of the total crop area under pulses (23.6 million hectares) and the grain produced accounts for 1.9 million tonnes or 16% of the total pulse production of 12.2 million tonnes (Anon, 1980). Its use for pod production is confined almost to India, but in many tropical area of the world it is used as food for livestock.

Pigeonpea has a number of useful characteristics, especially tolerance to drought and low soil fertility (Pathak, 1970), which indicate that it may perhaps be grown much more widely in the semi-arid tropics (SAT). Pigeonpea will grow under a wide range of agronomic conditions where the climate is frost free and the soils are free from waterlogging and high acidity, and it can be grown on soils of markedly different textures (Pathak, 1970).

Although pigeonpea is of considerable importance as a source of protein, it is a supplementary food grain. It is therefore commonly grown in the SAT somewhat under neglected conditions, for example, as an intercrop within a main cereal crop under rainfed conditions of low fertility soils. It is particularly useful for low-input subsistence agriculture of the semi-arid tropics in that commonly there is little requirement for fertilizer. Because it biologically fixes atmospheric nitrogen, there is no need for nitrogenous fertilizer.

The second major nutrient usually needed for crops in the SAT is phosphorus (Kanwar, 1976) which is usually important for the legumes grown in temperate agriculture. Pigeonpea responds less to applied phosphorus than cereals such as millet and sorghum (ICRISAT, 1980). The reasons are not known. However, pigeonpea is one of the legumes that develops a deep tap root system (Pathak 1970, Jain 1979). As the plant grows, penetration of roots deep into the soil may therefore assist the plant to obtain phosphorus from deeper soil layers by root interception; it has been postulated that such a mechanism may be the reason why pigeonpea requires less fertilizer phosphorus than cereals. Another reason may be that the surface layer of the soil in the SAT is dry quite frequently during the growing season, often due to the erratic nature of the rainfall; it is also usually dry during the postrainy season when long duration pigeonpea makes its most rapid growth and highest demand for phosphorus. For diffusion of P, moisture is important (Heslep & Black 1954). Under dry weather conditions, the diffusion of phosphorus in the surface soil will be low. These considerations indicated a need to study whether fertilizer phosphorus might be better utilized if placed at depth in the soil, and whether the soil moisture content at the depth of placement is an important determinate of pigeonpea yield. Experimentation was therefore conducted with two objectives:

i) To study the effect of placement of phosphorus at different depths in the soil on grain yield and phosphorus uptake of pigeonpea.

ii) To test the effect of soil moisture content at the depth of placement of phosphorus fertilizer on grain yield and the uptake of applied phosphorus.

II. REVIEW OF LITERATURE

II.1. Importance of phosphorus to legumes

Phosphorus is one of the major fertilizer nutrients required for crops in India, being second in importance to nitrogen (Kanwar, 1976). Studies on the efficiency of phosphorus fertilizer merit considerable attention because a crop will respond fully to applied nitrogen only if there is an adequate supply of phosphorus (Brady, 1974). Improved efficiency in the use of phosphorus fertilizers is desirable because costs are increasing as a result of increasing transportation costs (FAI, 1979).

Phosphorus is important for plant growth, because of its role in enzymatic reactions especially energy transfer mechanisms, phosphorylation, cell division and the development of meristematic tissue (Russel, 1973). Van Schreven (1958) emphasized the need for adequate phosphorus nutrition for legumes and oil crops because these are producing energy rich compounds such as protein and oil materials. Franco and Avillo (1976) have suggested that legumes may require more phosphorus than non-legumes because of higher requirements for symbiotic nitrogen fixation.

II.2. Effect of phosphorus on the grain yield of pigeonpea

The importance of phosphatic fertilizer for improving the yield of pulse crops has been long recognized. Many reports have been published on the yield of pigeonpea in relation to the amount of phosphorus fertilizer applied; less attention has been given to the importance of the type of soil and the variety of the crop. The available literature mostly reports studies of the rainy season (kharif) crop. A summary has been prepared of the published data on the effect of P on grain yield of pigeonpea, and the maximum response obtained (Table 1).

The rates of application of fertilizer phosphorus that have resulted in a significant response by pigeonpea vary considerably, from 5.5 to 250 kg P/ha. The magnitude of response over the control yield was usually less than 50% with only a few exceptions (Table 1). An 80% increase in the grain yield of pigeonpea resulted from an application of 250 kg P/ha (Dalal and Quilt, 1977). Chowdhury and Bhatia (1971) observed a 114% yield increase with an application of 43.7 kg P/ha, and a 260% increase in the grain yield was observed with an application of 33.4 kg P/ha (Ramanath _et al_, 1977).

Veeraswamy _et al_ (1972) obtained a significant response even with a small rate of fertilizer phosphorus (9.8 kg P/ha) in the presence of a basal dressing of 5 tonnes of compost applied to pigeonpea on red loamy soil, low in fertility. Experiments conducted in the All India Coordinated Project for Dryland Agriculture (AICRPDA, 1977) clearly showed that the response to the rate of P fertilizer applied was related to soil pH; in soils of acid reaction (pH 5) the response to 13 kg P/ha was quite significant in the presence of 1.25 tonnes of lime applied per hectare, but there was no response when lime was not applied.

1. o.	Author and year	Soil type	Soil avail. P (Kg/ha)*	Sea-son	Variety	P applied (Kg P/ha)	P carrier**	P rate at which max. response observed (Kg P/ha)	Grain yield. Control (Kg/ha)	Max.	Maximum response to P over control (%)
.	Chowdhury and Bhatia (1971)	Sandy loam pH [illegible].2	2	Kharif	T_{21}	0,14,29,44	SSP	44	1290	2760	114
.	Rama and Gri (1973)	Sandy loam	low	Kharif	S3,pusa agati sharda mukta	0,22,44	SSP	22	1298	1671	28
.	Singh, K.B (1973)	-	-	-	T_{21}	18	-	-	-	-	-
.	Bains, S.S (1970)	-	-	-	T_{21}	0,14,29,44	-	44	-	-	150
.	Ahlawat *et al.* (1975)	Sandy loam pH 7.7	low	Kharif	-	0,13,26	-	26	660	960	33
.	Kaul & Sekhon (1975)	Loamysand	medium	Kharif (2 Irr.)	T_{21}	0,9,18,26	SSP	18	1550	1870	21
.	Veeraswamy *et al.* (1972)	Red loamy	-	Kharif	SA-1	10	SSP	10	1263	1420	13
.	Rathi *et al.* (1974)	Light textured loam	12	Kharif	T_{21}	0,18,35	SSP	35	1570	2080	32
l.	Singh & Prasad (1975)	Sandy loam pH 8.1	4.2	Kharif	T_{21}, AS3 AS5,P4785	0,11,22, 33,44	SSP	44	1620	2360	45
).	Yadav & Saxena (1975)	-	-	Kharif		21	SSP	-	-	-	-

Contd...

Sl. No.	Author and year	Soil type	Soil avail. P (Kg/ha)*	Season	Variety	P applied (Kg P/ha)	P carrier**	P rate at which max. response observed (Kg P/ha)	Grain yield. Control (Kg/ha)	Grain yield. Max. (Kg/ha)	Maximum response to P over control (%)
1.	Singh *et al.* (1976)	Sandy loam pH 8.1	4.2	Kharif (rainfall 747 mm)	T_{21}, AS3 AS_5, p 4785	0,11,22,33, 44	-	44	1640	2220	35
2.	Lenka & Satpathy (1976)	Sandy loam pH 6.0	13	Kharif	S_5, T_{21}, R 60	0,18,35,52	-	52	630	1170	41
3.	Dalal & Quilt (1977)	River estate loam pH 5.2	10 ppm	-	G 127-4A	0,50,100, 250	TSP	250	1716	3102	80
4.	Ramanath *et al.* (1977)	Calcareous Soil	-	-	CO_2	0,6,11,22 33	-	33	329	1187	260
5.	Manji *et al.* (1973)	Sandy clay loam pH 8.3	7.8	Kharif (rainfall 752 mm)	T_{21}, AS10 AS8	0,22,44	-	44	1600	2300	43
6.	A I C R P D A Ann.Rep.(1977)	Red sandy clay loam pH 5.0	10 ppm	Kharif	HY3	0,13,39 with lime	SSP	13	1950	2190	12
7.	-do-	Red loamy sand	9.8	Kharif	Pusa Agathi HY-1	0,9,18,26	-	18	790	970	22
8.	-do-	-	8.6	Kharif	UPAS	0.9,18,35	-	18	290	410	55
9.	Rathi & Tripathi (1978)	Sandy loam	-	Kharif rainfall 833 mm	T_{21}	0,18,35	SSP	18	1450	1810	27

Contd...3.

Sl. No.	Author and year	Soil type	Soil avail P (Kg/ha)*	Sea-son	Variety	P applied (Kg P/ha)	P carrier**	P rate at which max. response observed (Kg P/ha)	Grain yield. Control (Kg/ha).	Grain yield. Max. (Kg/ha).	Maximum response to P over control (%)
20.	Hegde & Saraf (1979a)	Sandy loam	low	Kharif	-	0,18,35	-	35	959	1424	48
21.	Singh et al. (1978)	Sandy loam pH 7.6	-	Kharif (rain-fall 940 mm)	-	0,13,26,39	SSP	39	1680	2060	24
22.	Andrews and Manajuti (1979)	-	-	-	Local variety	400 kg rock phosphate	RP	-	-	-	63
23.	ICRISAT Ann.Rpt. (1977)	Alfisols pH 6.0-6.5	2.8 ppm	Kharif	-	0,20,40	RP	40	620	790	27

Soil available P status given in kg P/ha (of 0-15 cm depth) unless otherwise indicated (Eg. low, medium or high; or as pp

P carrier : SSP = Single Super Phosphate

TSP = Triple Super Phosphate

RP = Rock Phosphate

There are a number of reports which quote available P status of the soil on which response experiments were conducted. Lenka and Satpathy (1976) obtained a maximum grain yield increase with 52.4 kg P/ha where the soil available phosphorus was 13 kg P/ha. Rathi et al (1979) observed a maximum grain yield with 35 kg P/ha on a soil which had an available P content of 12 kg/ha. Singh et al (1978) obtained a maximum increase in the grain yield of pigeonpea by the application of 39.3 kg P/ha where the soil available P content was 18 kg P/ha.

Single superphosphate was the source of phosphorus fertilizer applied to pigeonpea in most of the experiments reviewed. But Dalal and Quilt (1977) used triple superphosphate, applied at the rate of 250 kg P/ha to a loam whose available P content was 10 ppm. Andrews and Manujuti (1976) reported 83% yield increase over the control when the fertilizer used was 400 kg rock phosphate per hectare. In an intercrop system, the pigeonpea responded less than sorghum to applications of superphosphate and rock phosphate; The grain yield of sorghum (680 kg/ha in the control) increased to 1270 kg/ha when 160 kg P/ha was applied as rock phosphate, whereas pigeonpea grain yield (control 620 kg/ha) increased to only 790 kg/ha with 40 kg P/ha applied as rock phosphate; with a higher rate of phosphorus applied, pigeonpea yields did not increase (ICRISAT 1977).

All these results have been obtained from experiments conducted at different places. The response to the applied phosphorus depends upon physical and chemical characteristics of a particular soil, as well as the variety grown and the agroclimatic conditions of the area. There is still insufficient data available to be able to make accurate general recommendations on the amount of fertilizer required for various soil types. However, from the summary in Table 1, the maximum response has usually been obtained with an application of 12 to 35 kg P/ha.

11.3. Placement of phosphorus

Studies on the deep placement of phosphorus were made as early as 1960 by Nye and Foster, who investigated the rate of phosphorus uptake by different crops from subsoils especially those with low levels of available phosphorus. By using phosphorus fertilizer labelled with P32, Nye and Foster (1961) found that over 90% of the phosphorus was taken up from the surface soil (0-25 cm) by maize and pigeonpea, and that at 50 days after germination, the plant fed closer to its stem base than maize or millet. In the second year, they observed extraction of more phosphorus from the subsoil than was recorded at a comparable time in the first year; the layers deeper than 0-25 cm contributed 11% of the phosphorus taken up after 80 days of plant growth, and they contributed 22% after nearly four months in the subsequent year. The plants were absorbing most of their phosphorus from the surface soil; one possible contributing factor was the fact that water not a limiting factor in these studies, and the plants did not need to root deeply for water supplies. However Nye and Foster concentrated mostly on the uptake of phosphorus during vegetative growth from different soil compartments. They did not investigate the uptake of phosphorus during the reproductive stage or the effect of placed phosphorus on the grain yield of a particular crop under study.

A number of researchers have suggested that fertilizer phosphorus should be placed deeper into the soil for better utilization and a good response by legumes. Chowdhury (1968), Singh (1973), and Yadav and Saxena (1975) suggested drilling of the phosphatic fertilizer into the soil as deep as 15 cm for better yields. Also experiments at I.A.R.I (1971) showed that deep placement at 20 cm depth was superior(2660 kg/ha) to broadcast application (2160 kg/ha). Ahlawat et al (1975) conducted a different type of experiment by introducing a split application of P at different depths (15 cm and 30 cm) below the soil surface. They reported maximum (and significant) increase in yield when half of the fertilizer phosphorus was applied at 15 cm depth and the remaining half at 30 cm depth. Only one result suggests that banding at depth is not beneficial (see Khan and Muthur, 1962).

Even though relatively little work has been done on the benefit of deep placement of phosphorus for better pigeonpea yields, the existing literature indicates that usually some increase in yield may be expected from deep placement. However, more work is required to investigate the mechanisms responsible.

11.4. Phosphorus uptake

Plants differ in their rate of P uptake depending upon the ability of the plant to absorb P, and availability of phosphorus in the soil. The uptake of phosphorus by pigeonpea has been studied by a number of authors, especially with respect to the quantity of fertilizer applied, method of application, and the type of fertilizer. Pandey et al (1971) studied the comparative uptake of phosphorus by various crop plants, including pigeonpea, by using the radioactive P^{32}. They found that the rate of P uptake and incorporation into the leaves was a maximum during the early stages of the growth for almost all the types of plants studied but that the incorporation of P into the leaves decreased with age. Sheldrake and Narayanan (1976) investigated the absorption of phosphorus by long duration pigeonpea grown on Vertisols, and the distribution within the plant at different stages of growth. They found that the P concentration in the leaves, petioles and stems declined throughout the growing season, although the uptake of P by the whole plant continued to increase upto harvest. The rate of P uptake was reported to be maximum at 90-120 days after sowing; the total uptake of P by the above ground parts of the plants was 5.6 kg/ha at harvest (160 days). The P content of the mature leaves was reported to be 0.3%. These authors obtained similar results again in 1979.

The uptake of phosphorus increases with the application of phosphorus (Singh and Prasad, 1976; Ramanath _et al_, 1977; Dalal and Quilt, 1977). Singh and Prasad found that at 30 and 60 days after seeding, the uptake of phosphorus was not significantly influenced by the various rates of phosphorus applied. But, at 90 days, the uptake was significantly influenced by the rates of phosphorus applied. The main uptake of P by pigeonpea was between 90 days and 160 days. The total uptake was 16 kg P/ha at the time of harvest for a rate of fertilizer P application of 43.7 kg P/ha.

II.5. Soil moisture regime and phosphorus

Moisture plays a major role in the movement of nutrients to the root surface from the soil. Barber (1962) has described the two major mechanisms of ion transport in the soil: massflow and diffusion. In most soils, the concentration of phosphorus in the soil solution is very low; therefore mass flow makes only a minor contribution to the nutrition of the plant, and diffusion is the major mechanism responsible for P transport to the plant roots.

Phosphorus diffusion in the soil is dependent on the concentration gradient and soil moisture content (Heslep and Black, 1954; Fried and Shapiro, 1960; Olsen et al 1962). Soil water status therefore plays an important role in P uptake by plants. The reason for the low concentration of phosphorus ions in the soil solution is that the soluble fertilizer e.g. single superphosphate, rapidly loses its solubility when added to the soil, because it reverts to a less soluble form. Heslep and Black (1954) and Webb et al (1961) observed increased P diffusion with an increase in the amount of P in the watersoluble form.

Although it is well known that an adequate level of soil moisture is necessary for optimum availability of P in the soil, there is little detailed information on the effect of soil moisture status on P uptake by pigeonpea. In particular, there is no data on phosphorus x water x depth of placement interactions. The few limited reports that are available describe the effect of P fertilizer on water use efficiency or the effect of irrigation on response of pigeonpea to phosphorus.

Anon (1978) and Venkatratnam and Green (1979) reported that there was an overall 12% increase in seed yield of pigeonpea with irrigation in both the vegetative and reproductive stage. Hegde and Saraf (1979b) reported that phosphorus application increased the consumptive use of water and water use efficiency, but the interaction between irrigation and phosphorus levels was not significant for grain yield or plant characteristics.

III. FIELD EXPERIMENT

A field experiment to examine the effect of different moisture regime and depth of placement of phosphatic fertilizer on the phosphorus nutrition of pigeonpea was carried out at the International Crops Research Institute for the Semi-Arid Tropics (ICRISAT), Patancheru (near Hyderabad), during 1979-'80. This experiment was conducted in the post-rainy season on Field No. RA2, which is of particularly low fertility status. Surface soil collected from this site was used for a subsequent pot experiment in the glasshouse (See Section IV).

A survey of the low fertility soils at ICRISAT, conducted by Drs. T.J. Rego and K.L. Sahrawat* has shown that the surface soil (0-10 cm depth) in this field contains the lowest amount of available P of any field at ICRISAT Center. The physical and chemical characteristics of the soil are given in Table 2.

III.1. Materials and Methods.

The major comparisions to be made were the response of P fertilizer placed at a conventional shallow depth in the soil profile with that when P fertilizer was placed deep (30 cm), and the effects of contrasting moisture relations at the site of fertilizer placement at these two depths. Because it was not practicable to place fertilizer in bands at the 30 cm depth, it was decided to place phosphorus fertilizer at 30 cm by boring holes to this depth on a grid (30 cm x 30 cm) and placing the fertilizer at the bottoms of these holes. This

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* Personal Communication by T.J. Rego and K.L. Sahrawat, FSRP, ICRISAT.

Table 2. The physical and chemical characteristics of the soil (0-30 cm) at the experimental site in RA 2.

Characteristic		Value
1.	pH in 1:2.5 soil : water	7.5
2.	E.C., 1:2.5 soil : water	<0.15
3.	Sand (%)	77
	Silt (%)	11
	Clay (%)	12
4.	Organic carbon(%)	0.48
5.	Available nitrogen (ppm)	54
6.	Total Nitrogen (ppm)	385
7.	Available phosphorus (ppm)	<0.1
8.	Exchangeable potassium (ppm)	65
9.	Cation exchange capacity (meq/100g of soil)	11.6

placement is termed "spot placement". To provide a check on the effects of this type of placement on P nutrition, spot placement was compared with banding at 5 cm depth. The effect of moisture regime in the zone of fertilizer placement was examined by using treatments that involved weekly addition of water to the zones.

III.1.1. Treatments

A) No phosphorus + surface water application

B) No phosphorus + subsoil (30-cm depth) water application

C) 20 Kg P/ha, band placement at 5 cm depth + surface water application.

D) 20 Kg P/ha band placement at 5 cm depth + subsoil water application.

E) 20 Kg P/ha spot placement at 5 cm depth + surface water application.

F) 20 Kg P/ha spot placement at 5 cm depth + subsoil water application.

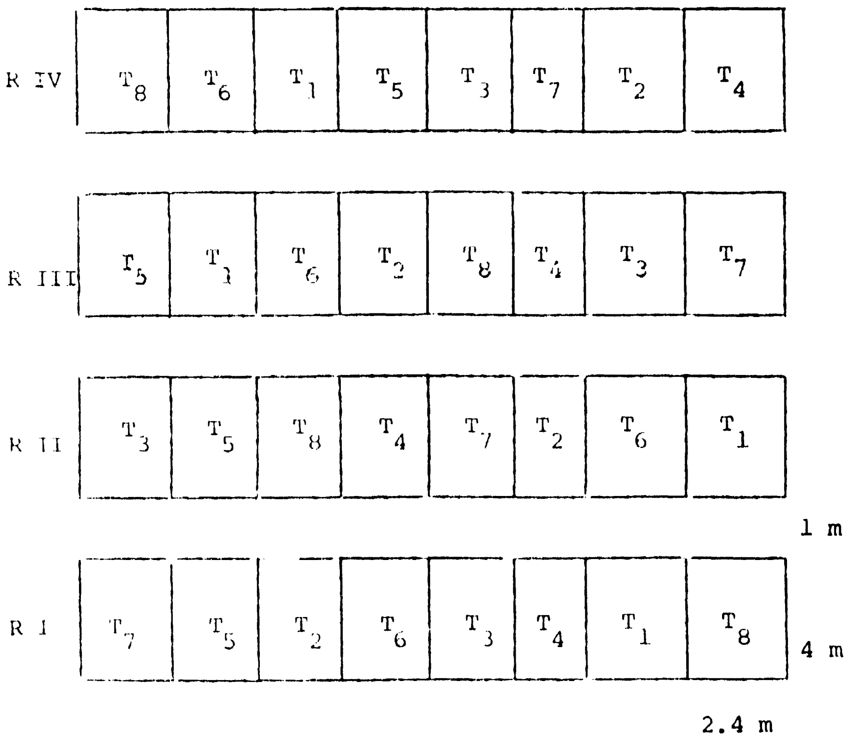
G) 20 Kg P/ha spot placement at 30 cm depth + surface water application.

H) 20 Kg P/ha spot placement at 30 cm depth + subsoil water application.

III.1.2. Experimental design and layout

The eight treatments were arranged in a randomized block design with four replications. Each plot was 4 m x 2.4 m in area and the replications were separated by pathways (see Figure 1) in which pigeonpea was planted in a similar fashion to that on the plots; this was done to minimize edge effects.

Figure 1. Field Layout.



T_1 = No phosphorus + surface water application

T_2 = No phosphorus + subsurface water application

T_3 = 20 Kg P/ha placed at 5 cm depth as band + surface water application.

T_4 = 20 Kg P/ha placed at 5 cm depth as band + subsurface water application.

T_5 = 20 Kg P/ha at 5 cm depth as spot placement + surface water application.

T_6 = 20 Kg P/ha at 5 cm depth as spot placement + subsurface water application.

T_7 = 20 Kg P/ha at 30cm depth as spot placement + surface water application.

T_8 = 20 Kg P/ha at 30 cm depth as spot placement + subsurface water application.

III.1.3. Land preparation, sowing and crop management

The land was ploughed with a tractor and shaped into a ridge-and-furrow system of 60 cm amplitude on 14th November 1979. On the following day, pigeonpea (C-11, a medium-duration variety) was sown as a late rabi* planting. The seed was treated with Rhizobium culture provided by the pulse microbiology sub-program at ICRISAT.

The sowing pattern was designed so that the eventual pigeonpea crop consisted of rows 30 cm apart with the rows being located 15 cm from the peak of a ridge. That is, there were 2 rows on each ridge. Plants were located 10 cm apart in the rows. This pattern was achieved by sowing at twice (56.6 kg/ha) the normal seed rate (28.3 kg/ha) for a rabi planting, and later thinning the population to a 10-cm inter-plant distance within a row. Thinning was completed on 7th December 1979.

III.1.4. Fertilizer application technique

Holes of 30 cm depth were bored at 30 cm intervals along the peak of the ridges in all plots, on 29th November 1979, to allow for fertilizer application at that depth and water application (during the crop growth) in those treatments that required them. For making the holes a Vehrmeyer soil sampling tube of 1¼" outside diameter was used. The upper portion of each hole was plugged with a piece of bamboo to prevent the sides of the holes from collapsing after application of fertilizer and water. Phosphate fertilizer in the form of sodium dihydrogen phosphate (Analytical Reagent Grade) was applied at the rate of 20 kg P/ha to treatments C to H. Fertilizer was applied on 8th

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* See appendix 1 for weather data.

December 1979; the quantity applied per plot was 96.7 g. This method of application was:

i) Band placement at 5-cm depth: A uniform furrow was opened at 5 cm depth between the two holes on the ridge, without disturbing the holes; fertilizer P was applied in the furrow, then the furrow was closed.

ii) Spot placement at 5-cm depth: One hole of 5-cm depth was made halfway between deep holes along the ridge; fertilizer P was applied uniformly in all spots, which were then covered with soil.

iii) Spot placement at 30 cm depth: For this purpose, the holes already bored upto 30 cm depth were used. Fertilizer P was applied in the solution form by dissolving 96.7 g of sodium dihydrogen phosphate in water to result in 1040 ml of solution, and 20 ml of the solution was applied to the bottom of each hole with the aid of a long-stemmed funnel. A quantity of water, equal to the solution applied to the phosphorus treatment (30 cm depth), was added to all other holes to compensate the effect of water added to apply P in the solution. The top of each bamboo tube was covered with a piece of polythene sheet, and secured in place with a rubber band.

III.1.5. Water application

Moisture treatments were imposed immediately after fertilizer application. Water (100 ml) was added to the bottom of the holes on the appropriate plots for the subsoil water application treatments (B,D,F, and H). For the surface water application treatments, the same amount of water was applied to the surface of the soil immediately above the site of the application of fertilizer at the 5 cm depth. These water applications were continued at weekly intervals till the pods had matured.

The above water applications were made at weekly intervals, as treatments. But, apart from these, it was necessary to give a general irrigation to the whole experimental area on two occasions, because plants wilted. Two light (3.2 cm) furrow irrigations (on 18th Jan and 18 Feb) were therefore made to the whole experimental area.

III.1.6. Plant sampling and final harvest

Harvests were made on two occasions. The first, 60 days after emergence, was made by cutting a one meter length of row from each plot. The leaves and stems were separated, dried at 60^{o}C, weighed, then ground for chemical analysis.

The crop was harvested at maturity on March 26, 1980 by cutting an area of 1.2 x 3 m on each plot. The grain, leaves, stems and pods were separated prior to drying and weighing. Pods were included with stems for convenience.

III.1.7. Laboratory methods for analysis of soil and plant tissue

The soil over the experimental area was sampled by taking 25 random cores from a depth of 0-30 cm, and compositing these into one sample. This bulk sample was airdried, and ground to pass a 2 mm sieve before analysis. There were no stones or gravel.

Soil pH of a soil suspension in water was measured using a glass electrode pH meter (ELICO reference electrode). Salt content of the soil water suspension was measured by using electrical conductivity bridge. For both measurements a soil : water ratio of 1:2.5 was used (Jackson, 1967).

Organic carbon was determined by Walkley and Black method as described by Allison (1965) and cation exchange capacity was determined by the sodium acetate (pH 8.2) method outlined by Jackson (1967). Exchangeable potassium was determined by atomic absorption spectrophotometer after extraction with 1 N neutral ammonium acetate solution.

Available nitrogen and phosphorus were determined by the alkaline permanganate method outlined by Subbiah and Asija (1956) and by the sodium bicarbonate method as described by Olsen and Dean (1965), respectively.

Total nitrogen was determined by the modified Kjeldahl method outlined by Jackson (1967). The particle size distribution of the soil was measured using the hydrometer method (Day 1965).

Plant analysis

Plant tissue samples were analysed from all the plots at 60 days and at harvest after separating leaves and stems. The samples were dried at 60°C, ground and analysed for total N and P. Sub-samples were digested with sulphuric acid containing 0.5% selenium at a temperature of 360°C for 1 hr and 15 minutes. Total nitrogen and phosphorus were estimated colorimetrically by using the "Technicon" Auto-analyser II. Nitrogen in the digests was estimated by the indophenol blue method in alkaline medium and phosphorus was estimated by vanadomolybdo phosphoric yellow colour method in acid medium (Industrial method No. 218-72, Technicon Autoanalyser Manual, 1972).

III.2. Results

III.2.1. Effect of P fertilizer on yield of pigeonpea

Placement of phosphorus fertilizer at the 30 cm depth caused an increase in the mean grain yield of pigeonpea about 70% over placement of phosphorus at shallow depth (Table 3a). There was no difference in yield between the control and the treatments involving phosphorus placed at shallow depth. A similar response to phosphorus placement at the 30-cm depth was observed in the total dry matter production at the time of harvest (Table 3c). In contrast there was no significant difference in the dry matter production at 60 days after emergence. Phosphorus placed at the 30 cm depth caused an increase in growth after 60 days, but shallow placement did not affect growth in either the early or late stages.

III.2.2. Effect of water addition and placement of phosphorus on grain yield and dry matter production.

The results in Table 3 show that there was no significant beneficial effect of moistening the zone of phosphorus placement on either grain yield or dry matter production. The interaction between placement and fertilization was significant for grain yield (Table 3 a) but this resulted from an increase in the yield on the control plot when water was placed at 30 cm depth; this therefore resulted in a lesser response to P applied at a depth of 30 cm. Nevertheless, the yields on both treatments receiving phosphorus placed at 30 cm were not significantly affected by the depth at which moisture was applied.

Table 3. Effect of P fertilization, and moistening the zone of P fertilization, on pigeonpea growth:

a) Grain yield
b) Total dry matter at 60 days
c) Total dry matter at harvest

Depth water added	P fertilization: No P applied (control)	20 Kg P/ha, Depth and method of placement: Shallow (5 cm) Band	Shallow (5 cm) Spot	Deep (30 cm) Spot	MEAN	LSD Main effect (P=0.05)	
a) Grain yield (kg/ha)							
*S	132	152	174	349	202	41+	81Ø
*D	244	208	179	291	231		
Mean	188	180	176	320		58++	
b) Total dry matter 60 days after emergence (kg/ha)							
*S	311	363	327	377	344	56+	
*D	284	334	361	337	329		
Mean	297	348	344	357	-	78++	
c) Total dry matter at harvest (kg/ha)							
*S	488	494	422	842	562	94+	
*D	695	604	554	741	649		
Mean	591	549	488	792	-	133++	

*Depth water addition : S = shallow (5 cm); D = deep (30 cm)

+LSD for Main effects water addition

++LSD for Main effect P fertilization

ØLSD for Interaction

Table 5. Effect of P fertilization, and moistening the zone of P fertilization, on phosphorus content of pigeonpea

a) Phosphorus content of leaf at 60 days

b) Phosphorus content of stem at 60 days

c) Phosphorus content of leaf at harvest

d) Phosphorus content of stem at harvest

*Depth water added	P fertilization: No P applied (control)	20 Kg P/ha, Depth and method of placement: Shallow (5 cm) Band	Shallow (5 cm) Spot	Deep (30 cm) Spot	MEAN	LSD Main effect (P=0.05)
a) Phosphorus content of leaf at 60 days (kg P/ha)						
*S	0.42	0.50	0.44	0.67	0.50	0.05^{+}
*D	0.42	0.50	0.50	0.64	0.50	
Mean	0.42	0.50	0.47	0.65	-	0.08^{++}
b) Phosphorus content of stem at 60 days (kg P/ha)						
*S	0.28	0.25	0.19	0.33	0.28	0.05^{+}
*D	0.22	0.25	0.25	0.56	0.31	
Mean	0.25	0.25	0.22	0.44	-	0.11^{++}
c) Phosphorus content of leaf at harvest (kg P/ha)						
*S	0.28	0.22	0.19	0.31	0.25	0.06^{+}
*D	0.22	0.22	0.25	0.42	0.28	
Mean	0.25	0.22	0.22	0.36	-	0.06^{++}
d) Phosphorus content of stem at harvest (kg P/ha)						
*S	0.28	0.19	0.14	0.47	0.28	0.14^{+}
*D	0.17	0.19	0.22	0.56	0.28	
Mean	0.22	0.19	0.19	0.51	-	0.19^{++}

*Depth water addition : S = shallow (5 cm); D = deep (30 cm)

+LSD for Main effect water addition

++LSD for Main effect water addition P fertilization

III.2.8. Phosphorus uptake

Placement of phosphorus fertilizer at 30 cm depth significantly increased the phosphorus content of the grain and the above ground parts of the plant when compared to both the control and shallow phosphorus placement (Table 4). Even though deep placement of phosphorus did not cause a significant increase (over the control) in dry matter production at 60 days after emergence (Table 3b), the phosphorus uptake at 60 days resulting from deep placement (30 cm) was significantly larger than that occurring under shallow placement (Table 4b). This clearly indicates that the phosphorus applied at the 30 cm depth was becoming available for absorption by the plant roots before 60 days after emergence were also significantly increased by the phosphorus application at 30 cm depth, when compared to both the shallow placement and control treatment (Table 5 a-d). There was only one instance of a significant increase due to phosphorus placement at shallow depth; the phosphorus content of the leaf at 60 days was significantly higher where phosphorus had been banded than where phosphorus applied as spot placement at 5 cm depth (Table 5 a).

The phosphorus content of the leaf was appreciably higher than that of the stem at 60-day harvest. There was little difference between the two at final harvest (Table 5). The changes with time in the phosphorus contents of the plant components (leaves and stems) were in agreement with the previous growth analysis studies by Sheldrake and Narayanan (1979). The total phosphorus content of the plant increased from 0.8 to 1.4 kg P/ha between the 60 day and final harvest in main effect. This increase was largely due to

Table 6. Effect of P fertilization, and moistening the zone of P fertilization, on **nitrogen content of pigeonpea**

a) Nitrogen content of grain

b) Total Nitrogen content of the dry matter at 60 days after emergence

c) Ntrogen content of the total dry matter at harvest

Depth water added	P fertilization				MEAN	LSD Main effect (P=0.05)
	No P applied (control)	20 Kg P/ha: Depth and method of placement				
		Shallow (5 cm)		Deep (30 cm)		
		Band	Spot	Spot		
a) Nitrogen content of grain (kg/ha)						
*S	4.61	5.06	5.84	12.20	6.92	1.47^{+} $2.94^{\emptyset}$
*D	8.31	7.17	6.37	9.95	7.95	
Mean	6.48	6.12	6.12	11.09	-	2.09^{++}
b) Total Nitrogen content of the dry matter at 60 days (kg/ha)						
*S	9.62	10.97	9.56	11.71	10.46	1.66^{+}
*D	8.56	9.99	10.91	10.33	9.94	
Mean	9.08	10.48	10.23	11.02		2.35^{++}
c) Nitrogen content of the total dry matter at harvest (kg/ha)						
*S	12.48	11.15	11.26	21.43	14.09	2.17^{+}
*D	15.26	14.23	11.79	19.18	15.62	
Mean	13.87	12.68	12.51	20.32	-	3.03^{++}

*Depth water addition : S = shallow (5 cm); D = deep (30 cm)

$^{+}$LSD for Main effect water addition

$^{++}$LSD for Main effect P fertilization

$^{\emptyset}$LSD for Main interaction

Table 7. Effect of P fertilization and moistening the zone of P fertilization, on nitrogen content of pigeonpea

a) Nitrogen content of leaf at 60 days

b) Nitrogen content of stem at 60 days

c) Nitrogen content of leaf at harvest

d) Nitrogen content of stem at harvest

*Depth water added	P fertilization: No P applied (control)	P fertilization: 20 Kg P/ha, Depth and method of placement, Shallow (5 cm), Band	Shallow (5 cm), Spot	Deep (30 cm), Spot	MEAN	LSD Main effect (P=0.05)
a) Nitrogen content of leaf at 60 days (kg/ha)						
*S	7.17	8.48	7.73	9.45	8.34	1.31+
*D	6.64	7.81	8.51	7.98	7.73	
Mean	6.92	8.15	8.12	8.21	-	1.83++
b) Nitrogen content of stem at 60 days (kg/ha)						
*S	2.45	2.47	1.83	2.25	2.25	0.58+
*D	1.92	2.17	2.42	2.36	2.22	
Mean	2.17	2.34	2.11	2.31	-	0.83++
c) Nitrogen content of leaf at harvest (kg/ha)						
*S	4.39	3.20	2.97	4.11	3.64	0.61+
*D	3.61	3.61	4.11	5.03	4.09	
Mean	4.00	3.39	3.53	4.56	-	0.89++
d) Nitrogen content of stem at harvest (kg/ha)						
*S	2.53	2.00	1.53	3.17	2.31	0.70+
*D	2.11	2.42	2.36	3.00	2.46	
Mean	2.31	2.22	1.95	3.09	-	1.00++

*Depth water addition : S = shallow (5 cm); D = deep (30 cm)

+LSD for Main effect water addition

++LSD for Main effect P fertilization

the formation of grain (containing 0.64 kg P/ha) which increase required phosphorus uptake mainly from the soil. Some translocation* from leaves and stems occurred, because leaf phosphorus content decreased from 0.50 kg P/ha to 0.27 kg P/ha. However, over this period, the exact contribution by translocation from leaves is not accurately known, as estimates were not made for the extent of leaf fall.

III.2.4. Nitrogen content:

The nitrogen content of the pigeonpea whole plants and components showed similar trends to those for phosphorus uptake. The nitrogen content was higher where the phosphorus uptake was higher (Tables 5,6). Placement of phosphorus at the 30-cm depth increased the nitrogen content of the whole plants as well as that of the grain when compared to shallow placement (band as well as spot placement). Addition of phosphorus at shallow depth did not increase the nitrogen content of the plant over that of the control plot.

At 60 days after emergence, the nitrogen content of neither the leaf nor the stem were influenced by the placement of phosphorus at 30 cm depth. At the time of harvest the nitrogen content of the leaf and stem was significantly increased in some comparisons with the placement of phosphorus at 30-cm depth, when compared to shallow placement; but there was no significant difference between the nitrogen contents of the shallow placement treatments and the control (Table 7).

III.3. DISCUSSION.

The field experiment was conducted to investigate whether fertilizer phosphorus is best utilized when it is applied at depth in the soil, and

*Concentration of nutrients in plant components show a decline with age (see appendix 2 and 3).

also to determine if the moisture content in the zone of placement (especially close to the soil surface) had any effect on the phosphorus nutrition of pigeonpea. The results show that deep placement of phosphorus at (30-cm depth) significantly increased grain yield and dry matter yield at harvest when compared to shallow placement (Table 3). However, the shallow placement (band and spot placement) of phosphorus resulted in very similar results to those for the control for most of the observations e.g. phosphorus uptake, nitrogen uptake, dry matter production and grain yields (Tables 3-7). Ahlawat et al (1975) obtained somewhat similar results, with only a small increase in yield for shallow placement, but significant and much larger increase for deep placement.

The data obtained in this study thus clearly indicated that phosphorus application just below the soil surface was not useful to the post-rainy season pigeonpea crop, even on a soil that was of very low phosphorus status. The reason is not clear. Nevertheless the lack of a significant effect of moistening the zone of fertilizer application, especially where this was in the surface soil, shows quite clearly that lack of response of pigeonpea to phosphorus was not due to dryness of the surface soil.

The lack of response to surface applied phosphorus may be a consequence of the deep tap root system of pigeonpea. With advancement in age of the plant, the roots penetrate deeper into the soil. In this experiment, phosphorus fertilizer was applied 15 days after emergence of the seedlings. For this 15-day period, the roots actually involved in phosphorus uptake might have grown deeper than a 5-cm depth in the soil, thus causing the zone of active root extention to be sited below the zone of phosphorus application. The marked increase in uptake of phosphorus within 60 days of emergence from the plots where phosphorus was placed at 30 cm indicates that the phosphorus at this depth was accessable to roots, whereas the lack of uptake from phosphorus placed at shallow depth (5 cm) shows that this phosphorus was not accessable to any appreciable extent. The earlier work of Singh and Prasad (1976) has showed that long duration pigeonpea takes up much of its phosphorus in the late stages of growth; over two-thirds of the phosphorus content at harvest (16 kg P/ha) of long duration pigeonpea was taken up after 90 days. The large uptake of phosphorus in the later stages of the growth would therefore seem to have occurred from roots located deep in the soil; it is therefore assumed that these were the only part of the root systems that was actively taking up phosphorus.

However, it is interesting to compare these results with those of Nye and Foster (1961) who studied the phosphorus uptake patterns as affected by the distance and depth of phosphorus application for maize, pigeonpea and millet plants. Although Nye and Foster showed that the phosphorus was taken up from the subsurface layers (below 25 cm), this uptake contributed only about 11% to the total uptake at 80 days in one year, and 22% to the total uptake after four months in the second year. The reason why, in Nye and Foster's experiment, there was not a greater uptake from greater depths in the soil is not clear. But it would appear to have been due to the fact that measurements were made only in the earlier stages of growth, when phosphorus uptake by pigeonpea can be assumed to have been small (See Singh and Prasad 1976) and the root system had not developed at depth. Another reason for relatively little phosphorus uptake from the deeper layer in Nye and Foster's experiment might be that water was not a limiting factor in their plots and therefore the rooting system might not have been as fully developed as under drier conditions.

In discussion of their earlier work, Nye & Foster (1958) drew attention to the fact that some plant species may be more efficient than others in extracting phosphorus from a soil, by a mechanism independent of depth of rooting. For example, some plants may be able to absorb phosphorus from soils whose phosphate is at a very low potential, and to absorb phosphorus which would not be available to a plant that is less efficient at extracting phosphorus from the soil.

Experiments at ICRISAT have shown that the order of responsiveness to phosphorus was sorghum > millet > pigeonpea. It may be inferred, therefore, that the ability of these species to satisfy their phosphorus requirement can be ranked pigeonpea > millet > sorghum. There are a number of possible different mechanisms: (i) First, the amount of total growth (dry matter production) and phosphorus uptake were in order of sorghum > millet > pigeonpea. The difference in uptake could therefore have arisen mainly from the fact that the soil could supply only a certain amount of phosphorus, and the responsiveness of a species was determined by its phosphorus demand for growth (ii) Second, the present experiment shown that the post-rainy season pigeonpea responds better to phosphorus if this has been placed at depth (30-cm) rather than in the surface soil (5-cm). The hypothesis raised by earlier workers must be considered; that is, that deep exploration of the soil profile by roots may be one of the mechanisms by which pigeonpea can grow better than other species on soils low in phosphorus. Yet sorghum responds to application of phosphorus at a depth of 5 cm; therefore it seems possible that there are differences between species in the depth at which roots take up phosphorus. In fact, the lesser phosphorus response by pigeonpea in agronomic response-to-phosphorus experiments may have resulted from the fact that the fertilizer was not placed at the optimum depth for phosphorus uptake by pigeonpea. (iii) Nye and Foster (1958) have raised the point that species differ in the ability to extract phosphorus from soil. The content of available phosphorus of subsoils is usually very low, and for effective uptake from subsoils, the roots may have to be more efficient at extracting phosphorus than those of a plant that obtains its phosphorus from surface soil. Thus, it can be inferred that deep exploration of the profile may be one mechanism by which pigeonpea is more efficient than other species at gathering phosphorus. However, there is also need to compare, against sorghum, its ability to extract phosphorus from soil to test whether it is also more efficient in removing phosphorus from a low phosphorus status soil.

IV. GLASS HOUSE EXPERIMENT

_ , To test the suggestions that pigeonpea could perhaps extract more phosphorus than sorghum from soil that had a very low phosphorus status, it was decided to conduct a pot experiment in the glass house. It was decided to compare growth and uptake of phosphorus, by growing these two species separately in a limited volume of soil; the latter was aimed at ensuring that the plant demand on the soil phosphorus supplies would be great; additionally it was decided to vary the populations in the pots, so that variable demands would be placed on soil P supplies by each species. By also examining the response to phosphorus fertilizer, the ability of the two species to satisfy their phosphorus requirements could be evaluated.

An experiment was therefore undertaken to observe the uptake of phosphorus and dry matter production in the early stages of growth (upto 40 days after emergence of the seedlings) both in pigeonpea and sorghum, with and without phosphorus addition, and with a range of populations in the pots.

IV.I. Materials and methods:

A bulk sample of soil was collected from the 0-15 cm depth from the field containing the field experiment (RA2). The sandy loam soil was lightly ground to pass a 2 mm sieve. Pots of 1 litre capacity were filled with 1.00 kg of the bulk sample of soil; the pots used were small plastic buckets with a drainage hole at the bottom.

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The treatments imposed for duplicate experiments on sorghum and pigeonpea were:

Phosphorus fertilizer (2) : Nil, and 20 ppm P added (W/W soil)

Populations (3) : Sorghum 2,5,12 plants/pot

Pigeonpea 4,10,25 plants/pot

A factorial design (2 fertilizer levels x 3 population densities) was used for each species with 5 replications; the pots were arranged in randomized blocks. These two groups of pots were designed to be harvested at 40 days after emergence. An additional set of pots were set up to provide an additional harvest for sorghum at 20 days after emergence of the seedlings.

The carrier for phosphorus was sodium dihydrogen phosphate, which was applied to the soil as an aqueous solution with thorough mixing prior to filling pots. Water was similarly mixed with the control pots. Pigeonpea and sorghum were sown on 6th and 14th March 1980, respectively. Pigeonpea was treated with Rhizobium culture, and 50 ppm of nitrogen (applied as urea) was applied to the sorghum. Emergence was observed on 14th and 20th March for pigeonpea and sorghum respectively; the populations were then thinned to the desired number of plants per pot. Deionized water was applied daily to compensate for loss of moisture by evapotranspiration. The above ground portions of plants were harvested at 20 and 40 days for sorghum, and at 40 days for pigeonpea. The plant tissue was dried, weighed, and ground. Analyses for nitrogen and phosphorus were made using the methods described earlier.

IV.2. RESULTS

IV.2.1. Dry matter production:

The dry matter production of sorghum at 20 and 40 days and at all populations was markedly and was significantly increased (2½-5 fold) by the application of phosphorus to the soil (Table 8 a,b). It also increased with increase in population. At both harvests, the percentage increase in dry matter production over the control was greater at lower plant populations than at higher plant populations. In contrast, pigeonpea dry matter production did not increase significantly with phosphorus application (Table 8 c).

IV.2.2. Nutrient uptake

Uptake of phosphorus by sorghum at 20 days and 40 days after emergence was markedly (3½-7 fold) increased by the fertilizer phosphorus application (Table 9). Phosphorus uptake also increased with increase in population. Uptake of phosphorus by pigeonpea was significantly increased by the addition of phosphorus fertilizer, but the magnitude of the increase was only small (30%).

Nitrogen uptake was also significantly influenced by phosphorus application to sorghum. Nitrogen uptake by pigeonpea was significantly increased by an increase in plant population but not by addition of phosphorus fertilizer (Table 10). The concentration of nitrogen in sorghum at 20 days was significantly increased by phosphorus application and increased plant population, whereas at 40 days it increased only as a result of fertilizer application (see appendix 4 and 2)

Table 8*. Effect of P fertilization and different plant populations on:

a) Drymatter production of sorghum at 20 days after emergence

b) Drymatter production of sorghum at 40 days after emergence

c) Dry matter production of pigeonpea at 40 days after emergence

Population (Plants/pot)	P fertilization: No. P applied (control)	P fertilization: P applied 20 ppm	MEAN	LSD Main effect (P=0.05)	
a) Drymatter production of sorghum at 20 days after emergence (g/pot)					
2	0.15	0.52	0.34		
5	0.34	1.20	0.77	0.14^{+}	$0.20^{Ø}$
12	0.73	1.83	1.28		
Mean	0.41	1.81	-	0.11^{++}	
b) Drymatter production of sorghum at 40 days after emergence (g/pot)					
2	0.52	2.83	1.68		
5	0.70	3.46	2.08	0.38^{+}	
12	1.34	4.07	2.70		
Mean	0.85	3.45	-	0.31^{++}	
c) Drymatter production fo pigeonpea at 40 days after emergence (g/pot)					
4	1.24	1.43	1.34		
10	2.39	2.39	2.39	0.58^{+}	
25	3.94	2.83	3.39		
Mean	2.52	2.21	-	0.47^{++}	

$^{+}$LSD (P = 0.05) for Main effect of population

$^{+}$LSD (P = 0.05) for Main effect of P fertilization

^{Ø}LSD (P = 0.05) for interaction

*For result on per plant basis, see appendix 6.

Table 10.* Effect of P fertilization and different plant populations on:

a) Nitrogen content of sorghum at 20 days after emergence

b) Nitrogen content of sorghum at 40 days after emergence

c) Nitrogen content of pigeonpea at 40 days after emergence

Population (Plants/pot)	P fertilization: No P applied (control)	P fertilization: P applied 20 ppm	MEAN	LSD Main effect (P=0.05)	
a) Nitrogen content of sorghum at 20 days after emergence (mg/pot)					
2	4.59	12.31	8.45		
5	9.34	25.10	17.22	2.80+	3.96Ø
12	17.52	32.54	25.03		
Mean	10.48	23.32	-	2.29++	
b) Nitrogen content of sorghum at 40 days after emergence (mg/pot)					
2	9.61	27.72	18.66		
5	12.76	33.02	22.39	3.11+	4.40Ø
12	22.50	31.40	26.95		
Mean	14.96	30.38	-	2.54++	
c) Nitrogen content of pigeonpea at 40 days after emergence (mg/pot)					
4	34.18	43.23	38.70		
10	57.39	77.29	67.34	23.02+	
25	110.56	77.61	94.09		
Mean	67.38	66.04	-		

+LSD (P = 0.05) for Main effect of population

++LSD (P = 0.05) for Main effect of P fertilization

ØLSD (P = 0.05) for interaction

*For results on per plant basis see appendix 6.

IV.3. Discussion

The results clearly show that phosphorus fertilization increased sorghum dry matter production by 2½-5 fold, but not that of pigeonpea. The phosphorus uptake by sorghum increased (3½-6 fold) as a result of phosphorus fertilization, whereas this caused only a small increase in uptake of phosphorus by pigeonpea. In addition, pigeonpea growth did not respond to phosphorus fertilization. The growth of pigeonpea with and also without added phosphorus was almost the same as that of phosphorus-fertilized sorghum, and these were several fold greater than the growth of unfertilized sorghum. Phosphorus uptake by unfertilized pigeonpea was only little less than that of sorghum at 40 days with phosphorus application, but 7-14 fold greater than that of unfertilized sorghum.

These results clearly show pigeonpea was much more efficient than sorghum at extracting phosphorus from a soil that was very low in phosphorus. Pigeonpea could not only extract much more phosphorus from unfertilized soil but this amount appeared to be sufficient to satisfy its phosphorus requirement for normal growth.

V. CONCLUDING DISCUSSION

The field experiment results clearly showed that deep (30 cm) placement of phosphorus increased grain yield, dry matter production and phosphorus uptake of pigeonpea. The increased growth as a result of deep placement was only apparent during the later period of growth of the pigeonpea crop that is, between the 60 day harvest and the final harvest. These beneficial effects of deep placement were in general agreement with previous work, but it was somewhat surprising that there was no response whatsoever compared to the control or to phosphorus placed at shallow depth. Most previous work has involved relatively shallow placement.

The response to placement of phosphorus at the 30 cm depth would appear to have been a consequence of the deep tap rooting system of pigeonpea. It would seem that at shallow depth, there was relatively little branching and development of new roots with the ability to absorb phosphorus, and that active uptake occurred only by the new roots associated with extension of the root system. In this present work some excavation of root systems were made at the time of maturity of the plants; these showed the presence of roots to as deep as 40 cm but no clear evidence could be obtained to indicate whether there was a greater root density in the vicinity of the site of fertilizer application; however, very few roots were detected in the surface soil (0-10 cm).

The finding that moisture relations did not influence the efficiency of the use of phosphorus fertilizer is of considerable interest and importance. For some time there has been considerable interest in the effects of moisture content of surface soils on the availability of phosphorus.

The additional experiment conducted in the glass house clearly showed that, in addition to its ability to obtain phosphorus by root interception, pigeonpea was much more efficient than sorghum at extracting phosphorus from a soil that has a very low content of available phosphorus. When the results of the field and glasshouse experiments are considered together, it can be concluded that the pigeonpea plant obviously possesses two mechanisms that assist it to grow better than sorghum on soils that are relatively low in available phosphorus: these are the ability to obtain phosphorus from deep in the soil, and ability to obtain more phosphorus than sorghum from soils low in phosphorus.

However, some caution is required in the interpretation and use of the results. In the field experiment the yields were very low due to poor growth of the crop, mainly because of very late planting in the post rainy season. Although deep placement (30-cm) increased yields markedly - from 180 to 320 kg/ha - these yields were small. It is desirable to repeat this type of experiment in the kharif season, when yields and demand for phosphorus will be much greater. Additionally, because deep placement has given a beneficial effect, it should not be inferred that placement at such a depth is advocated for general practice. The aim of the present study was to improve our understanding of the way in which pigeonpea can grow efficiently in soils of low phosphorus status.

Useful positive evidence has been provided by the results. The Pulse Program at ICRISAT has for some time investigated the nutrition of pigeonpea, and deduced that lack of responses to phosphorus were probably due to its ability to forage for nutrients at depth in the soil. But, verification was hindered by the difficulty of finding sites with sufficiently low phosphorus status that phosphorus was limiting for pigeonpea. This was needed to allow measurement of growth and phosphorus uptake responses. The site used in this study was extremely low in available phosphorus - it contained 0.1 ppm in the 0-30 cm depth or only about 0.2 kg available phosphorus per hectare 30 cm. The positive results obtained confirm the need to use extremely phosphorus deficient soil for investigating the phosphorus nutrition of pigeonpea. A soil with some history of phosphorus fertilization may not be adequate, as this plant is very efficient at obtaining phosphorus from the soil.

VI. SUMMARY & CONCLUSIONS

Experiments were initiated in the field and glasshouse to investigate the effect of placement of phosphorus at depth in the soil, and to determine if the soil moisture regime of the zone of fertilizer placement played an important role in the nutrition of pigeonpea. Previous work had indicated that pigeonpea may require relatively little fertilizer phosphorus, even on soils of low phosphorus status; the present study represented an attempt to clarify the mechanisms responsible.

The results obtained, in a late-sown postrainy season field experiment with the medium-duration C-11 variety, showed that phosphorus placed deep in the soil (30 cm) caused a significant increase in yield, total dry matter production, and phosphorus uptake when compared to the control treatment. There was no response to phosphorus fertilizer placed at shallow depth (5 cm). Moistening the fertilizer zone did not result in any improvement in response. There was therefore no evidence in favor of the earlier hypothesis that suggested that lack of moisture in the surface soil was a factor causing a lack of response by pigeonpea to phosphorus. Instead, it is now postulated that the deep tap rooting system of pigeonpea may favor uptake of phosphorus from deep in the soil (e.g. 30 cm) because the uptake of phosphorus occurs mainly by new roots which are located deeper in the soil with increasing age of the plant.

An additional experiment was conducted in the glasshouse to compare the ability of pigeonpea and sorghum to absorb phosphorus from soil of very low phosphorus status. The results confirm that pigeonpea is more efficient than sorghum at extracting phosphorus from a low phosphorus status soil. Therefore it is suggested that the root system of pigeonpea may be much more efficient at absorbing phosphorus from subsoils than that of sorghum.

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APPENDIX.1.

Meterological information during the period of experimentation

Weeks after emergence	Mean weekly rainfall (mm)	Mean weekly maximum temp °C	Mean weekly minimum temp °C	Mean weekly humidity 0714 hr	Mean weekly humidity for week 1414 hrs
-1	0	28.8	19.5	87	48
0	1.4	27.6	19.2	92	57
1	1.2	27.8	19.1	92	56
2	0	28.3	16.3	90	45
3	0	27.4	14.9	82	38
4	0	28.3	15.6	86	40
5	0	27.4	14.6	86	38
6	0	28.1	13.3	85	33
7	0	28.3	16.7	83	41
8	0	28.2	13.7	85	33
9*	0	29.0	14.6	79	29
10	0	30.2	14.9	73	29
11	0	30.2	16.9	69	31
12	0	31.0	17.9	84	38
13*	0	32.4	18.0	76	32
14	0	34.5	18.0	65	31
15	0	35.2	17.4	68	19
16	0	34.6	20.3	68	34
17	1.2	34.0	19.6	74	38
18	0	37.1	20.9	54	25

* light (3.2 cm) furrow irrigationswere given in these weeks.

Appendix. 2. Mean nutrient concentrations of pigeonpea plant tissue at 60 days after emergence[+]

a) Phosphorus concentration (%) in leaf
b) Phosphorus concentration (%) in stem
c) Nitrogen concentration (%) in leaf
d) Nitrogen concentration (%) in stem

*Depth water added	No P applied (control)	P fertilization 20 Kg P/ha — Depth and method of placement		
		Shallow (5 cm)		Deep (30 cm)
		Band	Spot	Spot
a) Phosphorus concentration (%) in leaf				
*S	0.24	0.23	0.23	0.29
*D	0.24	0.24	0.25	0.34
b) Phosphorus concentration (%) in stem				
*S	0.19	0.17	0.15	0.24
*D	0.19	0.17	0.16	0.34
c) Nitrogen concentration (%) in leaf				
*S	4.1	4.1	4.0	4.2
*D	4.1	4.0	4.1	4.2
d) Nitrogen concentration in stem				
*S	1.7	1.7	1.3	1.5
*D	1.6	1.5	1.6	1.6

* Depth water addition : S = Shallow (5 cm); D = Deep (30 cm)

+ Data not analysed statistically.

Appendix. 3. Mean nutrient concentration of pigeonpea plant tissue at the time of harvest.+

a) Phosphorus concentration in leaf
b) Phosphorus concentration in stem
c) Phosphorus concentration in grain
d) Nitrogen concentration in leaf
e) Nitrogen concentration in stem
f) Nitrogen concentration in grain.

*Depth water added	No P applied (control)	P fertilization 20 Kg P/ha Depth and method of placement Shallow (5 cm) Band	Spot	Deep (30 cm) Spot
a) Phosphorus concentration (%) in leaf				
*S	0.18	0.16	0.17	0.19
*D	0.15	0.16	0.17	0.23
b) Phosphorus concentration in stem				
*S	0.18	0.13	0.12	0.24
*D	0.09	0.11	0.15	0.28
c) Phosphorus concentration (%) in grain				
*S	0.34	0.32	0.32	0.37
*D	0.31	0.34	0.35	0.39
d) Nitrogen concentration (%) in leaf				
*S	2.9	2.5	2.6	2.7
*D	2.6	2.7	2.7	2.8
e) Nitrogen concentration (%) in stem				
*S	1.7	1.4	1.3	1.6
*D	1.1	1.3	1.5	1.6
f) Nitrogen concentration (%) in grain				
*S	3.5	3.3	3.3	3.5
*D	3.4	3.5	3.6	3.4

* Depth water addition : S = Shallow (5 cm); D = Deep (30 cm)

\+ Data not analysed statistically.

Appendix. 4. Effect of P fertilization and different plant populations on:

a) Phosphorus concentration (%) of sorghum at 20 days after emergence.
b) Phosphorus concentration (%) of sorghum at 40 days after emergence.
c) Phosphorus concentration (%) of pigeonpea at 40 days after emergence.

Population (Plants/pot)	P fertilization No P applied (control)	P applied 20 ppm	MEAN	LSD Main effect (P-0.05)
a) Phosphorus concentration (%) of sorghum at 20 days after emergence.				
2	0.07	0.11	0.09	
5	0.06	0.12	0.09	0.02+
12	0.06	0.10	0.07	
Mean	0.06	0.11	-	0.01++
b) Phosphorus concentration (%) of sorghum at 40 days after emergence.				
2	0.09	0.11	0.1	
5	0.08	0.11	0.1	0.01+
12	0.06	0.10	0.08	
Mean	0.07	0.11	-	0.01++
c) Phosphorus concentration (%) of pigeonpea at 40 days after emergence.				
4	0.17	0.22	0.20	
10	0.11	0.20	0.16	0.02+
25	0.15	0.19	0.17	
Mean	0.14	-.21	-	0.02++

\+ LSD (P = 0.05) for Main effect of population

++ LSD (P = 0.05) for Main effect of P fertilization.

Appendix. 5. Effect of P fertilization and different plant population on:

a) Nitrogen concentration (%) of sorghum at 20 days after emergence.
b) Nitrogen concentration (%) of sorhgum at 40 days after emergence.
c) Nitrogen concentration (%) of pigeonpea at 40 days after emergence.

Population (Plants/pot)	No P applied (control)	P applied 20 ppm	MEAN	LSD Main effect (P-0.05) ~
a) Nitrogen concentration (%) of sorghum at 20 days after emergence.				
2	3.18	2.49	2.83	
5	2.80	2.11	2.45	0.30+
12	2.39	1.78	2.09	
Mean	2.78	2.13		0.24++
b) Nitrogen concentration (%) of sorghum at 40 days after emergence.				
2	1.91	0.98	1.45	
5	1.86	1.09	1.48	0.22+
12	1.71	0.78	1.25	
Mean	1.83	0.95		-
c) Nitrogen concentration (%) of pigeonpea at 40 days after emergence.				
4	2.63	3.21	2.77	
10	2.32	3.21	2.77	-
25	2.79	2.62	2.70	
Mean	2.58	2.92	-	0.31++

+ LSD (P = 0.05) for Main effect of population

++ LSD (P = 0.05) for Main effect of P fertilization.

APPENDIX 6.

Effect of P fertilization and different plant populations on:

a) Dry matter production of sorghum at 20 days after emergence.

b) Dry matter production of sorghum at 40 days after emergence.

c) Dry matter production of pigeonpea at 40 days after emergence.

Population (Plants/pot)	P fertilization: No. P applied (control)	P fertilization: P applied 20 ppm	MEAN
a) Drymatter production of sorghum at 20 days after emergence (g/plant)			
2	0.08	0.26	0.17
5	0.07	0.24	0.16
12	0.06	0.15	0.11
Mean	0.07	0.22	
b) Drymatter production of sorghum at 40 days after emergence (g/plant)			
2	0.26	1.42	0.84
5	0.14	0.69	0.42
12	0.11	0.34	0.23
Mean	0.17	0.82	-
c) Drymatter production of pigeonpea at 40 days after emergence (g/plant)			
4	0.31	0.36	0.34
10	0.24	0.24	0.24
25	0.16	0.11	0.14
Mean	0.24	0.24	-

APPENDIX 7.

Effect of P fertilization and different plant populations on:

a) Phosphorus content of sorghum at 20 days after emergence

b) Phosphorus content of sorghum at 40 days after emergence

c) Phosphorus content of pigeonpea at 40 days after emergence

Population (Plants/pot)	P fertilization No P applied (control)	P applied 20 ppm	MEAN
a) Phosphorus content of sorghum at 20 days after emergence mg/plant)			
2	0.05	0.29	0.17
5	0.04	0.29	0.17
12	0.04	0.14	0.09
Mean	0.04	0.24	-
b) Phosphorus content of sorghum at 40 days after emergence (mg/plant)			
2	0.22	1.59	0.91
5	0.11	0.80	0.46
12	0.06	0.33	0.20
Mean	0.13	0.91	-
c) Phosphorus content of pigeonpea at 40 days after emergence (mg/plant)			
4	0.50	0.77	0.64
10	0.26	0.49	0.38
25	0.23	0.21	0.22
Mean	0.33	0.49	-

APPENDIX 8.

Effect of P fertilization and different plant populations on:

a) Nitrogen content of sorghum at 20 days after emergence

b) Nitrogen content of sorghum at 40 days after emergence

c) Nitrogen content of pigeonpea at 40 days after emergence.

Population (Plants/pot)	P fertilization: No P applied (control)	P fertilization: P applied 20 ppm	MEAN
a) Nitrogen content of sorghum at 20 days after emergence (mg/plant)			
2	2.30	6.16	4.23
5	1.87	5.02	3.45
12	1.46	2.71	2.09
Mean	1.88	4.63	-
b) Nitrogen content of sorghum at 40 days after emergence (mg/plant)			
2	4.81	13.86	9.34
5	2.55	6.60	4.58
12	1.88	2.62	2.25
Mean	3.08	7.69	-
c) Nitrogen content of pigeonpea at 40 days after emergence (mg/plant)			
4	8.55	10.81	9.68
10	5.74	7.73	6.74
25	4.42	3.10	3.76
Mean	6.24	7.21	-