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CHARACTERISTICS OF PHOSPHORUS UPTAKE OF CHICKPEA IN COMPARISON WITH PIGEONPEA, SOYBEAN, AND MAIZE

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Phosphorus depletion curves were used to compare the P uptake characteristics of roots of chickpea, pigeonpea, soybean, and maize in solution culture. Half-maximal P uptake rates (*Km*) were attained at lower concentrations of P in the solution in chickpea and pigeonpea. These species also absorbed P less rapidly than maize or soybean at higher concentration of P in the solution. However, the differences in the kinetic parameters could not adequately account for the lack of response of chickpea to P fertilizer on soils with <1 μM P in the soil solution. Further mechanisms by which P uptake efficiency in chickpea is enhanced, such as development of root hairs, role of mycorrhizae and the ability to solubilize soil P, would have to be considered.

Key Words: phosphorus uptake, chickpea, pigeonpea, soybean.

The yield response of chickpea to phosphorus (P) fertilizer is low compared to that of cereal crops such as maize (7). In the deep black soils (Vertisols) of India chickpea often fails to respond to P even when available soil P levels (Olsen P) are below 2 ppm (N.P. Saxena, personal communication). This may be due to the fact that chickpea is normally grown under conditions of receding soil moisture, and P applied at or near the soil surface may not be available to the plant when the soil dried out. Alternatively, chickpea may have particular mechanisms which allow it to meet its P requirement even when the levels of available P in soil are low.

This study examines the latter possibility by measuring some physiological characteristics of P absorption by chickpea in comparison with three other crop species.

MATERIALS AND METHODS

The four test species used in this study were chickpea (*Cicer arietinum* L. cv. K 850), pigeonpea (*Cajanus cajan* (L.) Millsp. cv. ICPL 87), soybean (*Glycine max* (L.)

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Merr. cv. JS 72-44), and maize (*Zea mays* L. cv. Deccan 103). Like chickpea (*7*), soybean is less responsive to P fertilizer than maize (*4*).

Seeds of the test crops were germinated in washed sand and transferred to a solution culture. The composition of the nutrient solution was (μM): N 3,100, P 200, K 1,300, Ca 800, Mg 600, S 600, B 5, Mn 1.3, Zn 0.1, Cu 0.1, Mo 0.04, and Fe (as EDTA-Fe) 25. The solution was continually aerated and changed when its volume or electrical conductivity decreased. Four plants of the same species were grown in each container. The volume of the nutrient solution in each pot was initially 2 liters and was increased to 4 liters after 24 or 33 days, depending on the size of the plants. The study was conducted in a greenhouse at 35°C maximum and 15°C minimum temperatures.

For experiments to measure P depletion from the nutrient solution, plants were initially transferred to P-free nutrient solutions for 24 h either 24 or 39 days after sowing. The plants were then transferred to a nutrient solution containing 20 μM P and P-absorption characteristics were measured using the depletion method (*2*). The absorption solution was labelled with ^{32}P and the rate of P depletion from the nutrient solution was measured by frequent assays of solution samples for Cherenkov radiation (*3*). After following the P depletion over 24 h the plants were harvested and their dry weights, root lengths, and root radii measured. In addition to harvests performed after the depletion experiments, an unreplicated harvest was also made at 13 days.

Soil solution extracts were taken from: i) a Vertisol from an ICRISAT field that had not received P fertilizer and that contained a low level of available P, ii) a Vertisol from an ICRISAT field that had received 150 kg P_2O_5/ha in the previous year, and iii) an alluvial soil from Gwalior that contained a moderate level of available P. The soil samples were moistened to field capacity and the soil solution was obtained by partial displacement (*1*). The P content of the eluent was measured using the ascorbic acid method (*8*).

RESULTS

The test plants, particularly maize, showed some yellowing in their early growth stages but this symptom disappeared one week after the transfer to the solution culture, and plant growth appeared normal thereafter. Plant growth parameters are shown in Table 1. Logistic growth curves fitted well to dry matter data (Fig. 1).

A typical depletion curve is shown in Fig. 2. The P concentration of the nutrient solution decreased rapidly for about the first hour. The rate then steadied for a few hours until the solution was almost depleted. A finite concentration of P always remained in the nutrient solution and this is indicated as C_{min} in Table 2. The values of this parameter differed depending on the species, with soybean causing most depletion and pigeonpea least.

Phosphorus uptake characteristics were obtained by plotting the values of P uptake rate/concentration against P uptake rate of the depletion data along Hofstee plots

Table 1. Total dry matter, root length, average root diameter, root surface area, and ratio of total weight to root surface area of plants grown in the depletion experiments.

Crop species	Total dry matter (g)	Root length (m)	Average root radius (mm)	Root surface area (10^2 cm^2)	Total weight to root surface area ratio (10^{-2} g·cm^{-2})
13 days					
Chickpea	1.1	1.2	0.425	3.14	0.35
Pigeonpea	0.45	6.5	0.295	1.20	0.38
Soybean	0.77	17.5	0.260	2.86	0.27
Maize	1.27	41.1	0.224	5.77	0.22
26 days					
Chickpea	2.5±0.1[a]	43±4	0.361±0.013	9.7±0.7	0.26
Pigeonpea	4.8±0.1	145±15	0.237±0.022	21.3±0.8	0.23
Soybean	6.3±0.9	259±24	0.186±0.005	30.2±2.5	0.21
Maize	24.3±3.3	914±76	0.184±0.015	105.4±4.1	0.23
41 days					
Chickpea	32.1±1.4	1,009±22	0.282±0.004	178.4±6.0	0.18
Pigeonpea	28.8±2.3	407±48	0.266±0.004	67.8±7.1	0.43
Soybean	55.7±3.0	1,647±135	0.174±0.008	179.7±10.5	0.31
Maize	141.0±5.0	1,627±59	0.224±0.009	228.0±10.5	0.62

Each value refers to four plants. [a] indicates standard error of mean.

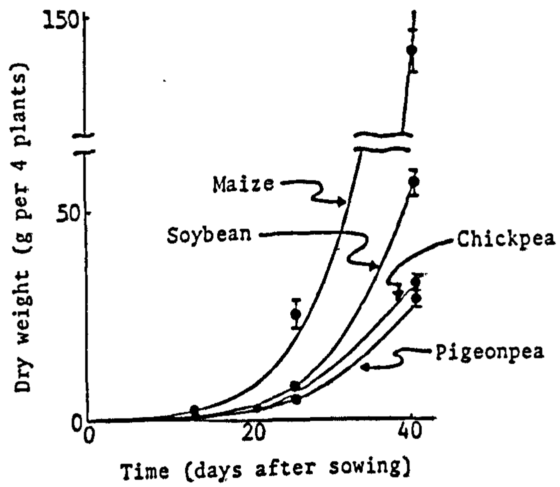

Fig. 1. Dry weight changes with plant age. Relative growth rates (g·g^{-1}·d^{-1}) of the four crop species obtained by the least-squares method were 0.168 maize, 0.153 soybean, 0.121 chickpea, and 0.141 pigeonpea.

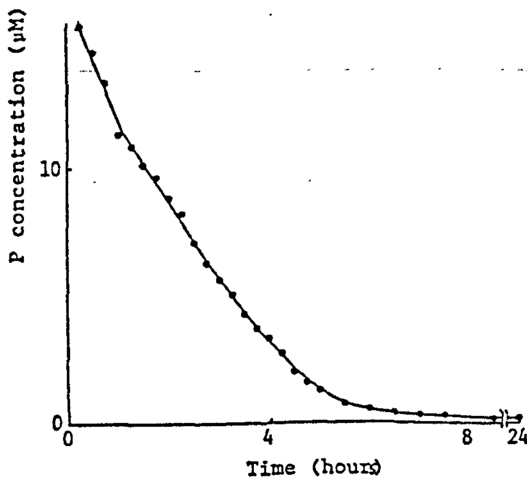

Fig. 2. Depletion of P with time from 4 liters of solution by 41-day-old chickpea plants.

Table 2. Phosphorus uptake parameters calculated from Hofstee plots of depletion data.

Crop species	I_{max} (μmol·h^{-1}·m^{-2})	Km (μM)	α (10^{-4} cm·h^{-1})	C_{min} (μM)
26 days				
Chickpea	41.2±4.3[a]	2.6±0.5	15.8±3.9	0.14±0.04
Pigeonpea	62.2±6.7	6.0±0.8	10.4±0.2	0.24±0.04
Soybean	111.9±7.2	5.8±1.3	19.3±3.9	0.07±0.01
Maize	70.8±6.0	9.1±0.9	7.8±0.1	0.19±0.03
41 days				
Chickpea	9.4±1.8	3.4±2.0	2.8±0.9	0.17±0.02
Pigeonpea[b]	12.2	2.1	5.8	0.24
Soybean	28.4±2.0	20.0±0.6	1.4±0.1	0.11±0.01
Maize	29.5±0.6	16.4±0.2	1.8±0.1	0.13±0.04

[a] indicates standard error of mean. [b] replicated data not available.

(Fig. 3). Table 2 shows the values for the maximum uptake rate (I_{max}), Michaelis constant (Km), and relative uptake parameter (α; I_{max}/Km). These Km values are in the same range as those cited by NYE and TINKER (*6*).

The P concentration in the soil solutions at field capacity were 0.2 μM for the low-P Vertisol, 35 μM for the high-P Vertisol, and 3 μM for the Gwalior soil.

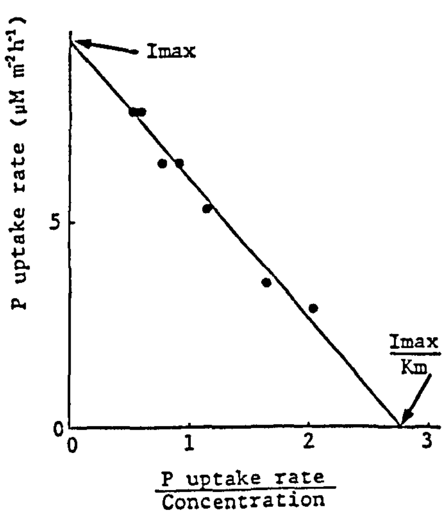

Fig. 3. Hofstee plot of the depletion data of 41-day-old chickpea plants.

DISCUSSION

The *Km* of chickpea was lower than that of soybean or maize at both 26 and 41 days. Pigeonpea had a smilar *Km* to that of chickpea at 41 days. Thus half-maximal P uptake rates for chickpea and pigeonpea were attained at lower P concentrations. At high solution concentrations of P soybean and maize were able to take up P more rapidly than chickpea and pigeonpea, as the I_{max} is higher. At low concentrations of P chickpea and pigeonpea could take up more rapidly than maize, as the α is higher. These root absorption characteristics may help to explain why chickpea and pigeonpea are less responsive than maize to fertilizer-P application. However, as these kinetic parameters are sensitive to the initial P status of the experimental plants, further experimentation with plants of different P status is required before the P-absorption characteristics of different species can be adequately compared.

The lower relative growth rates of chickpea and pigeonpea correspond to the lower I_{max} values for these species. Thus their potential for P uptake appears to match the demand created by plant growth.

The P concentration in the solution extract of the Vertisol that had received no fertilizer was of the same order as the C_{min} values obtained in the depletion experiments (Table 2). These findings imply that crops grown in this soil are able to extract very little P from the soil solution. This problem is further exacerbated when it is realized that, for plants growing in soils with low soil solution P concentrations, the P concentration near the root surface would be lower than in the bulk soil solution because of the diffusion gradient created (*5*). Chickpea usually grows well without P application in Vertisols with such low soil solution P levels, suggesting that other factors contribute to the enhancement of P uptake from low P concentrations in the soil solution. These could include extensive root hair development, the role of mycorrhizae, and the ability to solubilize soil P.

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