Proc. Indian natn. Sci. Acad., **55**, A, No. 3, 1989, pp. 535-545.

SIGNIFICANCE OF DIFFUSION IN THE UPTAKE OF PHOSPHORUS BY CHICKPEA PLANTS (*Cicer arietinum*) GROWN ON FOUR SOILS UNDER VARYING PHOSPHORUS LEVELS

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(*Received 9 November 1987; Accepted 18 April 1988*)

Diffusion is the primary mechanism of supplying phosporus to the root surface in soil. Solution of the partial differential equation $d_c/d_t = \frac{D_p}{b+\theta} \cdot \frac{d^2c}{dX^2}$ (Fick's second law based on diffusion theory) with the boundary conditions of constant rate of uptake and constant concentration of the root surface gives a prediction of the phosphorus concentration at the root surface (C_r) at different time intervals and phosphorus uptake (Q) by the plant respectively. In the present experiment C_r was found to decrease with time irrespective of the soils and levels of P application. Area under each curve, also known as depletion zone, was more as the level of P application increased in the soil. A close agreement ($r = 0.99$) between the predicted and the observed uptake of phosphorus by chickpea establishes that the assumed boundary conditions approximate the experimental conditions. Further the curvilinear relationship between the observed uptake of phosphorus and the porous diffusion coefficient (D_p) points out that the increase in diffusion coefficient may not necessarily be associated with the increased uptake by plant. In fact, uptake is likely to be maximum as long as the concentration gradient between the soil-P and root surface is maintained.

Key Words : Diffusion of Phoshorus; Predicted uptake; Boundary Condition; Constant Rate of Uptake; Porous Diffusion Coefficient; Depletion Pattern; Buffering Capacity

INTRODUCTION

PHOSPHORUS nutrition in chickpea is only acknowledged by several workers.[1-3] Possibilities of predicting phosphorus uptake through mathematical models, considering diffusion as the main mechanism for the supply of the nutrients to the plant root in soil, have been explored by various workers.[3-7] But in most of the cases the test plant was a cereal[8,9] or plants without root hairs like onion and leak. So, the present investigation was undertaken to study the relationship between the observed and predicted uptake of phosphorus by chickpea, a pulse crop, grown on four inceptisols at varying phosphorus levels.

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THEORETICAL

For the nutrients which mainly move to the plant roots by diffusion, it is possible to calculate their uptake by plant roots under different boundary conditions. The root acts as cylindrical sinks. The diffusion theory also facilitates calculation of the nutrient concentration at the root surface as a function of time and zone of depletion around the roots during the process of absorption.

The different boundary conditions for which Fick's second law,

$$d_c/d_t = \frac{D_p}{b+\theta} \cdot \frac{d^2c}{dX^2}, \qquad \ldots(1)$$

has been solved are :—

(*a*) Rate of uptake is proportional to the concentration in solution at the root surface,

(*b*) Rate of uptake is constant,

(*c*) Consentration at the root surface is constant, and

(*d*) Concentration at the root surface decreases exponentially.

In general, the actual boundary conditions for uptake process will be between the second and third simplified conditions. Olsen *et al.*,[10] Olsen & Watanabe[4,5] have given solution for the equation (1) under (*b*) and (*c*) boundary conditions. When the equation is solved for the boundary condition of constant rate of uptake, useful relationship has been obtained as shown below.

$$\frac{C_o - C_r}{aq} \cdot D_p = 2\left(\frac{a}{r}\right)^{1/2}, T^{1/2}\left(\text{ierfc}\,\frac{r-a}{2aT^{1/2}} - \frac{3r+a}{4r} \cdot T^{1/2}\, i^2\text{erfc}\,\frac{r-a}{2aT^{1/2}} + \ldots\right) \qquad \ldots(2)$$

where a = root radius (cm),

r = distance from the centre of the root (cm),

C_o = initial concentration (μg cm^{-3}),

C_r = concentration at the root surface (μg cm^{-3}),

D_p = porous diffusion coefficient (cm^2 sec^{-1}),

q = rate of uptake (μg cm^{-2} sec^{-1}),

t = time for which uptake is allowed to proceed (sec).

T = D_pt/Ba^2 (dimensionless)

B = $b + \theta$

and ierfc = integrated effor function complimentary.

The above equation may be used to calculate C_r as a function of distance from the root surface at a given time. The plot of dimensionless variable D_pt/Ba^2 vs $D_p\,(C_o - C_r)/aq$ may also be used to calculate C_r as a function of time.

The solution of equation (1) for the boundary condition of constant concentration at the root surface (C_r) can be represented by equation (3).

$$Q = aB\,(C_o - C_r).\,(2\pi^{-1/2}\,T^{1/2} + \frac{1}{2}\,T - \frac{1}{6}\,T^{3/2}\,\pi^{-1/2} + \frac{1}{16}\,T^2), \quad \ldots(3)$$

where Q = amount of uptake per unit of root surface area in time 't' with π as constant (3.14).

All other parameters have been defined in equation (2). When T in equation (3) is < 0.1, only a small error is introduced by neglecting all but the first term in equation (3). Substituting T in equation (3) and on simplification we get equation (4).

$$Q = B^{1/2}\,(C_o - C_r).\,2D_p^{1/2}\,(t/r)^{1/2} \quad \ldots(4)$$

Materials and Methods

The investigation was conducted on four inceptisols collected from Delhi State. The important soil properties are given in Table I.

Chickpea genotype (var. M 119) was grown in the growth chamber as described by Evans and Barber.[11] Chickpea seedlings were germinated in wet blotting paper and subsequently transferred to 12 cm glass tube after separating the secondary roots. The plants were grown in nutrient solution[9] till the primary roots became 10cm long. Some seedlings were placed in each box (three in each chamber) by inserting the glass tubes through the holes (Fig. 1) of the box grooved from top to bottom.

Three levels of phosphorus (10,20, 40 ppm P) as diammonium phosphate (DAP) were applied in four soils in factorial combination having three replications

Table I

Important characteristics of the soils

Characteristics	Todapur soil	Badarpur soil	Bamnoli soil	Alipore soil
1. Classification (sub group)	Typic ustochrept	Udic ustocrept	Udic ustocrept	Typic ustocrept
2. Clay %	14.21	21.60	37.60	22.00
3. pH (1:2.5)	7.20	7.30	8.10	8.40
4. EC (mmhos/cm)	0.45	0.20	0.20	0.70
5. $CaCO_3$ (%)	Nil	0.06	0.10	0.85
6. Org. Carbon (%)	0.20	0.22	0.23	0.20
7. CEC (me/100 g)	9.00	5.60	17.60	13.20
8. Totol P (mg/g soil)	4.64	4.54	4.40	4.54
9. Available P (Olsen) (μg/g soil)	10.00	5.00	4.50	8.00
10. Moisture at 1/3 bar (%)	12.79	11.54	24.41	22.21

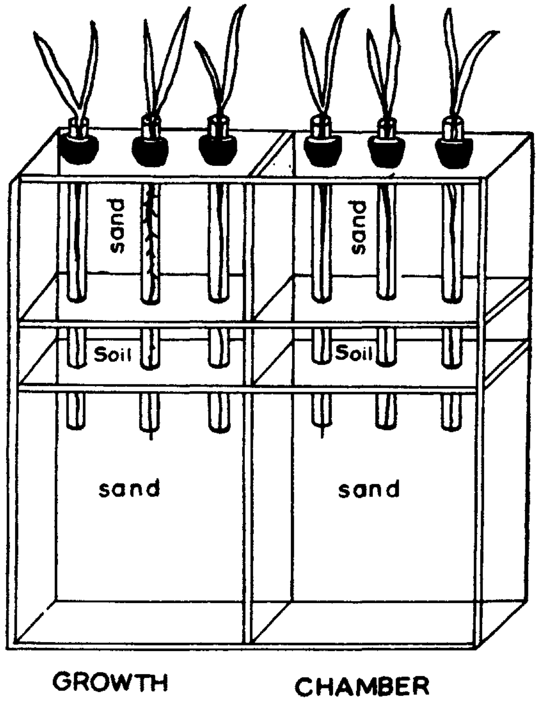

FIG 1

for each treatment. Soil-P was labelled with ^{32}P, @ 1 mCi/gP. The compartment of the growth chamber was packed with labelled soil to a bulk density of $1.4 g/cm^{-3}$. The soil in the middle band was wetted to 0.33 bar moisture tension by adding required amount of water. The upper and lower compartments were packed with quartz sand and thus saturated with water so as to minimise the absorption of water by the roots from soil, hence mass-flow checked. Each box was hinged with plexiglass door and was kept in growth chamber (constant temperature of 22 ± 1°C for 16 hours day period with a light intensity of 10K lux and RH between 60 and 65 percent) to minimise the evaporation loss of water, by wrapping with polythene sheets during the absorption period of 48 hr. The experimental design was compeltely randomized.

After 48hr absorption period, the plants were removed along with roots and dipped in 1 M $CaCl_2 . 2H_2O$ solution for ½hr followed by washing with doubled distilled water. The plant materials were oven dried at 60 °C and counting of ^{32}P was done in liquid scintillation counter.

The average root surface area was calculated from the mean diameter and length of the roots from the relationship $2\pi\ al$, where a = radius of the roots (cm) and l = average length of the root (cm) and $\pi = 3.14$.

The porous diffusion coefficients (D_p) of phosphorus in four soils and three levels of P applications were calculated by the procedure described by Brown *et al.*[12] Applied phosphorus in the saturated extract of the soil was measured following the procedure of Watanabe and Olsen[13].

The concentration of the applied phosphorus at three levels in four solis at the root surface (C_r) at different time intervals and the predicted uptake of applied phosphorus (Q) under two sets of boundary conditions were calculated using the equations described above.

Results and Discussion

Concentration of phosphorus at the root surface was calculated assuming constant rate of uptake. Figs. 2–5 depict the depletion patterns. In all the treatments, concentration at the root surface decreased with time from which it was evident that concentration of the nutrient at the root surface decreased as the absorption period increased. The depletion zone (i.e., the area under each curve) was more as the levels of applied P increased in the soil. The only exception was found in Badarpur soil (S_2) where at 10ppm P, the depletion zone was more than 20 ppm of P application. It is also worth-mentioning that the C_r values attained zero after a long interval of time as the levels of P application increased in the soil. The time required for C_r attaining, zero was different amongst the four soils at the highest rate of P application. In Todapur soil (S_1) at P_3, C_r was not zero even after 80 hr of P application, whereas in Bamnoli soil (S_3), C_r became zero within 38 hr of application. Alipore (S_4) and Badarpur (S_2) soils showed intermediate values. The patteren observed in Bamnoli soil for C_r with time may be explained by the buffering capacity (b) of the soil. When b is high (in Bamnoli soil), the

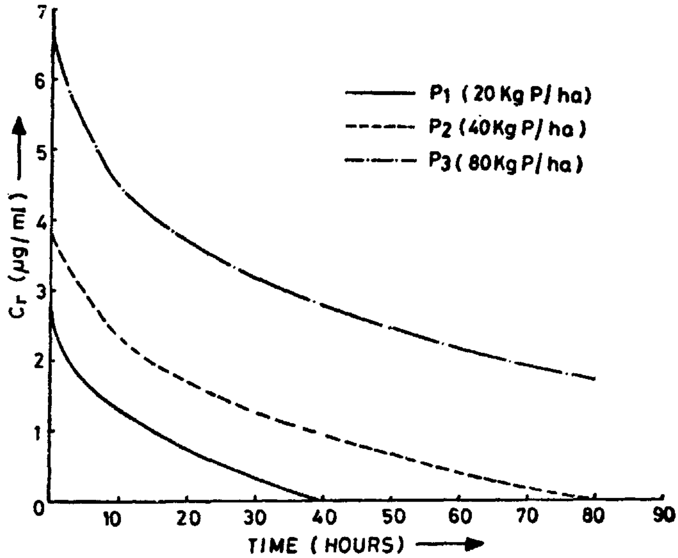

FIG 2 Concentration at the root surface with time in Todapur soil

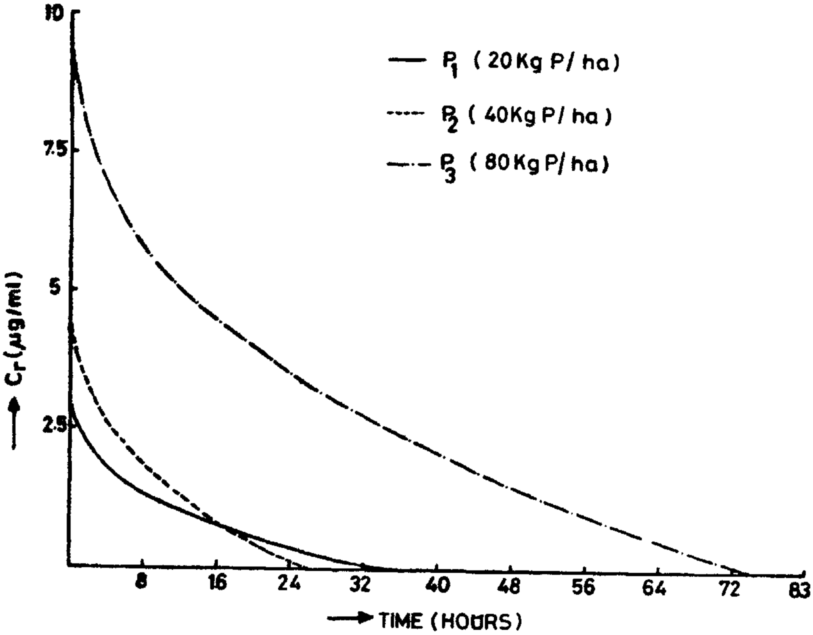

FIG 3 Concentration at the root surface with time in Badarpur soil

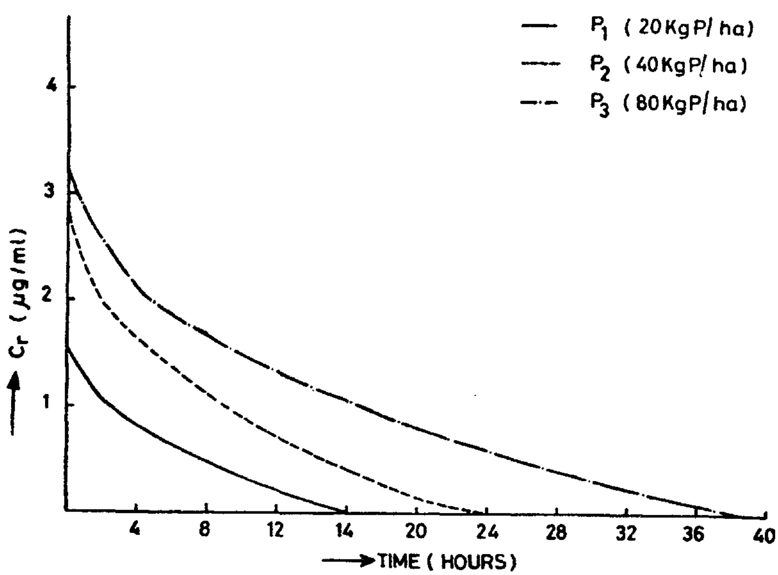

FIG 4 Concentration at the root surface with time in Bamnoli soil

depletion zone will be small because the concentration of nutrient in soil solution (C_o) is highly buffered.[14]

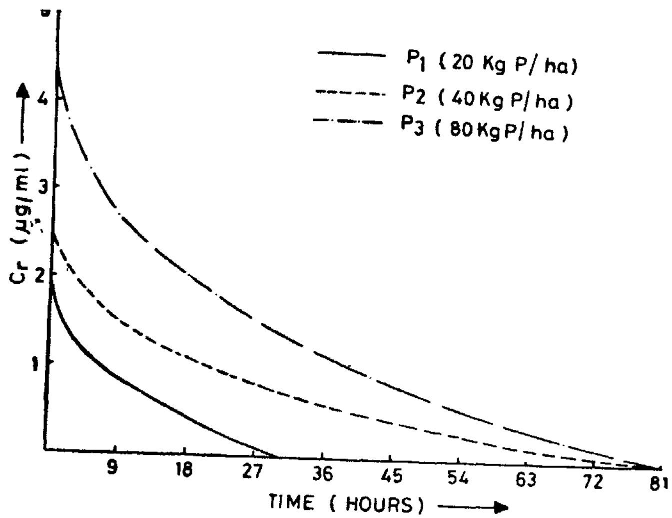

FIG 5 Concentration at the root surface with time in Alipore soil

Using the C_r values after 48 hr of absorption period the predicted uptake of phosphorus by plant was calculated (Table II). The significant correlation ($r = 0.99$) between the observed and the predicted uptake of P by chickpea suggested that the theoretical prediction is highly satisfactory in assessing the fertilizer P absorption by chickpea under given soil conditions. This also justifies

TABLE II

Observed and predicted uptake of phosphorus by chickpea plant under different phosphorus treatments after 48 hr of absorption period in four soils

Soils	P levels	Dp × 10^{11} Cm^2 sec^{-1}	Capacity factor	Co (µg/ml^{-1} of soln)	Cr (µg/ml^{-1} of soln)	Observed uptake (µg cm^{-2})	Predicted uptake (µg cm^{-2})
Todapur	P_1 (10ppm)	158.33	20	2.73	0	0.32	0.37
	P_2 (20ppm)	467.66	20	3.87	0.11	0.63	0.76
	P_3 (40ppm)	710.75	13	6.56	1.88	0.87	1.02
Badarpur	P_1 (10ppm)	93.20	41	2.66	0	0.36	0.44
	P_2 (20ppm)	235.84	34	4.44	0	1.01	1.17
	P_3 (40ppm)	393.72	26	8.98	0.10	1.49	1.63
Bamnoli	P_1 (10ppm)	88.08	73	1.62	0	0.40	0.50
	P_2 (20ppm)	158.60	60	2.86	0	0.74	0.88
	P_3 (40ppm) 666	270.08	58	3.20	0	0.84	0.98
Alipore	P_1 (10ppm)	428.53	40	1.94	0	0.60	0.68
	P_2 (20ppm)	863.08	37	2.42	0.05	0.73	0.89
	P_3 (40ppm)	859.56	26	4.35	1.11	1.11	1.34

that the experimental conditions approximated the assumed boundary conditions quite closely. Similar observations were made by Olsen and Watanabe,[5] O'Connor *et al.*[15]

The linear regression equation between the observed and predicted uptake is presented in Fig. 6. Overprediction of P uptake may be explained either by the fact that the capacity factor measurement was not reliable because of increased root competition and reduction of In (net influx), during the dark period.[16]

Uptake of phosphorus in four soils was plotted against their respective diffusion coefficient values (Fig. 7-10) Except for Alipore Soil, the curves, in general, showed curvilinear relationship. An explanation for this as given by Evans and Barber[11] is that, as the diffusion increases the root reaches the limits of its rate of absorption and therefore, uptake approaches a constant maximum value. This causes an increased concentration of the nutrient ions at the root surface and a subsequent decrease in the concentration gradient between the labelled soil and the root surface. This decreased concentration gradient is responsible for the decrease in the amount of nutrients diffusing to the root surface, since the amount diffusing is dependent upon both the diffusion coefficient and the concentration gradient.

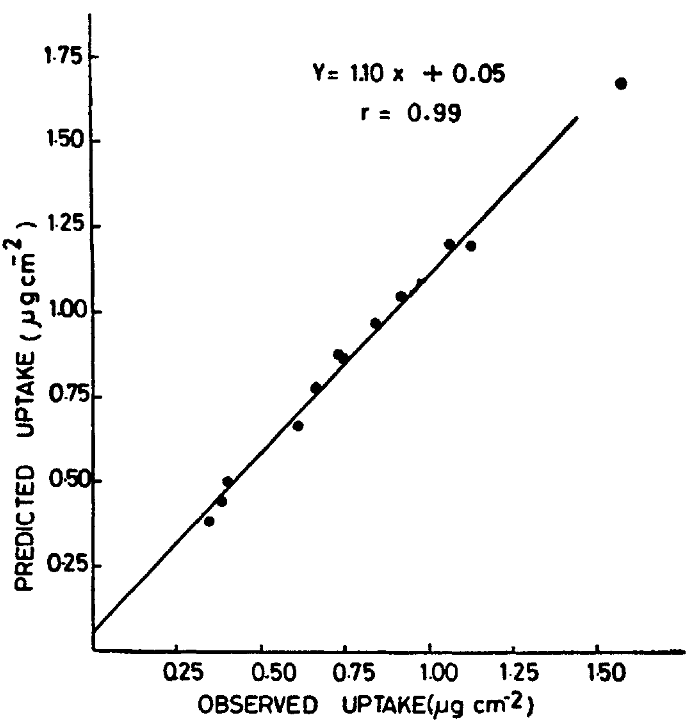

FIG 6 Relationship between observed and predicted uptake of phosphorus by chickpea

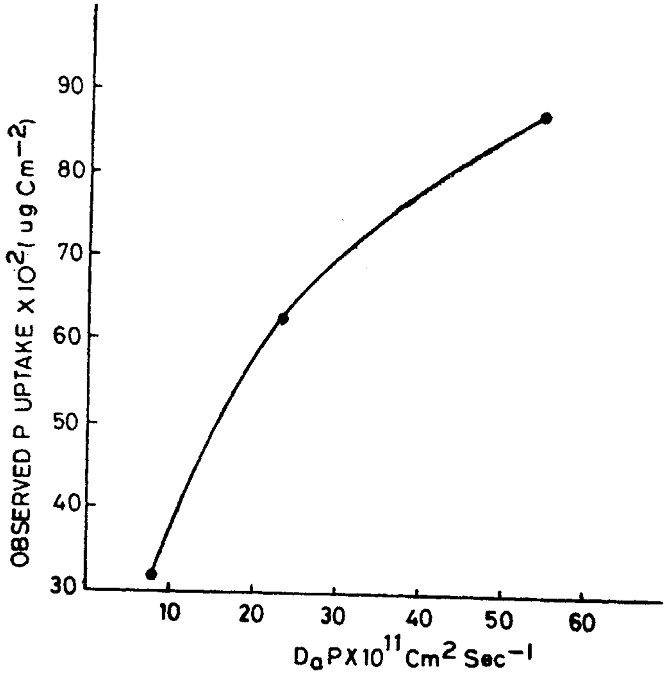

FIG 7 Relationship between observed P uptake and D_a P values in Todapur soil

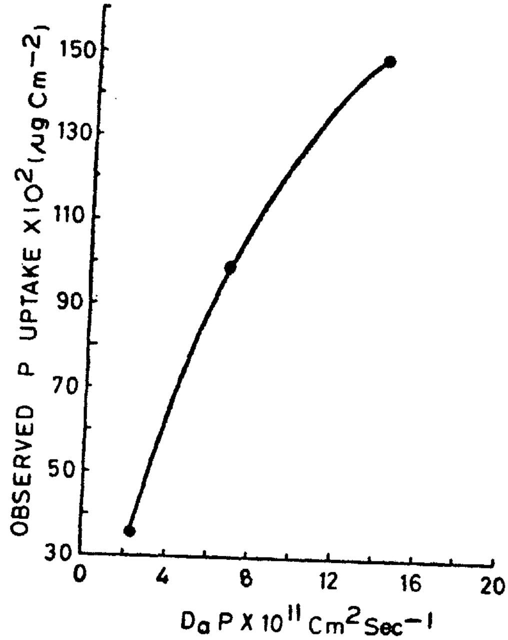

FIG 8 Relationship between observed P uptake and D_a P values in Badarpur soil

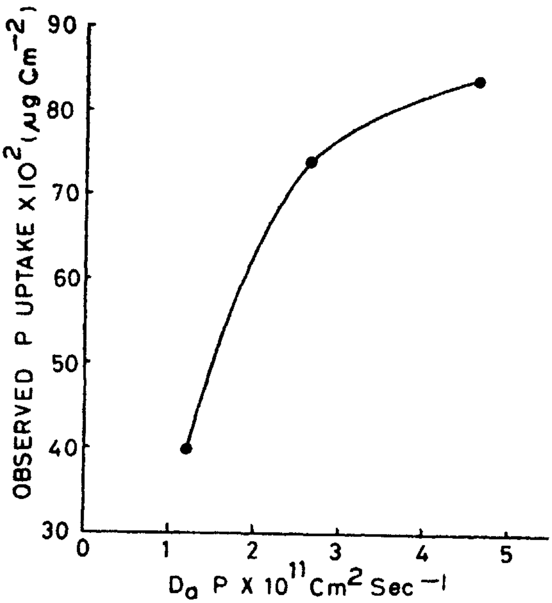

FIG 9 Relationship between observed P uptake and D_a P values in Bamnoli soil

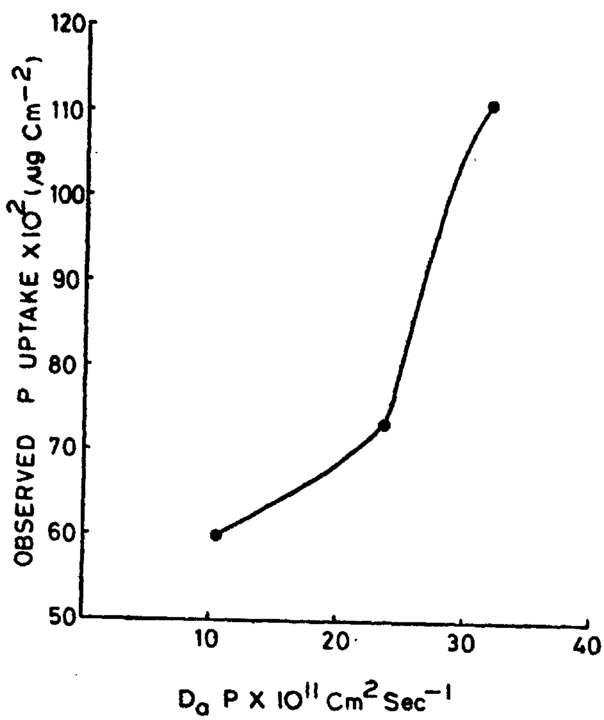

FIG 10 Relationship between observed P uptake and D_a P values in Alipore soil

Conclusions

Based on the results discussed so far, the following conclusions can be drawn :

1. Concentration of phosphorus at the root surface decreases with the increase of time or the absorption period irrespective of the soil conditions.
2. Area under each curve, also known as the depletion zone, increases as the level of P application in the soil increases.
3. Theoretical prediction of phosphorus uptake by plant is highly satisfactory in assessing the fertilizer P absorption by chickpea under given soil conditions, thus confirming the satisfactory presence of the assumed boundary conditions for prediction of phosphorus uptake.
4. The curvilinear relationship between D_p and phosphorus uptake proves that the increase in diffusion coefficient in soil may not necessarily be associated with increased uptake.

Acknowledgements

The authors are thankful to the Project Director, NRL, for providing facilities for the work. They also express their gratitude to Dr D L Deb, Senior Scientist, NRL for his keen interest and valuable suggestions during the course of this investigation.

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