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Assessing the Fertilizer Phosphorus Requirement of Grain Sorghum

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ABSTRACT

Assessing the fertilizer phosphorus (P) requirements (FPR) of crops is an important component of research for efficient and rational use of fertilizers. Soil and plant tests are employed to determine the FPR. Two methods were evaluated for determining the FPR of sorghum grown on a Vertisol under rainfed conditions. The first method was based on P on applied P uptake, and grain yield relationships for grain sorghum. In this method, P uptake at a given yield was determined from the relationship between total P uptake and grain yield. The amount of fertilizer P applied for the given P uptake and grain yield was then, determined from the relationship between P applied and P uptake. In the second method, FPR was determined using the equation: **FPR=(Up-U0)/PRF**, where **Up** is P uptake at a given yield, **U0** is P uptake from unfertilized soil, and PRF is the recovery of applied P. The parameters, U0, Up, and PRF were determined in a field experiment with sorghum grown

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on a Vertisol under rainfed conditions. There was a good agreement between the observed value of FPR and predicted values determined by the two methods. These results suggest that the simple models based on P uptake can be utilized for determining the fertilizer requirements of crops.

INTRODUCTION

Fertilizers are applied to increase economic yields. The increase in crop yields in response to fertilizer application, depends on the nutrient element status of soil and the nutrient element requirement for a given or targeted yield level. Although the low nutrient element status of most semi-arid tropical soils has been recognized, the fertilizer use under rainfed agriculture across the semi-arid tropics (SAT) is low except under irrigation. The uncertainty of assured returns from applied fertilizer inputs is the main reason for the low use of chemical fertilizers under rainfed cropping. However, within the assured rainfall area (>800 mm annual rainfall) of the Indian SAT, research has shown that nutrient inputs are one of important components of farming systems, especially on Vertisols which have relatively higher water-holding capacity than the other soil types (Burford et al., 1989).

Sorghum is an important crop of the SAT. Among plant nutrient elements, the deficiencies of nitrogen (N), P, and zinc (Zn) rank important for the growing of sorghum on calcareous Vertisols. We initiated research for developing P management strategy for grain sorghum on Vertisols under rainfed cropping because little systematic research had been conducted in this important area, for increasing the productivity of Vertisols through better understanding of P behavior in these soils (Sahrawat, 1988).

The basic research on phosphate sorption-desorption, revealed that the Vertisols have low phosphate-sorption capacity compared to other tropical soils, such as Ultisols and Oxisols. More importantly, all the P sorbed remained in an easily desorbable form (Sahrawat and Warren, 1989; Shailaja and Sahrawat, 1990).

Among the chemical tests evaluated for predicting the availabilty of fertilizer P and its residues, Olsen P was found to be effective in assessing the residual value of P (Warren and Sahrawat, 1993). Research on the calibration of soil test for P showed that a single critical limit of available P (Olsen P) does not hold true for grain sorghum in the two soil types, Vertisol and Alfisol, under similar agroclimatic conditions, and that the critical limit is lower for the clayey Vertisol (2.8 mg P kg^{-1} of soil) than the nearby sandy Alfisol (5 mg P kg^{-1} of soil) (Sahrawat et al., 1996).

This research also indicated that lack of P response on the Vertisols having available P in the range 3 to 5 mg kg^{-1} Olsen P was not due to P sorption (Murthy, 1988), but because the critical concentration of available P in the soil was lower. Significant responses to applied P by sorghum, have been obtained on Vertisols with available P lower than 2.5 mg P kg^{-1} soil (Sahrawat, 1988; Burford et al., 1989; Sahrawat et al., 1995).

While soil tests are useful in determining the long-term nutrient element requirements of crops, plant tests are necessary for correcting the nutrient element deficiencies of the current crops. More importantly, under rainfed agriculture, the plant P tests become necessary for achieving economic yields of crops because fertilizer use is generally not adequate for achieving the potential maximum yields. This can be achieved by establishing relationships between plant P concentration and yield. In a field experiment conducted for three years, the leaf P concentration was found to be linearly related to sorghum grain yield and the critical leaf (newest, fully developed leaf) P concentration at 90% of the maximum yield was found to be 0.25% (Sahrawat et al., 1998).

For efficient and rational P fertilization, it is important to determine the fertilizer P requirement of the crop. Little attention has been devoted to research for determining the fertilizer P requirement especially for sorghum under-rainfed field conditions (Jones et al., 1990). This paper describes two simple and practical methods for determining the FPR of sorghum for a given yield level, utilizing the P uptake data from the field experiment conducted for three consecutive years.

MATERIALS AND METHODS

Determining FPR

Two simple and practical methods were employed to determine the FPR of grain sorghum. In first method, the relationships between total P uptake and grain yield were utilized to determine the P uptake at a given sorghum grain yield. The relationships between P applied and P uptake were then utilized to determine the amount of P applied for the given P uptake, at the targeted yield.

In the second method, FPR was determined using the simple equation suggested by Driessen (1986) and Cornforth et al. (1990): **FPR=(Up-U0)/PRF**, where **Up** is P uptake by sorghum at the targeted yield, **U0** is P uptake by the crop from P unfertilized soil, and **PRF** is the recovery of applied P. The parameters, U0, Up, and PRF were determined from a field experiment conducted for three consecutive years.

Field Experiment

A field experiment was conducted during the wet (rainy) seasons in 1987, 1988, and 1989 at the ICRISAT Center, Patancheru (near Hyderabad), India (17.5°N, 78.5°E; 545 m altitude).

The soil at the experimental site is a Vertisol (Typic Pellustert) and belongs to the Kasireddipalle series. The soil is calcareous (56 g $CaCO_3$ kg^{-1}, pH 8.3), low in organic matter (3.3 g kg^{-1} organic C, 401 mg kg^{-1} total N) and extractable P (0.4 mg P kg^{-1} of soil Olsen P), and clay in texture. For the soil analyses, pH was

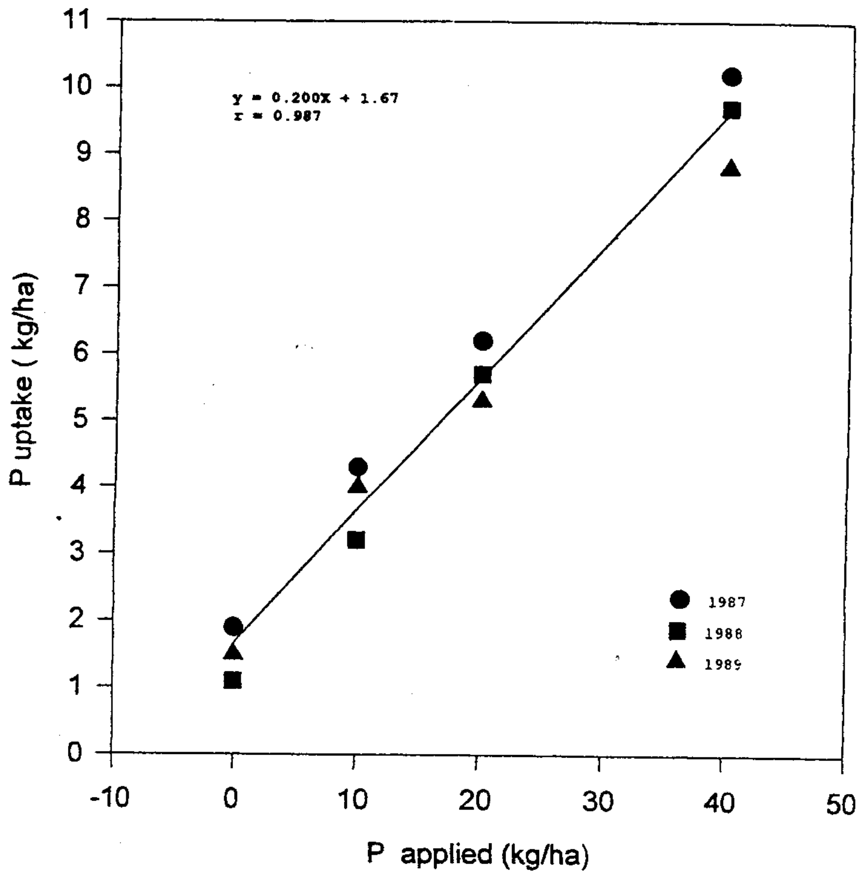

FIGURE 1. Relationship between total P uptake and fertilizer P applied for sorghum grown on a Vertisol for three years (1987-1989). Each point represents an average value of four replications.

measured by a glass electrode using a soil to water ratio of 1:2. Organic C was determined by the Walkley-Black method (Nelson and Sommers, 1982) and total N as described by Dalal et al. (1984). Particle size was done by the hydrometer method (Gee and Bauder, 1986) and carbonate content was determined by acid neutralization (Allison and Moodie, 1965). Extractable P was determined by extracting the soil samples with 0.5 *M* sodium bicarbonate ($NaHCO_3$) as described by Olsen and Sommers (1982).

Details of the field experiment were described in Sahrawat et al. (1995). The experiment used a split-split-plot design with four replications. The main plot was sorghum cultivar and split plot treatment was fertilizer P. Diammonium phosphate (DAP), as fertilizer P source, was applied at four rates of 0, 10, 20, and 40 kg P ha^{-1} in 1987. In the 1988 cropping season, each plot was split into four subplots and the four rates of fresh P applied in the subplots. In the 1989 cropping season, the subplots were further split in the same manner to give sub-subplots for the application of fresh P in 1989. All plots received uniform applications of

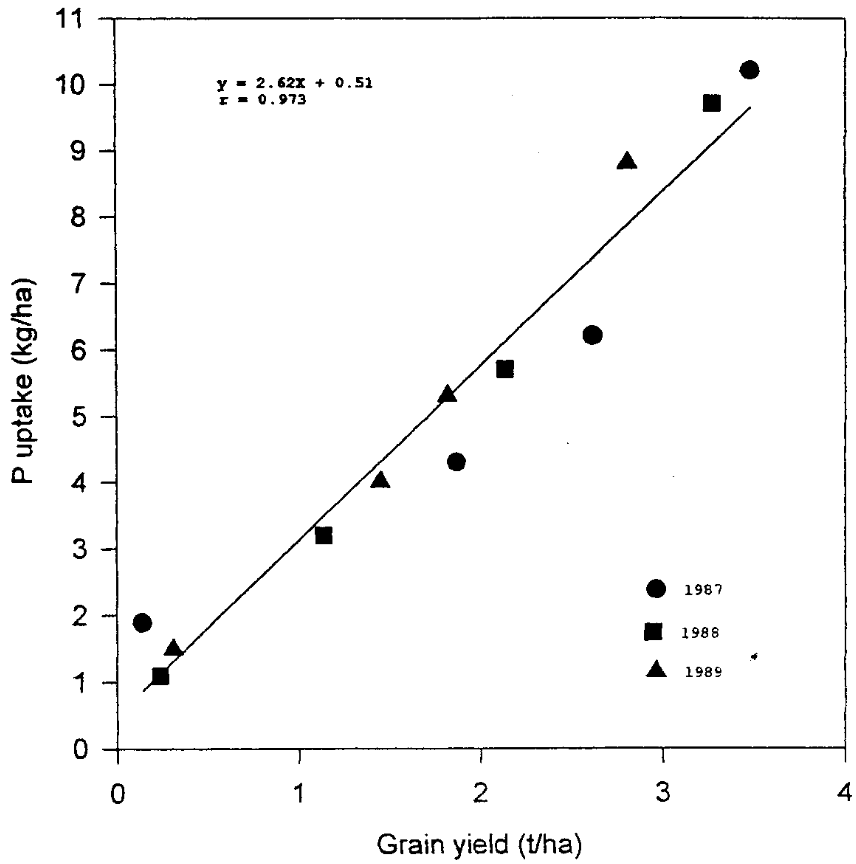

FIGURE 2. Relationship between total P uptake and grain yield of sorghum grown on a Vertisol for three years (1987-1989). Each point represents an average value of four replications.

N (120 kg N ha^{-1}), K (90 kg K ha^{-1}), and Zn (10 kg Zn ha^{-1}). Nitrogen application rate by DAP at sowing was balanced by applying urea in treatments that received 0, 10, and 20 kg P ha^{-1}.

One sorghum (cv. CSH 6) crop was grown each year in the wet season from June to September under rainfed conditions. All other details are in Sahrawat et al. (1995).

During the growing seasons rainfall was variable. From sowing to harvest of the crop, 604 mm of rainfall was received in 1987, 941 mm in 1988, and 583 in 1989.

Selected treatments dealing with the response of sorghum to fresh P in each of the three years (1987-1989) are used in this paper. The grain and stalk samples of sorghum were analyzed for P contents. The plant materials were digested and P in the digests was determined by an AutoAnalyser colorimetric procedure (Technicon Industrial Systems, 1972). The data were statistically analyzed using the analysis of variance procedure.

TABLE 1. Yield and total P uptake by sorghum (cv. CSH 6) at four rates of fertilizer P in 1987, 1988, and 1989.

	P applied (kg ha^{-1})				
	0	10	20	40	SE
1987					
Grain yield, t ha^{-1}	0.14	1.87	2.62	3.48	0.189
Stalk yield, t ha^{-1}	2.10	4.11	4.78	4.68	0.100
Total P uptake, kg ha^{-1}	1.90	4.30	6.20	10.20	0.150
1988					
Grain yield, t ha^{-1}	0.24	1.14	2.14	3.27	0.117
Stalk yield, t ha^{-1}	1.34	3.55	5.28	7.01	0.241
Total P uptake, kg ha^{-1}	1.10	3.20	5.70	9.70	0.790
1989					
Grain yield, t ha^{-1}	0.31	1.45	1.82	2.81	0.224
Stalk yield, t ha^{-1}	1.83	3.13	3.60	4.47	0.328
Total P uptake, kg ha^{-1}	1.50	4.00	5.30	8.80	0.620

RESULTS AND DISCUSSION

First Method: Phosphorus Applied—Phosphorus Uptake Yield Relationships

Based on three years results, it was found that the fertilizer P applied and total P uptake by sorghum were significantly and linearly related (Figure 1), and described by the following regression equation:

$$\text{P uptake (kg ha}^{-1}) = 1.67 + 0.200 \text{ P applied (kg ha}^{-1}), r = 0.987 \qquad [1]$$

Total P uptake by the crop in turn, was closely and linearly related to sorghum grain yield (Figure 2):

$$\text{P uptake (kg ha}^{-1}) = 0.51 + 2.62 \text{ grain yield (t ha}^{-1}), r = 0.973 \qquad [2]$$

The relationships shown in Figures 1 and 2, and described by regression Equations [1] and [2], were employed for determining the FPR of the crop. First, relationship between total P uptake and grain yield (Equation 2) was utilized to determine the P uptake at a given sorghum yield. Relationship between P applied and P uptake (Equation 1) was then used, to determine the amount of P applied for the given P uptake, at the targeted grain yield.

Second Method

Fertilizer P requirement (FPR) was calculated from the following simple equation:

$$\text{FPR} = (\text{Up} - \text{U0})/\text{PRF} \qquad [3]$$

TABLE 2. Fertilizer P recovery fraction by one crop of sorghum (cv. CSH 6) in 1987, 1988, and 1989.

Year	P applied (kg ha^{-1})			
	10	20	40	Mean
1987	0.24	0.22	0.21	0.22
1988	0.21	0.23	0.21	0.22
1989	0.25	0.19	0.18	0.21
Mean	0.23	0.21	0.20	

where: **Up** is P uptake by sorghum at the targeted yield, **U0** is P uptake by the crop from P unfertilized soil, and **PRF** is the recovery of applied P, referred to as P recovery fraction. The U0, Up, and PRF were determined from field experiments. This simple model of determining FPR of crops has been suggested by Driessen (1986) and Cornforth et al. (1990).

The values of Up at three rates of fertilizer P (10, 20, and 40 kg P ha^{-1}) and U0 (no P applied), and the associated sorghum grain and stalk yields, determined from a field experiment in 1987, 1988, and 1989 are given in Table 1. There were seasonal variations in Up and U0 as affected by sorghum yields. The values of PRF by one crop of sorghum were fairly consistent during the three years (Table 2) and the mean PRF was 0.22 in 1987 and 1988, and 0.21 in 1989. Relatively lower value of PRF in 1989 was due to lower yield of sorghum in the 1989 season than in 1987 and 1988.

The fertilizer P recovery fraction, FPR of sorghum was affected by fertilizer P rate and seasonal effects. Generally, PRF was higher at the smallest P rate, and it decreased with further increase in P rate, but the differences were rather small. Seasonal differences in sorghum yields also affected the PRF. The mean PRF at 10 kg P ha^{-1} was 0.23, 0.21 at 20 kg P ha^{-1} and 0.20 at 40 kg P ha^{-1} during the three years (Table 2).

TABLE 3. Grain yield in relation to total P uptake by sorghum (cv. CSH 6) at 40 kg ha^{-1} of fertilizer P in 1987, 1988, and 1989.

Year	Grain yield (t ha^{-1}) at 40 kg P ha^{-1}	P uptake (kg ha^{-1}) by one crop	P uptake (kg ha^{-1}) for 1 t grain
1987	3.48	10.2	2.9
1988	3.27	9.7	3.0
1989	2.81	8.8	3.1
Mean	3.19	9.6	3.0

The amounts of total P taken up by the crop to produce one ton sorghum grain, were consistent during the three years (Table 3) and indicated that about 3 kg of total P was taken up by the crop to produce one ton of grain.

From these data, the P requirement of sorghum at a given or targeted yield level can be calculated. This can be achieved in two steps. First, the amount of total P uptake needed for achieving the targeted yield is determined, based on the results that 3 kg of P is taken up to produce one ton of grain. This value is Up and along with U0 and PRF, they can be utilized to compute the FPR of sorghum using Equation [3].

There was an excellent agreement between the actual FPR values and those predicted by the two models. For example, using the first method, the amount of fertilizer P applied for 3 t ha^{-1} sorghum grain yield worked out to be about 35 kg P ha^{-1} and using the second model, the FPR was 33.5 kg P ha^{-1}. The values of FPR predicted by the two methods were similar, and were generally close to the actual amounts of fertilizer P needed to achieve given yield levels. These simple and practical models, essentially based on P uptake data, can be utilized for computing fertilizer P requirements for sorghum under the prevailing dryland conditions.

Additionally, the second model which utilizes both P uptake and PRF data seems suitable also for determining the FPR when fertilizer P residues need to be considered.

REFERENCES

Allison, L.E. and C.D. Moodie. 1965. Carbonate. pp. 1479-1400. In: C.A. Black (ed.), Methods of Soil Analysis. Part 2. Agronomy 9. American Society of Agronomy, Madison, WI.

Burford, J.R., K.L. Sahrawat, and R.P. Singh. 1989. Nutrient management in Vertisols in the Indian semi-arid tropics. pp. 147-159. In: Management of Vertisols for Improved Agricultural Production: Proceedings of an IBSRAM Inaugural Workshop, 18-22 February 1985, Patancheru, India. International Crops Research Institute for the Semi-Arid Tropics (ICRISAT), Patancheru, India.

Cornforth, I.S., A.K. Metherell, and P. Sorn-Srivichai. 1990. Assessing fertilizer requirements. pp. 157-166. In: Phosphorus Requirements for Sustainable Agriculture in Asia and Oceania. International Rice Research Institute, Manila, Philippines.

Dalal, R.C., K.L. Sahrawat, and R.J.K. Myers. 1984. Inclusion of nitrate and nitrite in the Kjeldahl nitrogen determination of soils and plant materials using sodium thiosulphate. Commun. Soil Sci. Plant Anal. 15:1453-1461.

Driessen, P.M. 1986. Nutrient demand and fertilizer requirements. pp. 182-202. In: H. van Keulen and J. Wolf (eds.), Modelling of Agricultural Production: Weather, Soils and Crops. PUDOC, Wageningen, The Netherlands.

Gee, G.W. and J.W. Bauder. 1986. Particle-size analysis. pp. 383-409. In: A. Klute (ed.), Methods of Soil Analysis. Part 1. 2nd ed. Agronomy 9. American Society of Agronomy, Madison, WI.

Jones, Jr., J.B., H.V. Eck, and R. Voss. 1990. Plant analysis as an aid in fertilizing corn and grain sorghum. pp. 521-547. In: R.L. Westerman (ed.), Soil Testing and Plant Analysis. 3rd ed. Series 3. Soil Science Society of America, Madison, WI.

Murthy, A.S.P. 1988. Distribution, properties and management of Vertisols of India. Adv. Soil Sci. 8:151-214.

Nelson, D.W. and L.E. Sommers. 1982. Total carbon, organic carbon, and organic matter. pp. 539-579. In: A.L. Page, R.H. Miller, and D.R. Keeney (eds.), Methods of Soil Analysis. Part 2. Agronomy 9. American Society of Agronomy, Madison, WI.

Olsen, S.R. and L.E. Sommers. 1982. Phosphorus. pp. 403-430. In: A.L. Page, R.H. Miller, and D.R. Keeney (eds.), Methods of Soil Analysis. Part 2. Agronomy 9. American Society of Agronomy, Madison, WI.

Sahrawat, K.L. 1988. Overview of research on phosphorus in Vertisols. pp. 4-8. In: ICRISAT, Phosphorus in Indian Vertisols: Summary Proceedings of a Workshop, 23-26 August 1988, Patancheru, India. International Crops Research Institute for the Semi-Arid Tropics (ICRISAT), Patancheru, India.

Sahrawat, K.L. and G.P. Warren. 1989. Sorption of labelled phosphate by a Vertisol and an Alfisol of the semi-arid zone in India. Fert. Res. 20:17-25.

Sahrawat, K.L., M.H. Rahman, and J.K. Rao. 1998. Leaf phosphorus and sorghum yield under rainfed cropping of a Vertisol. Nutr. Cycl. Agroecosyst (in press).

Sahrawat, K.L., G. Pardhasaradhi, T.J. Rego, and M.H. Rahman. 1996. Relationship between extracted phosphorus and sorghum yield in a Vertisol and an Alfisol under rainfed cropping. Fert. Res. 44:23-26.

Sahrawat, K.L., T.J. Rego, J.R. Burford, M.H. Rahman, J.K. Rao, and A. Adam. 1995. Response of sorghum to fertilizer phosphorus and its residual value in a Vertisol. Fert. Res. 41:41-47.

Shailaja, S. and K.L. Sahrawat. 1990. Adsorption and desorption of phosphate in some semi-arid tropical Indian Vertisols. Fert. Res. 23:87-96.

Technicon Industrial Systems. 1972. Technicon Autoanalyser II Manual. Industrial Method No. 218-72A. Technicon Industrial Systems, Tarrytown, NY.

Warren, G.P. and K.L. Sahrawat. 1993. Assessment of fertilizer P residues in a calcareous Vertisol. Fert. Res. 34:45-53.