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Criteria for Assessment of the Residual Value of Fertilizer Phosphorus

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Abstract: Sorghum yield and P uptake response data from a field experiment conducted at the ICRISAT farm, Patancheru (near Hyderabad) consecutively for four years (1987-1990) were used for determining the residual value of fertilizer P under rainfed cropping on a Vertisol acutely deficient in P. There were seasonal differences in the residual values of P. But more importantly, the residual P value varied depending on the criteria employed for crop response. On an average, the residual value of fertilizer P in the succeeding season was 52 per cent as effective as the fresh P when dry matter yield response was used as the criterion. The residual value of applied P was found to be 47 per cent as effective using grain yield response as the criterion, and the residual P was only 35 per cent as effective as the fresh P when total P uptake response was used as the criterion. It is suggested that the dry matter yield response of sorghum is a simple and practical criterion for determining the residual value of fertilizer P under rainfed cropping. (*Key words : Dry matter yield, P response, P uptake, rainfed cropping,* Sorghum bicolor, *Vertisol*)

Vertisols in the semi-arid tropics (SAT) are considered as a group of productive soils, especially because of their high water holding capacity. Nutrient inputs are one of the important components of improved cropping systems on Vertisols within the assured rainfall area (> 800 mm annual rainfall) of the Indian SAT. The deficiencies of N and P are common for cereal crops such as sorghum (Burford *et al.* 1989; Katyal & Das 1993).

The low P status of most soils in the Indian SAT has been fully demonstrated (Tandon 1987). Fertilizer P use on Vertisols is becoming more common and thus it is important that the residual value of fertilizer is considered and allowed for. From a three-year-field study of P response of sorghum (*Sorghum bicolor* L. Moench) under rainfed cropping on a Vertisol, Sahrawat *et al.* (1995) reported that the P response of sorghum in a season was significantly influenced by the residues of fertilizer P from the previous season but not by the residues of P added two seasons earlier.

The objective of the work reported in this paper was to evaluate and compare the methods based on sorghum yield (grain and stalk yield) and P uptake responses for determining the value of fertilizer P residues using data from an experiment conducted consecutively for four years (1987-1990). There is a lack of information on the comparative value of such methods. Such comparisons are needed to identify an appropriate criterion that can be employed for the assessment of fertilizer P residues. The work reported is a part of a project initiated for understanding the behaviour of P in Vertisols with a view to developing effective P management strategies (Sahrawat 1988; Sahrawat & Warren 1989; Shailaja & Sahrawat 1990; Warren & Sahrawat 1993; Sahrawat *et al.* 1995).

Materials and Methods

The details of the field experiment including

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description of the soil at the experimental site are available in an earlier publication (Sahrawat *et al.* 1995). Relevant description of the experiment, however, is provided.

The soil at the experimental site was of the Kasireddipalle series, a benchmark Vertisol (Typic Pellustert) at the ICRISAT centre, (pH 8.3, organic C 3.3 g kg^{-1}, total N 401 mg kg^{-1}, extractable P 0.4 mg kg^{-1}, total P 150 mg kg^{-1}, $CaCO_3$ 56 g kg^{-1}). The surface (0-15 cm) samples were taken before initiating the experiment. The site did not receive any fertilizer P since 1972. Soil pH was measured by a glass electrode using a soil to water ratio of 1:2. Organic C was determined as described by Walkley and Black (1934) and total N as described by Dalal *et al.* (1984). Carbonate (expressed as $CaCO_3$) content was determined by acid neutralization (Allison & Moodie 1965). Total P content was determined by digestion with perchloric acid, and extractable P was determined by extracting the soil samples with 0.5 *M* $NaHCO_3$ as described by Olsen and Sommers (1982).

Field experiment was conducted during the rainy season (June to September) in 1987, 1988, 1989 and 1990 at the ICRISAT center, Patancheru (near Hyderabad), Andhra Pradesh (17.5° N, 78.5° E; 545 m altitude). The objective of the experiment was to determine the response of sorghum to fertilizer P and its residual value in a Vertisol, acutely deficient in extractable P (Sahrawat *et al.* 1995).

In order to compare fresh and residual P directly in each season, the experiment used a split-split-plot design with four replications. The main-plot was sorghum cultivar and split plot treatment was fertilizer P. The experiment had 64 treatment plots. The layout of the experiment was in split-split plot from the 1987 season itself and each plot measured 4 m x 4 m. In practice, sub-plot became effective in 1988 and sub-sub-plot was effective in the 1989 season. Diammonium phosphate (DAP), as fertilizer P source, was applied at 4 rates (0, 10, 20 and 40 kg P ha^{-1}) in 1987 season. In the 1988 cropping season, each plot was split into 4 sub-plots and the 4 rates of fresh P applied in the sub-plots. Finally, in the 1989 cropping season, the sub-plots were further split in the same manner to give sub-sub-plots (each 4 m x 4 m) for the application of fresh P at the same 4 rates in 1989. In the 1990 cropping season, the experiment was continued without the application of fresh P.

One sorghum (cv CSH 6) crop was grown each year during four years from June to September under rainfed conditions. The crop was seeded at a spacing of 50 cm x 16 cm. Each cropping season, all plots received uniform rates of N, K and Zn. Nitrogen was applied at a rate of 120 kg N ha^{-1}, 36 kg at seeding and the rest at 3 weeks after emergence of the crop. Nitrogen application rate by DAP at seeding was balanced by applying urea in treatments that received 0, 10 and 20 kg P ha^{-1}. Nitrogen was top dressed as urea. Potassium chloride was used to supply K at a rate of 90 kg K ha^{-1} and zinc sulphate was used to supply Zn at a rate of 10 kg Zn ha^{-1}. The crop was harvested at maturity using a harvested area of 6 m^2 (gross area 16 m^2) (Sahrawat *et al.* 1995).

The grain and stalk samples of sorghum were analysed for P. Phosphorus was analysed in the plant digests by an autoanalyser colorimetric procedure (Technicon Industrial Systems 1972).

Selected fertilizer treatments dealing with the response of sorghum to fresh P(0, 10, 20 and 40 kg P ha^{-1}) and residual P (first year residual P only) during three consecutive seasons (fresh P in 1987, residual P in 1988, residual P in 1989; fresh P in 1988, resudal P in 1989, residual P in 1990) are used in this paper. Sorghum yield and P uptake responses to fresh P and the P residues were calculated from the increase in yield or P uptake caused by the levels of applied P or their residues. For example, to obtain yield or P uptake responses to fresh and first residual P at different P treatments in the 1988 season (shown in Table 2), the yield or P uptake from the P unfertilized treatment in the season was subtracted from those obtained at different P treatments.

Rainfall during the growing season, as expected, was variable. From sowing to harvest of the crop, 604 mm of rainfall was received in 1987, 941 mm in 1988 and 583 mm in 1989.

Apparent recovery of the fertilizer P, referred to as recovery fraction of fertilizer P, was calculated using total P uptake data from the check (no P applied) and different P treatments.

Results and Discussion

The data on dry matter (grain + stalk) yield, grain yield and total P uptake, and their response used for assessing the residual value of fertilizer P are summarized in table 1 and 2. The yield and P uptake response for the residual P in the current season increased with the rate of applied P in the preceding season. There were seasonal differences in the residual value of P during the three seasons (1988-1990). Phosphorus uptake responses were

Table 1. Effects of fertilizer P and its residues on dry matter yield, grain yield and total P uptake of sorghum crop grown on a Vertisol consecutively for four years (1987-1990)

P rate (kg ha^{-1})	Fresh P (1987)	Residual P (1988)	Fresh P (1988)	Residual P (1989)	Fresh P (1989)	Residual P (1990)
			Dry matter yield (kg ha^{-1})			
0	2240	1580	1580	2141	2141	2616
10	5980	2630	4690	2630	4574	3765
20	7400	3260	7420	4985	5418	4809
40	8160	6520	10280	6842	7280	7286
LSD (0.05)	523	500	440	554	999	755
			Grain yield (kg ha^{-1})			
0	140	240	240	310	310	987
10	1870	580	1140	311	1450	1415
20	2620	700	2140	1040	1820	1847
40	3480	1470	3270	2300	2810	3380
LSD (0.05)	342	250	212	371	406	429
			Total P uptake (kg ha^{-1})			
0	1.88	1.08	1.46	1.46	1.47	1.10
10	4.29	1.79	3.17	1.46	4.00	1.79
20	6.19	2.10	5.69	2.69	5.27	2.82
40	10.17	4.52	9.55	4.04	8.76	5.82
LSD (0.05)	0.282	0.742	0.282	0.794	1.126	0.333

Table 2. Effects of fertilizer P and its residues (first year residual P only) on dry matter yield, grain yield and total P uptake responses of sorghum grown on a Vertisol during 1987-1990. (Yield and P uptake responses were obtained by subtracting from the respective P treatments no P treatment values)

P rate (kg ha^{-1})	Fresh P (1987)	Residual P (1988)	Fresh P (1988)	Residual P (1989)	Fresh P (1989)	Residual P (1990)
			Dry matter yield response (kg ha^{-1})			
10	3740	1050	3110	489	2433	1149
20	5160	1680	5840	2844	3277	2193
40	5920	4940	8700	4701	5139	4670
Mean	4940	2557	5883	2678	3616	2671
			Grain yield response (kg ha-1)			
10	1730	340	900	0	1140	428
20	2480	460	1900	730	1510	860
40	3340	1230	3030	1990	2500	2393
Mean	2517	677	1943	1360	1717	1227
			Total P uptake response (kg P ha^{-1})			
10	2.41	0.71	2.09	0	2.53	0.69
20	4.31	1.02	4.61	1.23	3.80	1.72
40	8.29	3.44	8.47	2.58	7.29	4.72
Mean	5.00	1.72	5.06	1.91	4.54	2.38

low especially from the residues of the lowest rate of P. The dry matter yield responses to residual P were larger and easier to discriminate. The grain yield responses to the residual P were low from the lowest rate of P application (Table 2).

The data on the residual value of P, relative to fresh P, showed that the effectiveness of the residual P increased with the rate of P applied in the previous season (Table 3). The mean effectiveness, averaged over 3 years, of the residual P relative to fresh P increased from 30 to 76 per cent for the dry matter response, 29 to 66 per cent for the grain yield response, and 28 to 45 per cent for the P uptake response.

tage for assessing the bioavailability of fertilizer P residues. The residual value of fertilizer P (52% of fresh P) one season after application using dry matter yield response as the criterion, is close to the residual value (58% of fresh P) obtained using the Mitscherlich yield response equation (Sahrawat *et al.* 1995). The results further showed that dry matter yield response as the criterion for assessing the P residues was sensitive enough even to pick up the residual P response arising from the lowest rate of P (10 kg P ha^{-1}) application (Table 2). Additionally, the method does not require any P analysis on plant tissue.

Table 3. Residual value of fertilizer P, relative to fresh P, determined at three rates of P during three seasons using dry matter yield, grain yield and P uptake responses (kg ha^{-1}) of sorghum as the criteria

Criteria used	Year	Effectiveness of residual P (% of fresh P) at 3 rates of P			
		10	20	40	Mean
Dry matter	1988	28	33	83	48
	1989	16	49	54	40
	1990	47	67	91	68
	Mean	30	50	76	
Grain yield	1988	20	18	37	25
	1989	0	38	66	52
	1990	37	57	96	63
	Mean	29	38	66	
P uptake	1988	29	24	41	31
	1989	0	27	30	29
1990	27	45	65	46	
	Mean	28	32	45	

The results showed large response of sorghum to residual P from modest rates of fertilizer P applied in the previous season. The wide range in effectiveness of the residual P indicates that they were affected by season and more importantly, by the rates of fertilizer P applied to the previous crop. Overall, on an average, the residual P was 52 per cent as effective as the fresh P using dry matter yield response as the criterion. The residual P was found to be 47 per cent as effective using grain yield response as the criterion, and only 35 per cent as effective as the fresh P using P uptake response as the criterion.

It would appear from these results that dry matter yield response can be utilized with advan-

Warren and Sahrawat (1993) evaluated several chemical methods for assessing the fertilizer P residues in the Vertisols and concluded that the development of an appropriate model based on records of P fertilization should be seen as the most effective way to predict availability of residual P. This conclusion was based on the results which showed that sorghum yield or P uptake by the crop gave the best correlations with the amounts of P applied in the previous seasons.

For assessing fertilizer P residues from fertilizer records, two parameters relating to the P recovery fraction, and effectiveness of the residual P relative to fresh P are required initially. As shown, the results of this study based on three seasons field data, dry matter response seems a sensitive index for predicting P residues (Tables 2 & 3). The data on the recovery fraction by one crop of sorghum determined during three consecutive seasons are given in table 4. It is evident that the P recovery fraction was fairly consistent despite a variability in the rainfall received during the cropping period in all the three seasons. An average P recovery fraction of 0.22 was obtained, indicating that about 22 per cent of the applied P is taken up by the first crop of sorghum. This P recovery fraction from fresh P appears within the range of P recovery fraction values reported in the literature.

Table 4. Fraction of fertilizer P recovered by one crop of sorghum, determined under rainfed cropping on a Vertisol for three years

Year	Level of applied P (kg P 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	

The data on P recovery fraction and effectiveness of fertilizer P residues (determined by dry matter response) can be utilized for predicting fertilizer P residues. Using a recovery fraction of 0.22 for sorghum crop under rainfed cropping on a calcareous Vertisol and further noticing that the residual value of fresh P in the succeeding year (first residual) was equivalent to about 50 per cent of the fresh P, we can predict the fertilizer P residues.

As an example, suppose a plot received 40 kg P ha^{-1} in the first year. Based on the P recovery value for the crop of 0.22 in the first year, the amount of P taken up by a crop of sorghum in the first year would be equal to : level of applied P (kg ha^{-1}) x P recovery fraction, or 40 x 0.22, or 8.8 kg P ha^{-1}. Therefore, the amount of fertilizer P remaining in the plot after the first year of cropping would be 40.0 - 8.8 or 31.2 kg P ha^{-1}. Since the residual P in the succeeding year is only 50 per cent as effective as the fresh P, the residual value of 31.2 kg P in terms of P uptake in the succeeding year would be equal to : (0.22/2) x 31.2, or 3.4 kg P, which would be the amount of P to be absorbed by sorghum crop during the first residual season. This estimated value is close to the actual average value of residual P, 3.6 kg P determined during three seasons from 40 kg P ha^{-1} applied in the previous season (see data in table 2). Although the extent of deviation in estimated values from the actual ones tended to be larger at the lowest rate of P they were in good agreement.

In summary, these results provide evidence that the residual value of P can be determined from the fertilization records of a crop. They have important implications for practical agriculture.

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