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Residual Phosphorus and Management Strategy for Grain Sorghum on a Vertisol

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ABSTRACT

Fertilizer phosphorus (P) use on Vertisols of the semi-arid zone in India is becoming more common, so it is important that for developing P management strategies the residual value of P is allowed. Little information is available on this aspect for crops such as sorghum under rainfed cropping. A field experiment was conducted for three years to study the response of sorghum to fertilizer P (0, 10, 20, and 40 kg P ha^{-1}) in the absence and presence of P residues from the preceding year on a Vertisol (Typic Pellustert), low in extractable P (0.4 mg kg^{-1} soil Olsen-P). Despite the variable rainfall received during the cropping season (June-September), P applied in the previous season had strong residual effects. Sorghum yield and P uptake in treatments in which P was applied at 20 or 40 kg P ha^{-1} once in two years was at par with or higher than in treatments in which 10 kg or 20 kg P ha^{-1} was added every year. Ninety percent relative grain yield was achieved at about 20 kg ha^{-1} of fresh P and the results presented show that application of 40 kg P ha^{-1} once in two years can satisfactorily meet the P requirement of sorghum on the Vertisol.

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INTRODUCTION

Sorghum (*Sorghum bicolor* (L) Moench) is an important crop of the semi-arid tropics (SAT). Among the nutrients, the deficiency of nitrogen (N), phosphorus (P) and zinc (Zn) are considered important for the growing of sorghum on calcareous Vertisols. The uncertainty of assured returns from applied fertilizer is the main reason for the low use of chemical fertilizer under rainfed cropping. Past research showed that within the assured rainfall area (>800 mm annual rainfall) of the Indian SAT, nutrient inputs are important components of improved farming systems, especially on Vertisols which are bestowed with relatively higher water-holding capacity than the other soil types (El-Swaify et al., 1985; Burford et al., 1989).

We initiated research for developing P management strategy for grain sorghum on Vertisols under rainfed cropping. The results of this research showed that the Vertisols have low P sorption capacity and the sorbed P remained in an easily desorbable form (Sahrawat and Warren, 1989; Shailaja and Sahrawat, 1990). These investigators support the hypothesis that P is more freely available to crops on calcareous Vertisols than is indicated by the usual calibration of Olsen-P (Sahrawat and Warren, 1989). Equally importantly, research on the calibration of soil test for P showed that under similar agroclimatic conditions, the critical limit of available P (Olsen-P) is lower for the clayey Vertisol (2.8 mg P kg^{-1} of soil) than in the nearby sandy Alfisol (5 mg P kg^{-1}), roughly by a factor of two (Sahrawat et al., 1996). These results are consistent with the results on P response of sorghum, which showed that significant responses to applied P by sorghum were obtained on Vertisols with available P (Olsen-P) lower than 2.5 mg P kg^{-1} soil (Sahrawat, 1988; Burford et al., 1989; Sahrawat et al., 1995, 1999).

Fertilizer P use on Vertisols is becoming more common, it is, therefore, important that the residual value of P be considered while determining the fertilizer P requirement of a crop (Warren and Sahrawat, 1993). Little information is available on this aspect for crops such as sorghum grown on Vertisols under rainfed cropping (Probert et al., 1987; Sahrawat et al., 1995). This paper presents results that stress the importance of allowing for the residual value of P in developing P management strategies for grain sorghum on a Vertisol under rainfed cropping.

MATERIALS AND METHODS

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

Soil

The soil at the experimental site belongs to the Kasireddipalle series and is a benchmark Vertisol (Typic Pellustert) at the ICRISAT Center. Some characteristics

TABLE 1. Some characteristics of the Vertisol (Typic Pellustert) at the experiment site.

Soil characteristics	
Clay (g kg^{-1})	530
Sand (g kg^{-1})	210
Silt (g kg^{-1})	260
pH (1:2 water)	8.3
Organic C (g kg^{-1})	3.3
Total N (mg kg^{-1})	401
CEC (cmol kg)	49.2
Total P (mg kg^{-1})	150
Olsen-P (mg kg^{-1})	0.4
Exchangeable cations (mg kg^{-1})	
K	232
Ca	7575
Mg	1156
Na	184
DTPA extractable Zn (mg kg^{-1})	5.8
$CaCO_3$ (g kg^{-1})	56

of the surface soil (0-0.15 m) before initiation of the field experiment are given in Table 1. For soil analysis, pH was 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 analysis was done by the hydrometer method (Gee and Bauder, 1986) and carbonate content was determined by acid neutralization (Allison and Moodie, 1965). Total P content was determined by digestion of soil with perchloric acid, and extractable P was measured by extracting soil samples with 0.5 *M* $NaHCO_3$ as described by Olsen and Sommers (1982). Cation exchange capacity (CEC) (Chapman, 1965), exchangeable K, Ca, Mg, and Na (Jackson, 1967), and extractable Zn (Lindsay and Norvell, 1978) were also determined.

Field Experiment

Details of the field experiment were described in a previous paper (Sahrawat et al., 1995). The experiment used a split plot design with four replications. The main plot was sorghum cultivar and split plot treatment was fertilizer P. Diammonium phosphate (DAP) was used as the fertilizer P source, 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 4 sub-plots and the 4 rates of fresh P applied in the sub-plots. In the 1989 cropping season, the sub-plots were further split in the same manner to give sub-sub-plots for the application of the 4 rates of fresh P in 1989. All plots received uniform rates

TABLE 2. Eight P treatment combinations used in the study to compare the performance of sorghum in response to fertilizer P and its residues (first residual only) on a Vertisol in a field experiment conducted for three years (1987-1989).

Treatment combinations of P	Abbreviated form used in Figures 1-3
10 kg P ha^{-1} in 1987 and 1988	P10(87) - P10(88)
20 kg P ha^{-1} in 1987 and residual P in 1988	P20(87) - PR(88)
20 kg P ha^{-1} in 1987 and 1988	P20(87) - P20(88)
40 kg P ha^{-1} in 1987 and residual P in 1988	P40(87) - PR(88)
10 kg P ha^{-1} in 1988 and 1989	P10(88) - P10(89)
20 kg P ha^{-1} in 1988 and residual P in 1989	P20(88) - PR(89)
20 kg P ha^{-1} in 1988 and 1989	P20(88) - P20(89)
40 kg P ha^{-1} in 1988 and residual P in 1989	P40(88) - PR(89)

of N, K, and Zn. Nitrogen was applied at a rate of 120 kg N ha^{-1}, 36 kg at sowing and the rest at 3 weeks after emergence of the crop. Nitrogen application rate by DAP at sowing of the crop was balanced by applying urea in treatments that received 0, 10, and 20 kg P ha^{-1}. Potassium chloride (KCl) was used to supply K at a rate of 90 kg K ha^{-1} and zinc sulfate ($ZnSO_4$) was used to supply Zn at a rate of 10 kg Zn ha^{-1}.

One sorghum (cv CSH 6) crop was grown each year in the rainy (wet) season (June to September) under rainfed conditions. The crop was seeded at a spacing of 0.50x0.16 m providing a final stand of 125,000 plants ha^{-1}. At maturity, the crops were harvested from an area of 3x2 m (gross area 4x4 m) of each sub-sub-plot. The harvested crop was separated into grain and stalk, and oven dried at 60°C. Grain yield is expressed at 14% moisture content.

Selected P treatments dealing with the response of sorghum to fresh P and the first residual P—fresh P in 1987/fresh P in 1988; fresh P in 1987/residual P in 1988; fresh P in 1988/fresh P in 1989; fresh P in 1988/residual P in 1989—were used in this paper. Details of the eight P treatment combinations used for comparing the response of sorghum to fresh P and residual P are given in Table 2.

During the growing season rainfall 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.

The grain and stalk samples from the harvested sorghum crop were analyzed for P contents. The plant materials were digested, and P in the digests was determined by an autoanalyzer colorimetric procedure (Technicon Industrial Systems, 1972).

The data were statistically analyzed using the analysis of variance procedure. The Cate and Nelson (1965) method of graphic presentation of relationship between fertilizer P and relative grain yield was used to arrive at a fertilizer rate that achieved 90% relative grain yield. Relative grain yield was calculated relative to the maximum yield, obtained with the application of 40 kg P ha^{-1}.

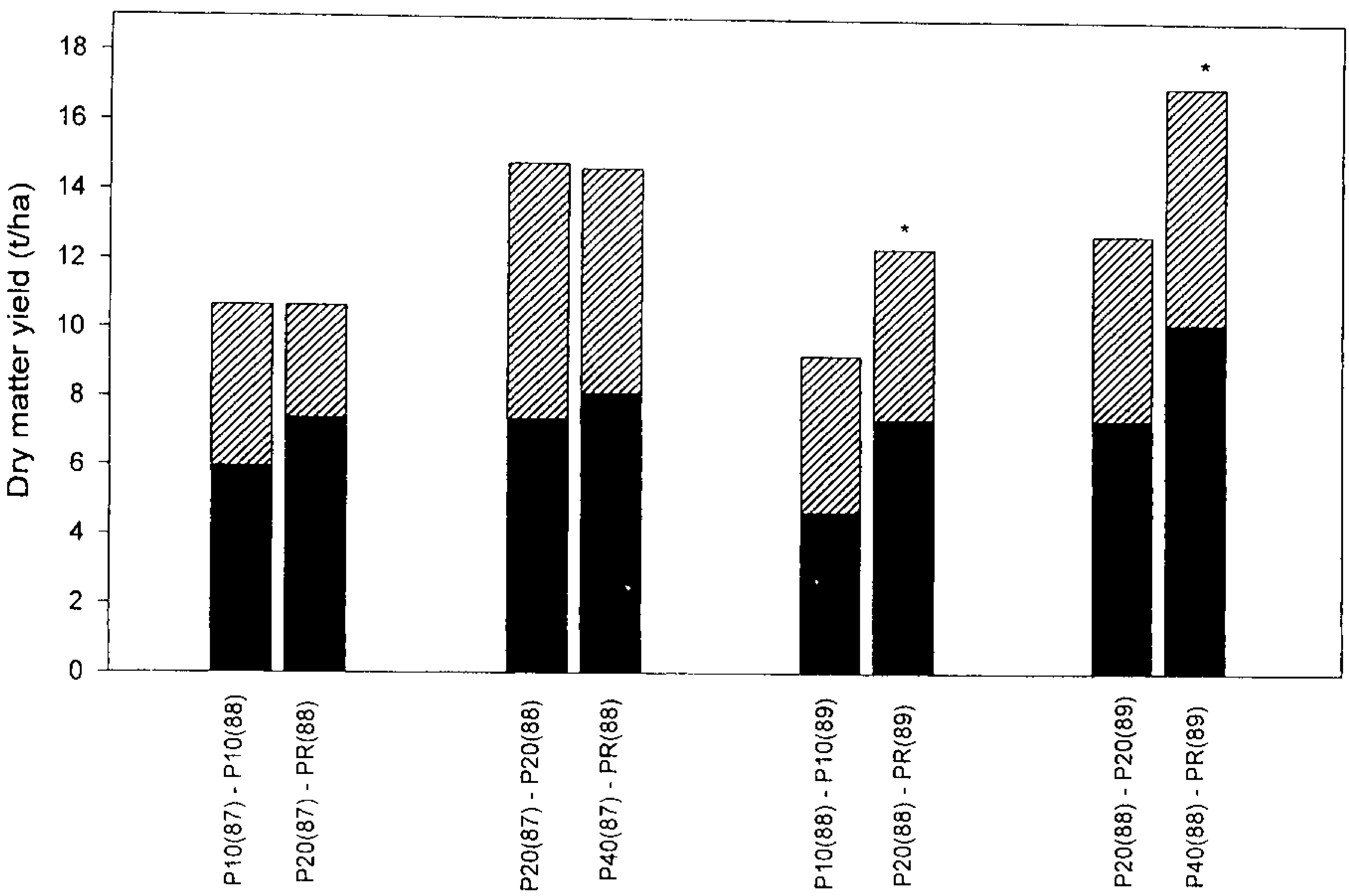

FIGURE 1. Effects of eight treatment combinations of fresh and residual P on the dry matter yield of sorghum grown on a Vertisol for three years (1987-1989). * indicates treatment is significantly different at $P<0.05$. For explanation of the various treatments see Table 2.

RESULTS AND DISCUSSION

During each of the three years the application of P fertilizer significantly increased sorghum yield and P uptake. Despite a large variability in the rainfall received during the growing season, P response was obtained up to 40 kg P ha^{-1} rate for yield and P uptake (Sahrawat et al., 1995).

There were seasonal differences in the highest yield achieved during three years. For example, the higher amount of rainfall received during the 1988 growing season (941 mm compared to 604 mm in 1987, and 583 mm in 1989) caused loss of applied N. Apparently, N deficiency in the sorghum crop reduced the overall yield level even at the highest rate of applied P or P residues from the previous year. We have observed that high losses of applied N, most probably via denitrification, can occur in the Vertisols in a high rainfall season when the soil profile is fully charged with water and these clay soils become partially anaerobic (Moraghan et al., 1984; Hong et al., 1992). Sahrawat et al. (1999) also found that in a season with higher

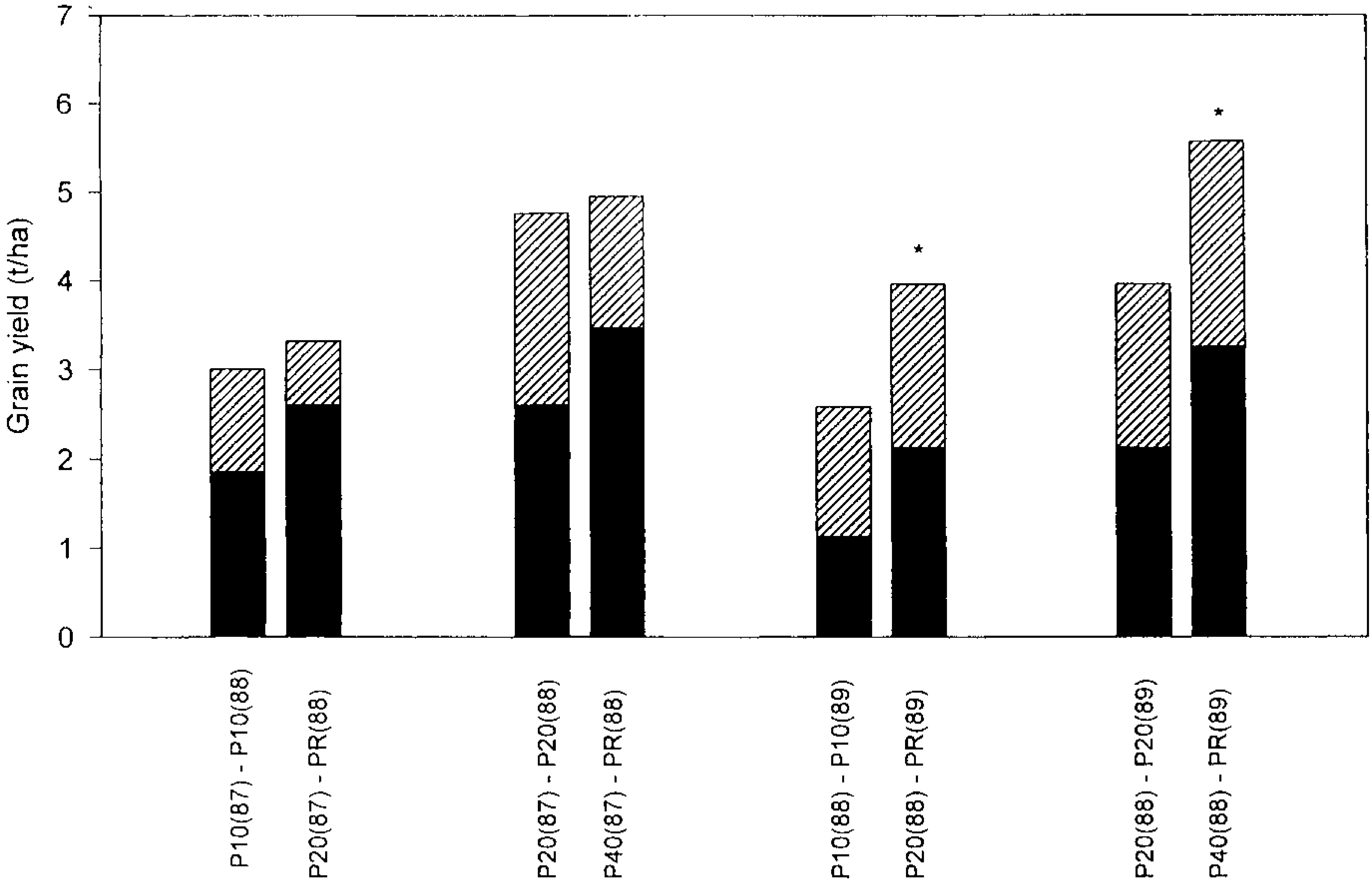

FIGURE 2. Effects of eight treatment combinations of fresh and residual P on the grain yield of sorghum grown on a Vertisol for three years (1987-1989). * indicates treatment is significantly different at P<0.05. For explanation of the various treatments see Table 2.

rainfall, the leaf P concentration in the sorghum crop at 40 kg P ha^{-1} was considerably lower than in the seasons when the rainfall was lower, but fairly distributed. This was caused by loss of N which affected utilization of P.

The results of eight P treatment combinations, consisting of various combinations of P rates and fresh and residual P in 1987-1988 and 1988-1989 for dry matter production (Figure 1), grain yield (Figure 2), and P uptake (Figure 3) showed that sorghum yield and P uptake in treatments in which P was applied at 20 or 40 kg P ha^{-1} once in two years was at par with or higher than in the treatments in which 10 or 20 kg P ha^{-1} was applied every year. In Figures 1-3, treatments marked with an asterisk (*) indicate that the yield or P uptake was significantly different at P<0.05.

It is implied that the practice in which fertilizer P is added at 20 kg P ha^{-1} once in two years can replace the practice in which 10 kg P ha^{-1} is applied every year. Similarly, the P management strategy of applying 40 kg P ha^{-1} once in two years is an able replacement for the practice of applying fertilizer P at a rate of 20 kg P ha^{-1} each year.

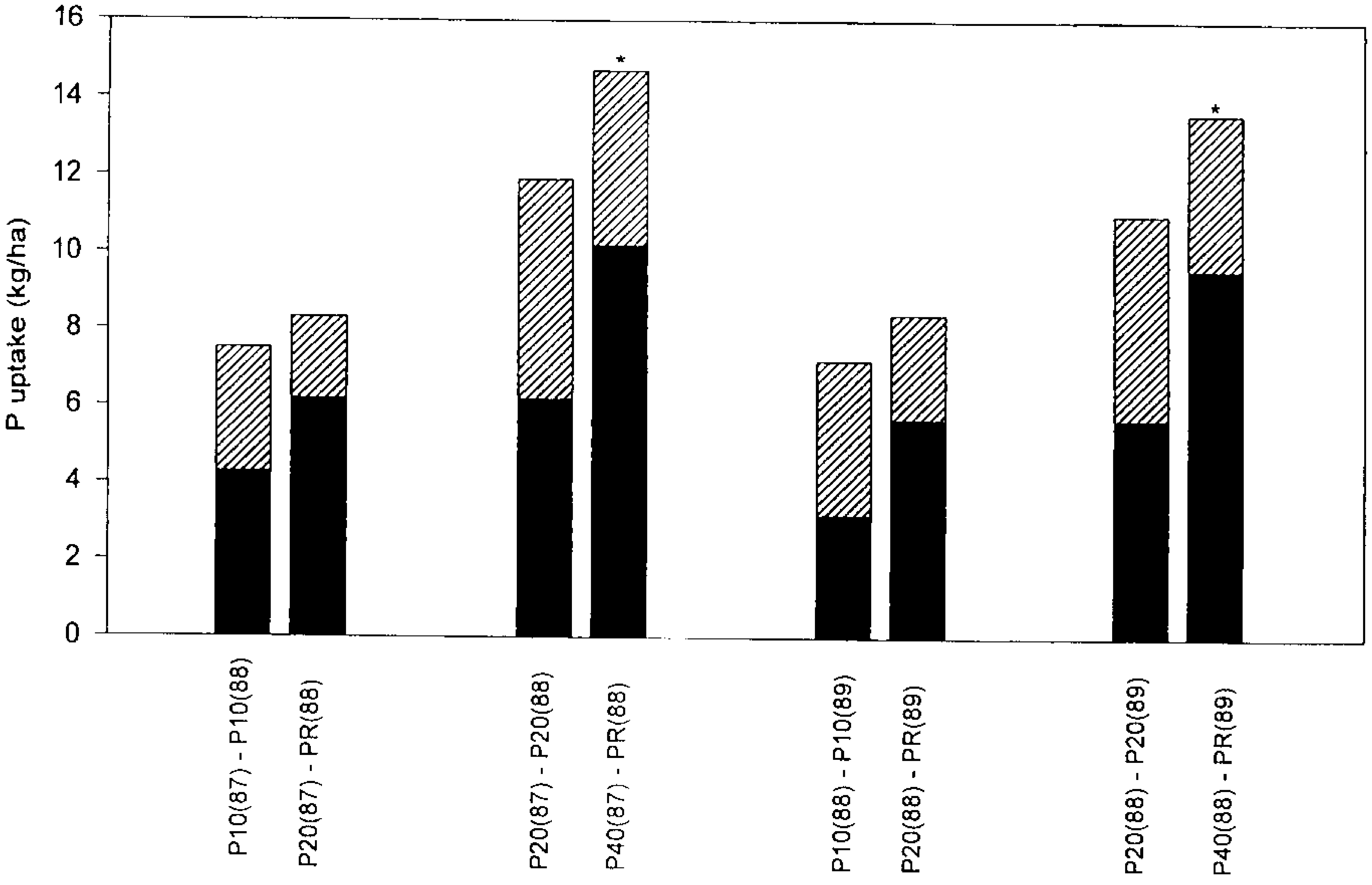

FIGURE 3. Effects of eight treatment combinations of fresh and residual P on the total P uptake by sorghum grown on a Vertisol for three years (1987-1989). * indicates treatment is significantly different at $P<0.05$. For explanation of the various treatments see Table 2.

The residual value of fertilizer P appears attractive even from moderate rates of applied P. These results support the earlier conclusion, that in the Vertisols P is more freely available than indicated by soil tests (Sahrawat and Warren, 1989; Warren and Sahrawat, 1993). Evidently, P sorption is reversible to a greater extent in the calcareous Vertisols (Sahrawat and Warren, 1989; Shailaja and Sahrawat, 1990) compared to other soil types such as Ultisols and Oxisols (Warren, 1992; Sahrawat et al., 1997; Linquist et al., 1996).

In a three-year field experiment the mean apparent recovery of fertilizer P on the Vertisol by one crop of sorghum was found to be 22% (Sahrawat et al., 1999) which is much higher than the P recovery values reported from tropical Ultisols and Oxisols (Warren, 1992; Sahrawat et al., 1997). The residual value of P on tropical soils such as Ultisols and Oxisols has been reported to be considerably lower than those obtained on the calcareous Vertisol (Warren, 1992; Linquist et al., 1996; Sahrawat et al., 1997). Sahrawat et al. (1995) reported that with sorghum as the test crop, fertilizer P applied in the previous year was 58% as effective as fresh P. From the results of the present study it would appear that about one-third of the fertilizer P applied was recovered by sorghum during two years of cropping.

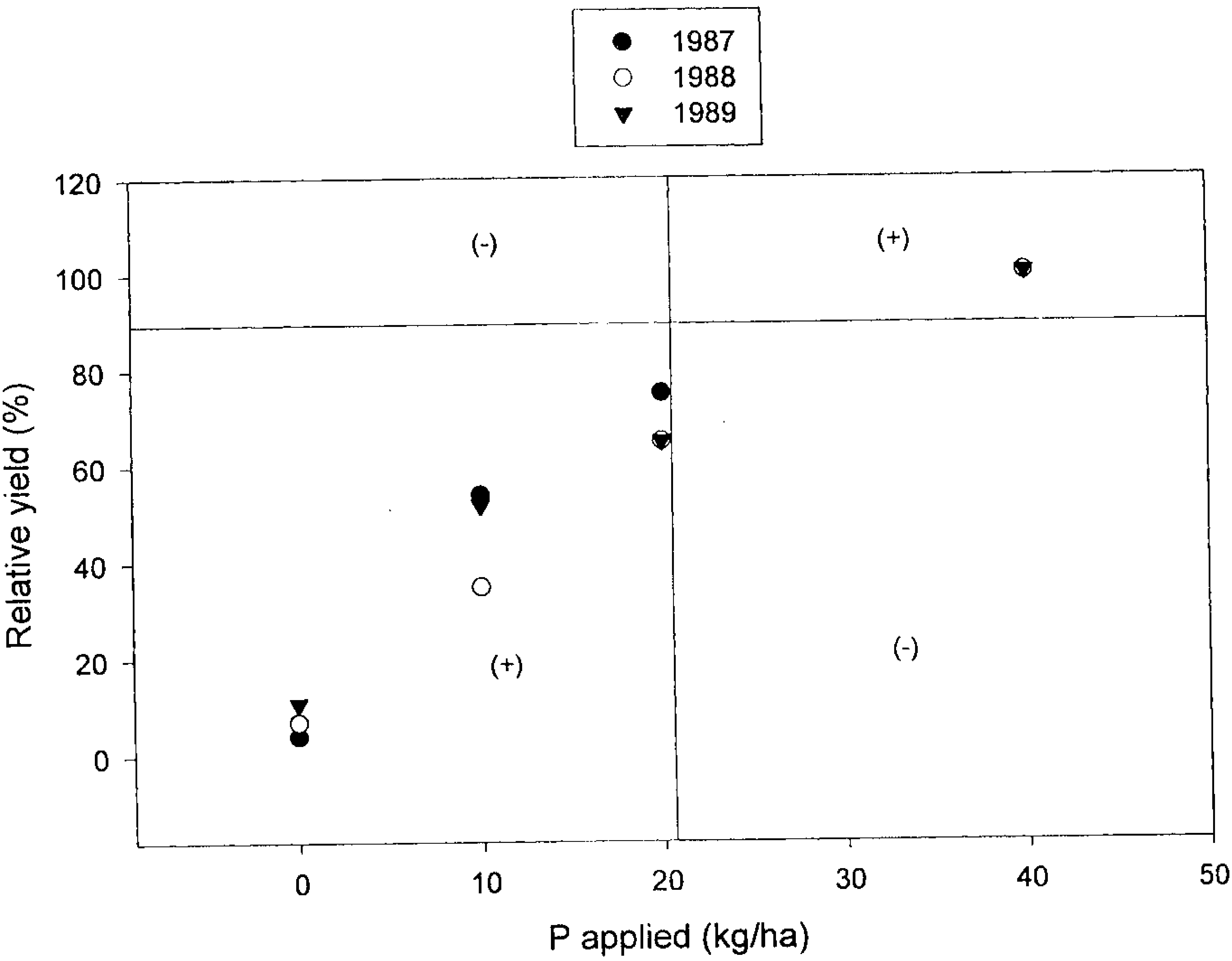

FIGURE 4. Relationship between relative grain yield of sorghum and fertilizer P applied on a Vertisol in a field experiment conducted for three years (1987-1989). Each point represents an average value of four replications.

Graphic presentation of the relationship between relative grain yield and fertilizer P applied, for three years data on P response of sorghum to fresh P, showed that 90% relative grain yield was achieved at about 20 kg P ha^{-1} (Figure 4), again indicating modest P requirement for crops such as sorghum on the Vertisol.

The practical implications of these results are that application of fertilizer P at a rate of 40 kg P ha^{-1} once in two years can satisfactorily meet the P requirement of sorghum at the 90% relative yield level, and can replace the practice of applying 20 kg P ha^{-1} each year.

REFERENCES

Allison, L.E. and C.D. Moodie. 1965. Carbonate. pp. 1379-1400. 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.

Cate, Jr., R.B. and L.A. Nelson. 1965. A Rapid Method for Correlation of Soil Test Analyses with Plant Response Data. Tech. Bull. 1. North Carolina Agricultural Experiment Station, International Soil Testing Series, Raleigh, NC.

Chapman, H.D. 1965. Cation exchange capacity. pp. 891-901. In: C.A. Black (ed.), Methods of Soil Analysis. Agronomy 9. American Society of Agronomy, Madison, WI.

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.

El-Swaify, S.A., P. Pathak, T.J. Rego, and S. Singh. 1985. Soil management of optimized productivity under rainfed conditions in the semi-arid tropics. Adv. Soil Sci. 1:1-64.

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.

Hong, C.W., J.C. Katyal, and P.L.G. Vlek. 1992. Losses and utilization of nitrogen by sorghum as affected by the depth of a swelling clay soil. J. Agron. Crop Sci. (Berlin) 18:263-271.

Jackson, M.L. 1967. Soil Chemical Analysis. Prentice-Hall, New Delhi, India.

Lindsay, W.L. and W.A. Norvell. 1978. Development of DTPA soil test for zinc, iron, manganese, and copper. Soil Sci. Soc. Am. J. 42:421-428.

Linquist, B.A., P.W. Singleton, K.G. Cassman, and K. Keane. 1996. Residual phosphorus and long-term management strategies for an Ultisol. Plant Soil 184:47-55.

Moraghan, J.T., T.J. Rego, R.J. Buresh, P.L.G. Vlek, J.R. Burford, S. Singh, and K.L. Sahrawat. 1984. Labelled nitrogen fertilizer research in the semi-arid tropics. II. Field studies on a Vertisol. Plant Soil 80:21-33.

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.

Probert, M.E., I.F. Fergus, B.J. Bridge, D. McGarry, C.H. Thompson, and J.S. Russell. 1987. The Properties and Management of Vertisols. CAB International, Wallingford, Oxon, UK.

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.P. Jones, and S. Diatta. 1997. Direct and residual phosphorus effects on yield and phosphorus efficiency of upland rice in an Ultisol. Nutr. Cycl. Agroecosyst. 48:209-215.

Sahrawat, K.L., M.H. Rahman, and J.K. Rao. 1999. Leaf phosphorus and sorghum yield under rainfed cropping of a Vertisol. Nutr. Cycl. Agroecosyst. 54:93-97.

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 soils. 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. 1992. Fertilizer Phosphorus: Sorption and Residual Value in Tropical African Soils. NRI Bull. 37. Natural Resources Institute, Chatham, UK.

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