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Leaf phosphorus and sorghum yield under rainfed cropping of a Vertisol

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Abstract

Little attention has been devoted to the calibration of plant P tests for sorghum, especially under rainfed cropping although information is needed for developing an efficient P management strategy for increasing crop productivity. A field experiment was conducted for three years (1987–1989) to study the response of sorghum to fertilizer P (0, 10, 20 and 40 kg P ha^{-1}) on a Vertisol, low in extractable P, at the ICRISAT Center, Patancheru (near Hyderabad), India. One sorghum crop was grown each year during the rainy season (June–September). Leaf tissue samples consisting of newest, fully-developed leaf, were collected at 50% flowering stage of the crop, for establishing relationship between leaf P concentration and grain yield. During the three years,sorghum grain yield and leaf P concentration increased in response to P application up to 40 kg P ha^{-1} and the leaf P concentration was linearly related to grain yield (r^2 varied from 0.724 to 0.993). The critical leaf P concentration at 90% of the maximum grain yield was found to be about 0.25% P. Phosphorus content in the grain was not significantly correlated to yield.

Introduction

Sorghum (*Sorghum bicolor* (L.) Moench) is an important crop of the semi-arid tropics (SAT). The mineral nutrition and fertilizer management of grain sorghum have been extensively reviewed (Clark, 1982; Myers and Asher, 1982; Grundon et al., 1987; Katyal and Das, 1993). The low nutrient status of most semi-arid tropical soils has been recognized but fertilizer use under rainfed agriculture across the SAT is low except under irrigated conditions (Burford et al., 1989).

Deficiencies of N, P and Zn are common for crops such as sorghum. Little attention has been devoted to calibrating the soil and plant tests for P in the field for sorghum under rainfed conditions (Tandon, 1987; Jones et al., 1990; Katyal and Das, 1993). Such information is needed to improve fertilizer P recommendations, especially for Vertisols in which the response of crops such as sorghum to added P is generally less predictable than in other soil types under similar agroclimatic conditions (Sahrawat et al., 1995). One reason is the uncertainity of the availability of natural and residual P. Secondly, it appears that P is more freely available in calcareous Vertisols than is suggested by the usual calibration of Olsen-P (Warren and Sahrawat, 1993).

In a previous paper, we reported results on the calibration of soil test for sorghum grown on a Vertisol and an Alfisol under rainfed conditions (Sahrawat et al., 1996). The results showed that the critical Olsen-P in the Vertisol was 2.8 mg P kg^{-1} soil compared to 5 mg P kg^{-1} soil for the nearby Alfisol. The critical limit of extractable P was lower for the clayey Vertisol than the sandy Alfisol.

While soil P tests are useful in determining the long-term fertilizer requirements of crops, plant P tests are necessary to correct the nutrient deficiency of the current crops. Under rainfed agriculture, the plant P tests become further 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

Table 1. Characteristics of the soil at the experimental site

Soil characteristic	
pH (1:2 water)	8.28
Organic C(%)	0.33
Total N (mg kg^{-1})	401
Clay (%)	53
Sand (%)	21
Silt (%)	26
CEC (cmol kg^{-1})	49.2
Total P (mg kg^{-1})	150
Extractable P, 0.5 M $NaHC0_3$ (mg kg^{-1})	0.4
Exchangeable cations,1 N NH_40AC (mg kg^{-1})	
Potassium	232
Calcium	7575
Magnesium	1156
Sodium	184
Extractable Zn, DTPA (mg kg^{-1})	5.8
$CaCO_3$ (%)	5.6

between plant P concentration and yield. The work reported in this paper was undertaken to calibrate plant tissue test by establishing relationship between leaf P content and sorghum yield in a field experiment conducted for three consecutive years.

Materials and methods

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

The soil at the experimental site belongs to the Kasireddipalle series, a benchmark Vertisol (Typic Pellustert) at the ICRISAT Center. Some important characteristics of the surface soil (0–15 cm) are given in Table 1. For the analyses reported in Table 1, 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). Particle size 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 determined by extracting the soil samples with 0.5 M $NaHCO_3$ as described by Olsen and Sommers (1982). Cation exchange capacity (Chapman, 1965), exchangeable K, Ca, Mg and Na (Jackson, 1967) and extractable Zn (Lindsay and Norvell, 1978) were also determined.

Details of the field experiment were described in a previous paper (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 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 fresh P in 1989. 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 sulfate 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 season (June to September) under rainfed conditions. The crop was seeded at a spacing of 50 cm $\times$ 16 cm providing a final stand of 125000 plant ha^{-1}. During each of the three years of field experimentation, leaf samples consisting of newest, fully- developed leaves, were collected at the 50% flowering stage of the crop. Twenty plants, at random, were selected for leaf sampling in each of the four replicate plots. The leaf samples were dried at 60 °C, ground and analysed for P content. Grundon et al. (1987) recommended that for grain sorghum the youngest leaf on which the legule has fully emerged be chosen as the standard index leaf.

At maturity, the crops were harvested from an area of 3 $\times$ 2 m (gross area 4 $\times$ 4 m) of each sub-sub-plot. The harvested crop were separated into grain and stalk, and oven dried at 60 °C. Selected treatments dealing with the response of sorghum to fresh P in each of the three years (1987–1989) are used in this paper.

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 in 1989.

The grain and stalk samples of sorghum were analysed for P contents. The plant materials were digested and P in the digests was determined by an auto-

Table 2. Effects of P fertilization on grain yield, P concentration in index leaf (newest, fully-developed leaf) and P content in grain of sorghum,for three years (1987–1989) at the ICRISAT Center

P rate (kg ha^{-1})	Grain yield (t/ha)	Leaf P content (%)	Grain P content (%)
1987			
0	0.14	0.15	0.22
10	1.87	0.21	0.15
20	2.62	0.23	0.17
40	3.48	0.27	0.24
SE/Sig.	0.189	*	*
1988			
0	0.24	0.16	0.18
10	1.14	0.18	0.17
20	2.14	0.21	0.17
40	3.27	0.20	0.21
SE/Sig.	0.117	*	*
1989			
0	0.31	0.17	0.20
10	1.45	0.22	0.18
20	1.82	0.25	0.20
40	2.81	0.28	0.24
SE/Sig.	0.224	*	*

* Significant treatment effects at $p < 0.05$.

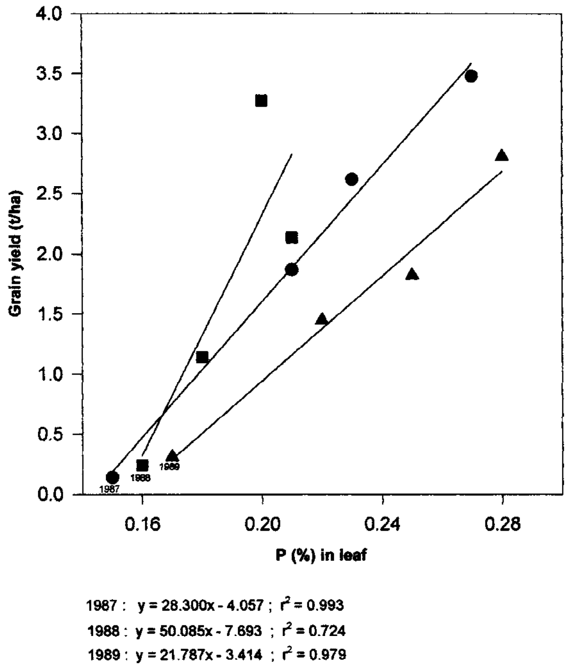

Figure 1. Relationship between grain yield and P content in the index leaf (newest, fully-developed leaf) at flowering in sorghum grown on a Vertisol for three years (1987–1989). Each point represents an average value of four replications.

analyser colorimetric procedure (Technicon Industrial Systems, 1972).

The data were statistically analysed using the analysis of variance procedure. Relationship between leaf P and grain yield was worked out using regression analysis. The Cate and Nelson (1971) method of graphic presentation of relationship between leaf P and relative sorghum grain yield was used to arrive at a critical limit of leaf P. Relative grain yield was calculated relative to the maximum yield, obtained with the application of P at 40 kg P ha^{-1}. The Cate and Nelson method has been found to be useful and has practical advantages in addition to showing whether good correlation existed. It divided the data into responsive and non-responsive populations (see for example, Dahnke and Olson, 1990).

Results and discussion

During each of the three years the application of P fertilizer significantly increased sorghum grain yield and index leaf P concentration (Table 2). Despite a large variability in the rainfall received during the growing seasons, P response was obtained up to 40 kg P ha^{-1} rate for both grain yield and index leaf P concentration.

While grain yield increased with the application of P at 10, 20 and 40 kg P ha^{-1}, the grain P content decreased, compared to no P treatment, with the first two rates of P application (10 and 20 kg P ha^{-1}). Grain P, however, was increased with the application of P at 40 kg P ha^{-1} (Table 2). This effect might have been caused by increased plant growth due to increased application of P.

Regression of grain yield on leaf P concentration, showed a linear relationship between grain yield and index leaf P concentration in each of the three years (Figure 1). The prediction of sorghum grain yield by leaf P concentration showed different trends as judged by the slope of the regression lines. The prediction of grain yield by leaf P was excellent in the 1987 (r^2 = 0.993) and 1989 (r^2 = 0.979) cropping seasons and was lower in the 1988 season (r^2 = 0.724). 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,

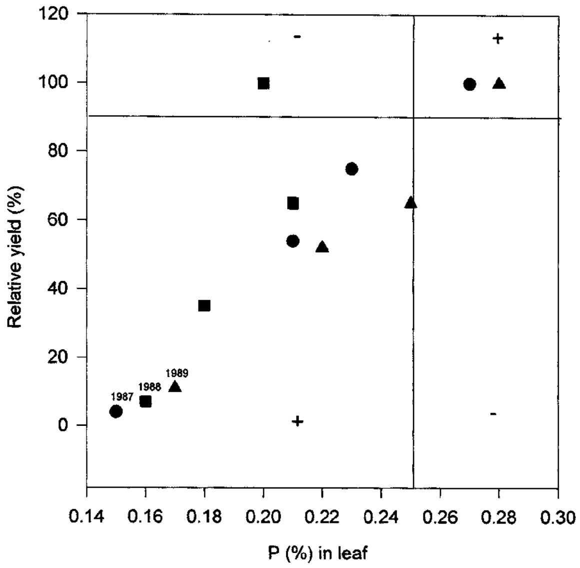

Figure 2. Relationship between relative grain yield and P content in the index leaf (newest, fully-developed leaf) at flowering in sorghum grown on a Vertisol for three years (1987–1989). Each point represents an average value of four replications.

N deficiency in the sorghum crop reduced the overall yield level, especially that achieved at the highest rate of P. The leaf P concentration at 40 kg P ha^{-1} rate was considerably lower in 1988 than in 1987 and 1989 seasons.

The linear relationship between leaf P and grain yield was indicative of the fact that quite large levels of P have to be applied to get near maximum yields, and is in accord with our earlier observation (Sahrawat et al., 1995). The relationship between sorghum grain yield and effective P rates (obtained by considering both fresh P and residual P) obtained by using 64 P treatments which received P levels from 0 to 120 kg P ha^{-1}, showed that the grain yield response continued up to 70.5 kg effective P ha^{-1}. A grain yield of over 3.8 t ha^{-1} was achieved at the highest rate of effective P. The effective P rate consisted of 40 kg P ha^{-1} applied in 1989 plus the residues of 40 kg P ha^{-1} of fertilizer added each in 1987 and 1988 cropping seasons. This high P requirement of the Vertisol is due to its high P buffering capacity (Sahrawat and Warren, 1989).

Using the Cate and Nelson (Cate and Nelson, 1971) method of graphical presentation of the relationship between leaf P and relative grain yield for the three seasons pooled data, it was found that 90% of the maximum grain yield was achieved at a leaf P concentration of about 0.25% (Figure 2). As noted earlier the method was found to be effective in separating the responsive populations from the non-responsive (Dahnke and Olson, 1990). These results on the index leaf P concentration are within P concentration range reported by other workers. For example, Lockman (1972) reported that P concentration in the range of 0.2 to 0.6% P in whole shoots of sorghum plants, depending on the growth stage of the crop, (up to growth stage 3), represented the sufficiency range for the sorghum crop. The contents of P in the whole shoots were especially high during the vegetative growth stage of the plants. Similarly, a critical concentration of 0.25% P in the second blade below apex at full heading was reported for grain sorghum (see Jones et al., 1990).

Based on a review of literature for grain sorghum, Reuter (1986) classed P concentrations between 0.15 and 0.35% in the upper leaves of sorghum plants at anthesis and during grain filling, as adequate for sorghum growth. As mentioned earlier, field data, especially for sorghum under rainfed conditions, are scarce (Jones et al., 1990). Our results indicate that a P concentration of at least 0.25% in the newest, fully-developed leaf is needed for sorghum growth and near optimum yield under the prevailing agroclimatic conditions. However, on the Vertisols, which have higher water holding capacity than other soil groups such as Alfisols, nutrients such as P are critical for the optimum productivity of cereals such as sorghum under rainfed conditions. The response to applied nutrients in the semi-arid tropical areas are more assured on these soils because of their higher water holding capacity (Burford et al., 1989).

Regression of grain yield on grain P content, showed that P content in grain was a poor indicator of sorghum grain yield (r = 0.288). This observation is in line with the observation made by several researchers for corn and sorghum (for review see Jones et al., 1990; Mallarino, 1996).

In summary, our results showed that the trends in linear relatioship between leaf P and sorghum grain yield varied during the three seasons. The prediction of grain yield by leaf P was excellent in two out of the three seasons. In one season the prediction was lower although good in predicting the yield. A critical index leaf concentration of about 0.25% P was suggested for grain sorghum production in the field under rainfed conditions.

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