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Effects of nitrogen on growth, and nitrogen and phosphorus uptake in tops and roots of sorghum grown in an Alfisol and a Vertisol*

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Abstract. A greenhouse pot experiment was conducted to study the effects of added nitrogen (0, 10, 25, 50 and 100 mg N kg^{-1} soil) on dry matter production, and N and P uptake in tops and roots of sorghum (cv CSH6) grown in a Vertisol and an Alfisol for 42 days at field capacity soil moisture content. More dry matter accumulated in the tops and roots of sorghum growing in the Alfisol than in the Vertisol. This resulted in higher N and P uptake. Top dry weight responded to N application up to 50 mg N kg^{-1} soil, whereas the root weight increased at N application up to 25 mg N kg^{-1}. Ratios of root dry weight to total plant dry weight and N uptake in roots total N uptake were similar in the two soils. Ratio of P uptake in roots to total P uptake was higher in Alfisol than in Vertisol. This result was attributed mainly to higher ratio of P content in roots compared to tops in the Alfisol.

Introduction

Field studies at the ICRISAT Center, Patancheru near Hyderabad (India) on P response of sorghum grown on Vertisols and Alfisols have shown that the response to applied P is higher in Alfisols than in Vertisols with similar levels of extractable P. These differential responses of grain sorghum to applied P could not be explained by phosphate adsorption because both soils had low phosphate adsorption capacity [4].

It is possible that P may be differentially apportioned in tops and roots of sorghum grown on Vertisol and Alfisol. If in fact this is the case, it could help explain the differential response of sorghum to P in Vertisol and Alfisol. This aspect has not been investigated earlier although it is known that P uptake by plants depends on root growth [1, 2]. Also Myers [6] found that root development of two grain sorghum hybrids (Texas 620 and Pioneer

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Table 1. Characteristics of soils used in experiment.

	Vertisol	Alfisol
pH (1:2 H_2O)	8.4	7.5
Organic C (%)	0.29	0.34
NH_4-N ($mg\,kg^{-1}$)	1	2
NO_3-N ($mg\,kg^{-1}$)	11	8
Available P ($mg\,kg^{-1}$)	10	12
Exchangeable K ($mg\,kg^{-1}$)	298	205

846) reached maximum dry matter levels by about 44 days after emergence. This suggests that short-term experiments could be useful for investigating the possible differential apportioning of P in roots of sorghum grown in the two type of soils.

The objectives of this study were to investigate the effects of N application on dry matter accumulaation, and N and P uptake in tops and roots of sorghum grown in an Alfisol and a Vertisol in a short-term greenhouse experiment under optimal conditions of soil moisture and nutrient supply.

Materials and methods

Soils

Soils used were surface (0–15 cm) samples of a Vertisol and an Alfisol from the ICRISAT Center farm, Patancheru, near Hyderabad (India). The samples were air-dried and ground to pass a 5-mm screen. A portion of each soil was ground to pass a 2-mm screen for laboratory analysis. For organic C analysis the soil samples were ground to pass a 0.5-mm sieve.

Soil pH was measured (1:2 soil to water) by a glass electrode, and organic C was determined by the method of Walkley and Black [9]. Extractable P (0.5 *M* $NaHCO_3$ extractable) and exchangeable K (1.0 N NH_4OAc, pH 7.0) were determined as described by Olsen and Sommers [7] and Jackson [5], respectively. Ammonium and nitrate-N contentd of soils were determined as described by Bremner [3]. Some characteristics of the two soils are given in Table 1.

Greenhouse trial procedure

Ten kg of soil was used per pot. Phosphorus was applied as single superphosphate (6.9% P) at rate of 40 mg P kg^{-1} soil. Nitrogen (as KNO_3) was added to supply 0, 10, 25, 50 or 100 mg N kg^{-1} soil. Zinc (as $ZnSO_4 \cdot 7H_2O$)

Table 2. Dry matter yields, and N and P concentrations of tops and roots of sorghum.

Treatment mg N kg^{-1} soil	Vertisol	Alfisol	Mean	Vertisol	Alfisol	Mean
	Yield of tops, g pot^{-1}			Yield of roots, g pot^{-1}		
0	8.0	5.2	6.6	2.6	2.0	1.3
10	15.1	20.0	17.5	4.3	5.3	4.8
25	30.0	34.0	32.0	6.3	8.2	7.2
50	34.0	42.0	38.0	6.5	7.7	7.1
100	27.0	42.0	34.5	6.1	9.3	7.7
Mean	22.8	28.6		5.2	6.5	

SE (±) of means to compare top yields: for N, 1.00; soil, 0.63; N × soil, 1.42 and to compare root yields: for N, 0.34; soil, 0.22; N × soil, 0.49.

	Vertisol	Alfisol	Mean	Vertisol	Alfisol	Mean
	N, % in tops			N, % in roots		
0	0.60	0.57	0.58	0.48	0.55	0.51
10	0.61	0.50	0.56	0.49	0.46	0.47
25	0.71	0.63	0.67	0.48	0.45	0.46
50	1.13	0.98	1.05	0.69	0.53	0.61
100	2.45	1.74	2.09	1.18	0.93	1.05
Mean	1.10	0.88		0.66	0.58	

SE (±) of means to compare N conc in tops: for N, 0.022; soil, 0.014; N × soil, 0.031 and to compare N conc in roots: for N, 0.020; soil 0.013; N × soil, 0.028.

	Vertisol	Alfisol	Mean	Vertisol	Alfisol	Mean
	P, % in tops			P, % in roots		
0	0.21	0.21	0.21	0.12	0.16	0.14
10	0.18	0.15	0.16	0.09	0.10	0.09
25	0.16	0.15	0.15	0.08	0.09	0.08
50	0.19	0.18	0.18	0.10	0.09	0.09
100	0.27	0.23	0.25	0.15	0.14	0.14
Mean	0.20	0.18		0.11	0.12	

SE (±) of means to compare P conc in tops: for N, 0.003; soil, 0.002; N × soil, 0.005 and to compare P conc in roots: for N, 0.004; soil, 0.003; N × soil, 0.006.

was added to supply 10 mg Zn kg^{-1} soil. To balance K, K_2SO_4 was added to make up to 278 mg K kg^{-1} soil in all treatments.

Water was added to bring soil water content to 38% (w/w) in the Vertisol and to 20% (w/w) in the Alfisol. These moisture contents were chosen from the results of a preliminary experiment where soil in pots was saturated for 24 h and then extra water had drained for 24 h. These are the normal water contents at field capacity for these soils. Thus five N treatments (0, 10, 25, 50 and 100 mg N kg^{-1} soil) for each soil with four replications were arranged in a randomized complete block.

Table 3. Nitrogen and P uptake (mg pot^{-1}) in tops and roots of sorghum.

Treatment mg N kg^{-1} soil	Vertisol	Alfisol	Mean	Vertisol	Alfisol	Mean
	N uptake in tops			N uptake in roots		
0	48	29	38	12	11	11
10	92	100	96	21	24	22
25	209	216	212	30	38	34
50	385	403	394	44	41	42
100	658	726	692	71	86	78
Mean	278	295		36	40	

SE (±) of means to compare N uptake in tops: for N, 10.2; soil, 6.5; N × soil, 14.5 and to compare N uptake in roots: for N, 1.8; soil, 1.1; N × soil, 2.5.

	P uptake in tops			P uptake in roots		
0	17	11	14	3	4	3
10	27	30	28	4	9	6
25	46	51	48	5	13	9
50	65	76	70	7	15	11
100	74	97	85	9	26	17
Mean	46	53		6	13	

SE (±) of means to compare P uptake in tops: for N, 1.9; soil, 1.2; N × soil, 2.6 and to compare P uptake in roots: for N, 0.6; soil, 0.4; N × soil, 0.9.

Eight sorghum (cv CSH6) seeds pot^{-1} were sown. On day 10 after germination, the plants were thinned to 4 plants pot^{-1}. Plants were watered daily and harvested at 42 days after sowing (DAS).

At harvest top and root samples were separated and dried at 60 °C and dry weights recorded. The top and root samples were finely ground for chemical analysis.

Plant samples were wet digested using digestion block, and N and P determined by an autoanalyzer colorimetric procedure [8].

Results

Dry matter

The dry matter yields of tops and roots (Table 2) were significantly higher in the Alfisol than in the Vertisol except in the control (N = 0) where the yields were higher in the Vertisol. For both soils, top weight increased with added N up to 50 mg N kg^{-1} soil rate. The ratios of root weight to total dry weight were similar in the two soils. On average, roots constituted 19.4 and

20.2% of the total dry matter of sorghum in the Vertisol and the Alfisol, respectively.

Nitrogen and phosphorus concentrations

Nitrogen concentration in the tops and the roots (Table 2) was significantly higher in the Vertisol than in the Alfisol and the ratios of N concentration in roots to tops were higher for sorghum grown in the Alfisol than the Vertisol except at N = 50. Phosphorus concentration in the tops were significantly higher in the Vertisol except at N = 0 whereas P concentration in the roots were higher in the Alfisol except at N = 50 and 100 (Table 2). The ratios of P concentration in roots to tops were significantly higher in the Alfisol than in the Vertisol.

Nitrogen and phosphorus uptake

As with dry matter yields of tops and roots, the uptake of N and P by tops and roots of sorghum was greater in the Alfisol with added N (Table 3). It was also found that the ratios of N uptake in roots to total N uptake of sorghum were similar in both the soils with added N. However, the results for P were in marked contrast. The ratios of P uptake in roots to total P uptake were always higher for sorghum grown in the Alfisol than in the Vertisol.

Discussion

There is no clear explanation of why the dry matter yields should be higher in the Vertisol at N = 0 and significantly lower in this soil compared to the Alfisol at all other N rates. The lower concentration of N in tops and roots may be explained at least partly on the basis of dry matter differences, i.e., due to a dilution effect. The most significant observation of this study is that the ratio of P uptake in roots to total P uptake in dry matter was always higher for the sorghum growing in the Alfisol as compared to the Vertisol. This difference is due to two factors higher P concentration in roots (compared to tops) and higher root yields.

The root distribution within the pots appeared similar for each soil although root mass was higher in the Alfisol. Whatever the reason for better growth in the Alfisol, there was higher root mass for the same volume which suggests a more intensive rooting system. This may explain why plants were able to take up more P (66 mg P pot^{-1} on average) in the Alfisol than in the

Vertisol (52 mg P pot^{-1}). However, while both Alfisol and Vertisol do not adsorb phosphate in the non-exchangeable form (phosphate not exchangeable by ^{32}P), the Vertisol holds phosphate more strongly than the Alfisol (author's unpublished data). Thus P is more easily available in the Alfisol and this coupled with higher root mas apparently results in higher P uptake.

For unexplained reasons sorghum roots are able to retain twice as much P in the Alfisol whereas P translocated to tops was higher in this soil only by a factor of 0.15. The translocation of P to the tops in Alfisol is higher than in Vertisol but is clearly not proportional to its accumulation in the roots. Apart from simple luxury consumption there is no explanation for the accumulation of higher amounts of P by sorghum roots in the Alfisol. These results show that there is differential apportioning of P in roots and tops of sorghum growing in the Alfisol and the Vertisol. There is an obvious need to verify these results under field conditions and to evaluate if differential apportioning is involved in the phosphate response soil P relationships observed in the field.

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