Widespread deficiencies of sulphur, boron and zinc in dryland soils of the Indian semi-arid tropics

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To characterize the fertility status of soils under dryland agriculture in the semi-arid regions of India, we collected 3622 soil samples from farmers' fields in watersheds, spread in several districts of Andhra Pradesh (AP; 5 districts), Karnataka (5 districts), Tamil Nadu (TN; 5 districts), Rajasthan (3 districts), Madhya Pradesh (MP; 2 districts), and Junagadh District, Gujarat. Results of the analysis of soil samples showed that almost all farmers' fields sampled were low in organic carbon and low-to-moderate in extractable phosphorus, but generally adequate in extractable potassium. The widespread deficiencies of sulphur (S), boron (B) and zinc (Zn) were most revealing; their deficiencies varied with nutrient, district and state. The deficiencies of S, B and Zn nutrients were more widespread in farmers' fields in AP, Karnataka, MP, TN and Gujarat than in the Rajasthan watersheds. Our results demonstrate that crops grown under rainfed agriculture in the semi-arid tropical regions of India not only face water shortages and deficiencies of major plant nutrients (nitrogen and phosphorus), but they also suffer from multi-nutrient deficiencies of S, B and Zn.

Keywords: Crop productivity, fertilizer recommendation, multi-nutrient deficiencies, rainfed agriculture, soil testing.

IN India, sulphur (S) and micronutrient deficiencies have been reported with increasing frequencies from intensive, irrigated production systems; and micronutrient deficiencies have been reported to be one of the main causes for yield plateau or even yield decline in irrigated intensified systems[1–4]. This is attributed to the use of soil and plant testing for diagnosing nutrient problems and their corrections through the fertilization of crops. On the other hand, little attention has been paid to diagnosing the deficiencies of secondary nutrients such as S and micronutrients in dryland production systems in the semi-arid tropical (SAT) regions of India.

Soils in the Indian SAT are marginal compared to irrigated soils. At relatively low yields of crops, the deficiencies of major nutrients, especially nitrogen (N) and phosphorus (P) are considered important for the SAT soils[5] and little research effort has been devoted to diagnose the extent of deficiencies of the secondary nutrients such as S and micronutrients in various crop production systems. It is, however, recognized and emphasized that the productivity of SAT soils is low due to water shortage. Apart from water shortage, low fertility is also an issue because it constraints crop productivity in the SAT regions of India; but in practice the deficiencies of major nutrients (N and P) are considered important. Even the inputs of major nutrients to dryland crops are meagre. Moreover, due to low productivity in the drylands, it is assumed that the mining of micronutrient reserves in soils is much less than in irrigated production systems[6].

However, for sustained increase in dryland productivity, soil and water conservation measures need to be integrated with plant nutrition, and choice of crops and their management[7]. The on-going farmer-participatory integrated watershed management programme at ICRISAT (International Crops Research Institute for the Semi-Arid Tropics), Patancheru, provided the opportunity to implement nutrient management strategy with soil and water conservation practices in farmers' fields in the Indian semi-arid tropics.

During an on-farm survey in the 1999 cropping season, we observed that soil samples collected from the Mili watershed in Lalatora village, Vidisha District, Madhya Pradesh (MP) were low in extractable S, boron (B) and zinc (Zn). The results of the follow-up field trial on the application of B and Zn significantly increased soybean yields. Following this observation, we conducted a detailed and systematic sampling and analysis of a large number of soil samples collected from the ICRISAT Consortium-managed watersheds in Andhra Pradesh (AP), Karnataka, Tamil Nadu (TN), Rajasthan, MP and Gujarat. This communication reports results on the general fertility status with emphasis on the extent of occurrence of deficiencies of S, B and Zn, as revealed by soil analysis.

The number of farmers cultivating arable land in watersheds (about 500 ha in area) varied along with land holding size and cropping systems. For effective sampling, the watersheds were divided into three groups based on the position of the fields on a toposequence: top, middle and bottom, depending on the elevation and drainage pattern. We separated different soil types in each category. For soil sampling, we randomly selected 20% farmers in each position on the toposequence, proportion to the farm size. The soil sampling programme of watersheds in various states was undertaken during 2002–06. Using stratified random sampling, we collected 8–10 cores of surface (0–15 cm depth) soils to make one composite sample. The soil samples were air-dried and powdered with a wooden hammer to pass through a 2-mm sieve. For organic carbon (C) analysis, the soil samples were ground to pass through a 0.25-mm sieve. Prepared samples were analysed for various fertility characteristics in the ICRISAT Central Analytical Services Laboratory.

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Table 1. Chemical characteristics of soil samples (1926 numbers) collected from farmers' fields in five districts of Andhra Pradesh, India, 2002–04

District	No. of fields		pH	Organic C (%)	Olsen-P (mg per kg)	Exchangeable K (mg per kg)	Extractable nutrient elements (mg per kg) S	B	Zn
Nalgonda	256	Range	5.7–9.2	0.12–1.36	0.7–24.9	34–359	1.4–24.9	0.02–1.48	0.08–16.0
		Mean	7.7	0.40	8.1	132	5.9	0.26	0.73
		% deficient[a]					86	93	73
Mahabubnagar	358	Range	5.5–9.1	0.08–1.20	0.7–61.0	25–487	1.2–98	0.02–1.62	0.12–35.60
		Mean	7.1	0.36	9.1	117	9.4	0.22	1.34
		% deficient					73	94	62
Kurnool	309	Range	5.6–9.7	0.09–1.06	0.4–31.5	33–508	1.4–26.9	0.04–1.64	0.08–4.92
		Mean	7.8	0.34	7.8	142	5.3	0.34	0.42
		% deficient					88	83	94
Ananthapur	511	Range	5.4–9.6	0.12–0.8	0.7–39.5	14–282	0.2–67.9	0.02–0.68	0.08–2.2
		Mean	7.5	0.28	7.6	70	3.6	0.20	0.55
		% deficient					95	100	86
Prakasam	492	Range	5.6–9.7	0.09–1.3	0.2–41.7	28–697	0.5–19.2	0.02–1.86	0.2–3.52
		Mean	7.8	0.43	5.7	205	4.1	0.45	0.51
		% deficient					94	70	88
	1926	Range	5.4–9.7	0.08–1.36	0.20–61.00	14–697	0.23–98.0	0.02–1.86	0.08–35.60
		Mean	7.7	0.36	7.54	133	5.6	0.30	0.71
		% deficient					89	88	82

[a]Critical limits in the soil used: 8–10 mg per kg calcium chloride extractable S; 0.58 mg per kg hot water extractable B; 0.75 mg per kg DTPA extractable Zn.

For soil analysis, pH was measured with a glass electrode using a soil-to-water ratio of 1 : 2; electrical conductivity (EC) was determined with an EC meter using a soil-to-water ratio of 1 : 2. Organic C was determined using the Walkley–Black method[8]. Exchangeable potassium (K) was determined using the ammonium acetate method[9]. Available S was measured using 0.15% calcium chloride ($CaCl_2$) as an extractant[10]; available P was measured using the sodium bicarbonate ($NaHCO_3$) test[11]. Available Zn was extracted by DTPA reagent[12], and available B was extracted by hot water[13].

The results of soil analysis for various fertility parameters, with emphasis on the concentrations of extractable or available S, B and Zn in the soil are discussed district-wise in a state.

It is known that the soils in the SAT regions of India are low in organic matter and the deficiencies of major nutrients such as N and P are most common in the production systems on these soils under dryland farming[5,14,15]. The results of the analysis of samples collected from farmers' fields in different watersheds in AP, Karnataka, TN, Rajasthan, MP and Gujarat showed that most of the fields were low in organic C, low-to-medium in extractable (available) P, but generally adequate in extractable K. The samples had a range in pH and electrical conductivity (indicative of soluble salt content; Tables 1–6).

Based on our experience at ICRISAT and also from published results, the critical limits in the soil used for separating deficient fields from non-deficient ones for available (extractable) S, B and Zn are: 8–10 mg per kg soil $CaCl_2$ extractable S, 0.58 mg per kg soil hot water extractable B, and 0.75 mg per kg soil DTPA extractable Zn in the soil. We found that field crops grown in fields deficient in S, B and Zn, according to the above-stated critical limits for S, B and Zn in the soil, gave significant yield responses to the applications of these nutrients[14]. The results were obtained from on-farm studies conducted during 2002–04 in three districts (Nalgonda, Mahabubnagar and Kurnool) of AP.

Out of the samples taken from 256 farmers' fields in the Nalgonda District, 86% was deficient in S, 93% in B and 73% in available Zn. In the Mahabubnagar District, out of 358 farmers' fields, 73% was deficient in S, 94% in B and 62% in Zn; in the Kurnool District, 88% was deficient in S, 83% in B and 94% in Zn out of 309 farmers' fields sampled. In the Ananthapur District (511 samples), 95% of the farmers' fields was deficient in S, 100% in B and 86% in Zn; in the Prakasam District (492 samples), 94% of the fields was deficient in S, 70% in B and 88% in Zn (Table 1).

Overall, out of the 1926 farmers' fields, 89% was deficient in available S, 88% in available B and 82% in available Zn (Table 1). In the light of these results, it is not surprising that application of S, B and Zn significantly increased crop yield in the on-farm studies[14]. However, under rainfed farming in the SAT regions, the crop-yield responses to added nutrients are greatly influenced and modified by the rainfall received and its distribution during the growing season[5,6].

Our results demonstrate widespread deficiencies of S, B and Zn in farmers' fields in the five districts of AP; the results have implication for production and productivity

Table 2. Chemical characteristics of soil samples (1260 numbers) collected from farmer's fields in five districts of Karnataka, India, 2005–06

District	No. of fields		pH	Organic C (%)	Olsen-P (mg per kg)	Exchangeable K (mg per kg)	Extractable nutrient elements (mg per kg) S	B	Zn
Kolar	408	Range	4.5–8.7	0.11–1.25	0.20–126	17–517	0.5–155.8	0.04–1.44	0.06–5.50
		Mean	6.7	0.37	15.3	84	7.3	0.31	0.82
		% deficient[a]					87	90	64
Tumkur	269	Range	4.8–9.6	0.10–1.05	0.20–33.2	16–402	1.1–59.6	0.06–0.98	0.14–2.34
		Mean	6.7	0.37	5.4	80	5.3	0.27	0.49
		% deficient					93	96	88
Chitradurga	231	Range	5.3–10.1	0.12–1.08	0.2–52.5	17–529	1.2–601.4	0.04–4.08	0.08–3.40
		Mean	8.0	0.40	5.6	140	18.7	0.53	0.40
		% deficient					82	75	93
Haveri	217	Range	5.1–9.0	0.31–0.89	0.6–46.0	39–267	1.8–60.7	0.08–1.58	0.20–2.32
		Mean	7.6	0.53	8.7	113	7.9	0.56	0.61
		% deficient					81	63	79
Dharwad	135	Range	5.1–8.7	0.45–1.99	0.8–54.4	37–563	1.8–118.2	0.12–2.44	0.28–4.72
		Mean	7.3	0.79	10.1	146	9.1	0.63	1.18
		% deficient					83	54	34
	1260	Range	4.5–10.1	0.1–2.0	0.2–126	16–563	0.5–601.4	0.04–4.08	0.06–5.50
		Mean	7.2	0.45	9.7	105	9.2	0.42	0.68
		% deficient					86	80	74

[a]Critical limits in the soil used are the same as in Table 1.

Table 3. Chemical characteristics of soil samples (179 numbers) collected from farmers' fields in three districts of Rajasthan, India, 2003–06

District	No. of fields		pH	Organic C (%)	Olsen-P (mg per kg)	Exchangeable K (mg per kg)	Extractable nutrient elements (mg per kg) S	B	Zn
Bundi	36	Range	6.2–8.7	0.18–1.17	0.9–20.1	23–563	3.3–51.0	0.1–0.98	0.2–1.8
		Mean	7.6	0.60	6.2	87	9.2	0.44	0.60
		% deficient[a]					72	72	67
Dungarpur	99	Range	6.2–8.0	0.48–1.99	1.0–28.2	34–240	4.0–31.3	0.28–1.50	0.88–14.10
		Mean	6.9	1.26	6.6	100	9.0	0.70	2.11
		% deficient					72	31	0
Udaipur	44	Range	7.3–9.0	0.25–2.37	2.6–41.0	52–288	3.2–274	0.22–1.50	0.70–3.92
		Mean	8.2	0.83	15.2	145	26.7	0.83	1.57
		% deficient					48	25	05
	179	Range	6.2–9.0	0.2–2.4	0.9–41.0	23–563	3.2–274	0.10–1.50	0.20–14.1
		Mean	7.4	1.02	8.6	108	13.4	0.68	1.68
		% deficient					66	38	15

[a]Critical limits in the soil used are the same as in Table 1.

of a diverse range of crops grown on these soils. On-farm trials conducted in Nalgonda, Mahabubnagar and Kurnool districts of AP during three seasons (2002–04) showed significant yield responses, compared to farmer input treatment, of maize, castor, groundnut and mung bean to the applications of S, B and Zn. The yield responses of field crops were larger when S, B and Zn were applied along with N and P. The results also demonstrated that soil testing was effective to diagnose and predict the occurrence of deficiencies of S, B and Zn in farmers' fields[14].

The results of analysis of soil samples collected from 1260 farmers' fields in watersheds in Karnataka are shown in Table 2. The deficiency of S, B and Zn varied among the five districts. In Kolar District (408 samples), 87% of the farmers' fields was found deficient in available S, 90% in B and 64% in Zn; in the Tumkur District (269 samples), 93% farmers' fields was deficient in S, 96% in B and 88% in Zn. In Chitradurga District, out of the 231 soil samples collected from farmers' fields, 82% was deficient in available S, 75% in B and 93% in Zn. In Haveri (217 samples) and Dharwad (135 samples) districts, 81%, 63% and 79%, and 83%, 54% and 34% farmers' fields were respectively, deficient in S, B and Zn.

Overall, the deficiency of S was most widespread, followed by B and Zn. In some fields high values of extractable or available S was recorded, due to the presence of free gypsum (calcium sulphate) in the soil profile.

Table 4. Chemical characteristics of soil samples (55 numbers) collected from farmers' fields in two districts of Madhya Pradesh, India, 2002–04

District	No. of fields		pH	Organic C (%)	Olsen-P (mg per kg)	Exchangeable K (mg per kg)	Extractable nutrient elements (mg per kg) S	B	Zn
Vidisha	31	Range	7.6–8.3	0.46–0.92	0.5–14.1	97–285	2.9–9.8	0.12–0.34	0.10–0.42
		Mean	8.1	0.64	2.7	212	5.1	0.2	0.23
		% deficient[a]					100	100	100
Dewas	24	Range	7.0–8.7	0.3–1.0	0.2–10.8	46–456	3.9–9.5	0.2–0.8	0.12–0.56
		Mean	8.0	0.60	2.1	137	6.3	0.5	0.24
		% deficient					100	96	100
	55	Range	7.0–8.7	0.31–1.00	0.20–14.1	46–456	2.90–9.75	0.12–0.56	0.10–0.82
		Mean	8.1	0.62	2.43	179	5.63	0.22	0.33
		% deficient					100	100	98

[a]Critical limits in the soil used are the same as in Table 1.

Table 5. Chemical characteristics of soil samples (82 numbers) collected from farmers' fields in Junagadh District, Gujarat, India, 2004

District	No. of fields		pH	Organic C (%)	Olsen-P (mg per kg)	Exchangeable K (mg per kg)	Extractable nutrient elements (mg per kg) S	B	Zn
Junagadh	82	Range	6.2–8.3	0.21–1.90	0.4–42.0	30–635	1.1–150.4	0.06–0.49	0.19–2.45
		Mean	7.5	0.77	6.9	105	16.2	0.22	0.45
		% deficient[a]					46	100	82

[a]Critical limits in the soil used are the same as in Table 1.

Table 6. Chemical characteristics of soil samples (119 numbers) collected from farmers' fields in five districts of Tamil Nadu, India, 2004–06

District	No. of fields		pH	Organic C (%)	Olsen-P (mg per kg)	Exchangeable K (mg per kg)	Extractable nutrient elements (mg per kg) S	B	Zn
Tirunelveli	39	Range	4.8–8.7	0.15–0.74	0.2–26.8	34–255	1.0–19.7	0.06–0.58	0.18–2.86
		Mean	6.7	0.39	5.5	98	4.2	0.23	0.62
		% deficient[a]					97	97	72
Salem	20	Range	5.8–8.9	0.14–1.37	1.0–40.4	29–438	3.6–93.6	0.14–0.48	0.22–2.86
		Mean	7.9	0.56	13.2	141	15.7	0.27	0.90
		% deficient					60	100	45
Kanchipuram	20	Range	5.6–9.4	0.19–1.06	0.8–27.0	13–108	1.6–51.7	0.10–0.60	0.28–1.46
		Mean	7.6	0.48	7.0	45	10.9	0.34	0.78
		% deficient					70	85	55
Vellore	20	Range	6.6–9.1	0.19–0.97	1.2–67.2	24–585	4.1–42.3	0.12–1.02	0.24–2.20
		Mean	8.5	0.62	14.6	115	13.9	0.35	0.81
		% deficient					55	90	65
Karur	20	Range	6.1–8.8	0.10–2.29	1.3–26.2	54–690	2.4–83.5	0.06–2.18	0.26–5.12
		Mean	8.0	0.63	9.2	235	18.6	0.62	0.94
		% deficient					50	65	60
	119	Range	4.8–9.4	0.08–1.36	0.20–67.2	13–690	1.0–93.6	0.10–2.20	0.20–5.10
		Mean	7.6	0.51	9.2	122	11.3	0.34	0.78
		% deficient					85	89	61

[a]Critical limits in the soil used are the same as in Table 1.

The results of the analysis of 179 soils collected from farmers' fields in Bundi, Dungarpur and Udaipur districts of Rajasthan showed that 66% was deficient in available S, 38% in B and 15% in Zn (Table 3). Some soil samples recorded high values of extractable S due to the presence of gypsum in the soil.

The results of soil analysis from the farmers' fields in the SAT districts of Rajasthan showed that the deficiency in S, B and Zn was not as widespread as observed in the case of soil samples collected from the watersheds in MP (Table 4), AP (Table 1) and Karnataka (Table 2).

Among the soil samples collected from 82 farmers' fields in the Junagadh district, Gujarat, 46% fields were deficient in available S, 100% in available B and 82% in available Zn. The results showed that B deficiency was most prevalent, followed by Zn and S deficiency (Table 5).

The variability in extractable or available S, B and Zn in soil samples collected from 119 farmers' fields in five districts of TN was rather large (Table 6). The number of farmers' fields deficient in extractable S varied from 50% (Karur District) to 97% (Tirunelveli District); the extent of occurrence of B deficiency in the five districts varied from 65% (Karur) to 100% (Salem).

In general, the occurrence of Zn deficiency in the five districts was lower than those of S and B, and it varied from 45% (Salem) to 72% (Tirunelveli). On an average, 85% of the farmers' fields was found to be deficient in extractable S, 89% in available B and 61% in available Zn (Table 6).

The results presented in the present study show that the deficiencies of S, B and Zn are widespread, although the extent of deficiency varied with the nutrient and location (district) in the SAT region of a state. Soil samples collected from Rajasthan watersheds showed the lowest extent of occurrence of S (66%), B (38%) and Zn (15%) deficiencies (Table 3). On the other hand, occurrence of deficiencies of these nutrients was highest in MP watersheds: 100% of the farmers' fields was deficient in S and B, and 98% of fields was deficient in Zn (Table 4). The occurrence of S, B and Zn deficiencies in Andhra Pradesh (Table 1) and Karnataka (Table 2) watersheds was also widespread.

The widespread occurrence of S, B and Zn deficiencies, as revealed by soil analysis, coupled with our earlier finding that the crops grown in fields having available nutrient status lower than the critical limits for S, B and Zn in the soil, significantly respond to the applications of these nutrients, imply that balanced plant nutrition is essential for sustained increase in the productivity of rainfed systems in the semi-arid regions of India.

To sum up, the results presented here show that although water shortages affect crop production and productivity in rainfed areas in the SAT regions of India, widespread deficiencies of nutrients such as S, B and Zn also hold back productivity of rainfed systems, resulting in low water use efficiency. Equally important is the demonstration and confirmation of the crucial role that soil testing can play in the diagnosis of nutrient deficiencies and in the judicious use of nutrient inputs in various production systems. Obviously, there is an urgent need to strengthen the soil testing programme for diagnosing emerging nutrient disorders and for determining nutrient sufficiency and requirements[16–18] leading to judicious and efficient use of nutrient inputs in rainfed systems at the local and regional levels. The results from soil testing should be shared with farmers to make dryland agriculture more efficient.

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