International Journal of Plant Production 2 (1), January 2008
ISSN: 1735-6814 (Print), 1735-8043 (Online)
This is a refereed journal and all articles are professionally screened and reviewed.
GUASNR
www.ijpp.info

Zinc, boron and sulphur deficiencies are holding back the potential of rainfed crops in semi-arid India: Experiences from participatory watershed management

Ch. Srinivasarao*, S.P. Wani, K.L. Sahrawat, T.J. Rego, G. Pardhasaradhi

Global Theme Agro Ecosystems, International Crops Research Institute for Semi Arid Tropics (ICRISAT), Patancheru 502 324, Andhra Pradesh, India.
*Corresponding author. Email: s.cherukumalli@cgiar.org

Accepted 14 October 2007; Published online 25 November 2007.

Abstract

Little attention has been paid to the diagnosis of deficiencies of micronutrients such as zinc (Zn) and boron (B) and secondary nutrient such as sulphur (S) in rainfed systems. We evaluated Zn, B and S status of 1617 farmers' fields in 14 districts of the semi-arid tropical India. Results showed that most of the soil samples were low to medium in organic carbon contents. Results also revealed that Zn deficiency ranged from 2 to 100%, B deficiency ranged form 0 to 100%, and S deficiency ranged from 40 to 100% in farmers' fields across the districts. On-farm trials were conducted to study the response of rainfed crops to Zn, B and S application, and the residual effects of B and S, genotypic variations in chickpea cultivars in response to these nutrients and the economics of Zn, B and S use. Results from on-farm trials conducted during 2002-2006 showed significant yield responses of finger millet, maize, sunflower, soybean, groundnut and chickpea to application of Zn, B and S. There was significant residual effect of B and S applied to rainy season soybean on post-rainy season chickpea. Among genotypes of chickpea, KAK-2 was more responsive than other cultivars. Application of Zn, B and S also significantly increased the uptake of Zn, B and S in the crop biomass. Results also showed that application of Zn, B and S along with N+P was economical and critical for higher and sustained productivity of rainfed crops in semi-arid regions of India.

Keywords: Balanced nutrition; Boron; Residual effects; Semi-arid tropics; Sulphur; Zinc

Introduction

Semi Arid Tropics (SAT) regions spread over 11.6 million square kilometers in the developing world, are densely populated and poverty stricken, largely as a result of dependence of the economy and livelihoods on subsistence agriculture. These regions did not benefit greatly from the green revolution and there is a need for "Grey to Green Revolution" in the SAT to feed and provide proper nourishment to the ever increasing population of the developing world. The soils of SAT are generally marginal and highly degraded and combating land degradation and increasing productivity is a major challenge (Singh et al., 1999).

Sulphur and micronutrient deficiencies have been reported in intensive, irrigated production systems globally and in Indian soils these deficiencies are reported as the main causes for yield plateau or declining yield levels (Takkar et al., 1989; Katyal and Rattan, 2003). While, much attention has been paid to correcting S and micronutrient deficiencies in irrigated systems (Takkar, 1996), little attention has been devoted to diagnose micronutrient deficiencies the rainfed systems of the SAT regions in India. It is well recognized that productivity of SAT soils is low due to water shortage. However, apart from water shortages, low soil fertility also constraints crop productivity in the SAT regions (Rego et al., 2003). Moreover, due to low crop productivity in the rainfed regions, it is assumed that mining of secondary and micronutrients is much less as compared to irrigated agriculture (Rego et al., 2003). In the SAT regions, higher productivity levels are achieved when the soil and water conservation practices are implemented along with nutrient management (Wani et al., 2003). The on-going farmer-participatory integrated watershed management program at ICRISAT provided the opportunity to implement nutrient management along with soil and water conservation practices in farmers' fields in the Indian semi-arid tropics. The experiences from Andhra Pradesh Rural Livelihood Program (APRLP) based on this strategy, revealed that extent of micronutrient deficiencies particularly zinc and boron along with sulphur were widespread and large scale yield benefits were recorded with the application of these nutrients along with N and P. (Rego et al., 2007). In the present study, similar experiences in other watersheds of India in Madhya Pradesh, Rajasthan, Gujarat, Haryana, Tamilnadu and Karnataka are presented by reporting on the extent of Zn, B and S deficiencies in farmers' fields, crop response to the applications of S and micronutrients and their residual effects, and the economics of nutrient use.

Materials and methods

Watershed locations and site description

Benchmark watersheds in the districts of Vidisha, Dewas and Guna (Madhya Pradesh), Bundi, Dungarpur and Udaipur (Rajasthan), Dharwad, Haveri, Kolar, Tumkur and Chitradurga (Karnataka), Bharuch (Gujarat), Gurgaon (Haryana), Tirunelvelli (Tamilnadu) were the test sites for studying the extent of nutrient deficiencies (Table 1). Most of these watersheds are about 500 ha in area (micro-watersheds) and number of farmers cultivating the arable land varied across the watersheds. These watersheds are located in the semi arid agroecological sub regions of central, southern and western India, are characterized by hot summer and mild to severe winter. The experimental sites receive low to high erratic annual rainfall (Table 1). The soils of the sites are mostly Vertisols and Alfisols, and the soil texture varied from sandy loam to clay. In general, the soils were low in fertility, especially organic carbon (<0.5%) and available nitrogen (<280 kg ha^{-1}). The inputs of plant nutrient through external sources and organic matter additions are very low, and are the cause of low fertility and low organic carbon status.

Table 1. Watershed locations and site description.

State	District	Type of soil	Average annual rainfall (mm)	pH (1:2)	EC (d S m^{-1})	OC (%)
Madhya Pradesh	Vidisha	Vertisol	1134	7.6-8.3	0.16-0.33	0.46-0.92
	Dewas	Vertisol	1083	7.0-8.7	0.06-0.17	0.30-1.00
	Guna	Vertisol	1166	7.5-8.5	0.07-0.40	0.51-1.11
Rajasthan	Bundi	Alfisol	809	6.2-8.7	0.09-0.97	0.18-1.17
	Dungarpur	Vertisol	770	6.2-8.0	0.08-3.32	0.48-1.99
	Udaipur	Alfisol	614	7.3-9.0	0.12-2.49	0.25-2.37
Karnataka	Dharwad	Vertisol	772	5.1-8.7	0.04-1.37	0.45-1.99
	Haveri	Alfisol	754	5.1-8.0	0.03-1.00	0.31-0.89
	Kolar	Vertisol	744	4.5-8.7	0.01-1.75	0.11-1.25
	Tumkur	Vertisol	689	4.8-9.6	0.02-1.70	0.10-1.05
	Chitradurga	Mixed	574	5.3-10.1	0.01-4.11	0.12-1.08
Gujarat	Bharuch	Vertisol	925	6.2-8.3	0.04-0.84	0.21-1.90
Haryana	Gurgaon	Inceptisol	553	4.8-8.7	0.20-0.98	0.32-0.42
Tamilnadu	Tirunelvelli	Vertisol	738	4.8-8.7	0.26-2.60	0.26-0.45

Soil sampling and analysis

The number of farmers in a watershed varied from 100 to 150. The farm holding size within a watershed also varied (from about 0.5 to >50 ha). For efficient, cost effective and representative soil sampling strategy, a stratified random sampling along the toposequence was developed. We assumed that soil fertility of a given field mainly depends on two main factors (i) inherent soil fertility, and (ii) the inputs of plant nutrients and organic matter by farmers. As a first step, a Rapid Rural Appraisal (RRA) was conducted and each watershed was 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. The farmers were grouped into large, medium and small holders in each watershed based on farmers' information. In all the watersheds, small farmers had<2.0 ha, medium farmers had between 2 and 5 ha, and large farmers had > 5 ha land. We randomly selected farmers in each position on the topo-sequence, proportion to the farm size. In each farmer's field, we selected a major crop in the field and collected 8 to 10 cores of samples from the soil surface (0-15 cm depth) layer. Before analyses, the soil samples were air dried and powdered with wooden hammer and pass through a 2 mm sieve. For organic carbon, the soil samples were finely powdered to pass through a 0.25 mm sieve.

Processed soil samples were analyzed in the ICRISAT Analytical Services Laboratory. The soil pH was measured by a glass electrode using a soil to water ratio of 1:2; electrical conductivity (EC) was determined by an EC meter using a soil to water ratio of 1:2. Organic C was determined using the Walkley-Black method (Nelson and Sommers, 1996). Available S was measured using 0.15% calcium chloride ($CaCl_2$) solution as an extractant (Tabatabai, 1996), available Zn was extracted by DTPA reagent (Lindsay and Norvell, 1978) and available B was extracted by hot water (Keren, 1996).

On-farm trials

For crops response studies, we conducted a number of trials in the districts of Madhya Pradesh and Karnataka during 2002-2006. Different nutrient management trials included response of rainfed crops to micronutrients and sulphur, residual effects of micronutrients, variations in response to micronutrients among chickpea cultivars, and the economics of Zn, B and S use. For various trials, control based on farmers' nutrient inputs mainly N and P (termed as FP) and application of nutrient amendments viz. 50 kg zinc sulphate (10 kg Zn ha^{-1}), 5kg borax (0.5 kg B ha^{-1}) and 200 kg gypsum (30 kg S ha^{-1}) were included along with FP. These nutrients were broadcast uniformly on the plot before the final land preparation. In all on-farm trials, farmers chose the crop and variety to be grown on their plots; however, similar crop management and cultural practices were followed at the plot level across farmers and sites.

Crop yields and plant analysis

For harvesting the crops, plant samples were collected from 3 spots in each treatment. For each spot, harvested area was 4 m^2. Thus in each trial crop plants covering a total area of about 12 m^2 was harvested, and the harvested plants were pooled. Economic parts of the plants were separated from the vegetative parts and weighed separately. Grain and stover or haulm weights were taken and brought to the ICRISAT center at Patancheru (India). The plant samples were dried at 60°C for 48 hrs and dry weights of grain and straw samples were computed.

Sub-samples of grain and straw were dried at 60°C, ground and analyzed for total Zn, B and S in the ICRISAT Analytical Services Laboratory. Zinc in plant samples was determined by digesting them with triacid; and Zn in digests was analyzed using atomic absorption spectrophotometer (Sahrawat et al., 2002). Total S and B in plant samples were determined by ICP-AES in digests prepared by digesting the samples with nitric acid (Mills and Jones, 1996).

Statistical Analysis

Crops yields obtained were converted to kg ha^{-1} and tabulated according to the crop and treatments. Total Zn, B and S uptake is the biomass was computed from the data on grain and straw yield and nutrient concentration in the grain and straw samples. The data was subjected to statistical analysis using the GENSTAT 7th edition package.

Results

A summary of the chemical analysis of soil samples from 1617 farmers' fields covering three districts of Madhya Pradesh, three districts of Rajasthan, five districts of Karnataka, one each district in Gujarat, Haryana and Tamilnadu during 2002-2006, showed that the fields had a wide range in pH and organic carbon (Table 1) and they were low to moderate in available P and generally adequate in exchangeable K (data not shown). However, the most revealing results on soil chemical analysis were the levels of extractable Zn, B and S in the samples (Table 2). The tentative critical limits in the soil, used for separating deficient fields from non-deficient for available Zn, B and S were 0.75 mg kg^{-1} DTPA extractable Zn, 0.58 mg kg^{-1} hot water extractable B and 10 mg kg^{-1} $CaCl_2$ extractable S in the soil (Katyal and Rattan, 2003; Rego et al., 2007). The samples lower than the critical limits are characterized as deficient in a nutrient (Sahrawat, 2002).

In the watersheds of Madhya Pradesh, the extent of Zn deficiency in farmers' fields was between 78 to 100%, it was 0 to 96% in B and 89 to 100% farmers' fields were S deficient (Table 2). In case of Rajasthan, the extent of Zn deficiency varied from 2 (Dungarpur) to 67% (Bundi), B deficiency varied from 21 to 72%, and S deficiency varied from 48 to 72%. In Karnataka, Zn deficiency varied from 34 to 93%, B deficiency from 54 to 96% and S deficiency from 81 to 93% (Table 2).

Crop response to Zn, B and S

Crop response data on several rainfed crops were obtained during trails conducted in 2002-2006, in different watersheds. Response of crops due to Zn, B and S application along with N, P over Farmers' Practice (FP) (only N and P) in finger millet (*Eleusine coracana*), maize (*Zea mays*), sunflower (*Helianthus annuus*), soybean (*Glycine max*) and groundnut (*Arachis hypogaea*) showed that significant yield responses in all the crops due to balanced nutrition treatment which includes Zn, B and S along with N and P (Table 3). The Zn, B, S + FP treatment yielded 44% more stover, 56% grain yield and 48% total biomass over farmers' practice in case of finger millet. In maize Zn, B, S + FP treatment yielded 28% and 52% higher stover and grain yield than FP. Sunflower yielded 72% more stover and 156% grain with Zn, B, S + FP treatment than FP (N+P). Significant stover (71%) and grain (70%) in soybean was obtained with Zn, B, S + FP treatment. In case of groundnut, significant yield response was obtained in stover (45%), grain (55%) and total biomass (47%).

Residual effects of B and S

In three micro watersheds in Guna district in Madhya Pradesh (Kailashpur, Baradokala and Banjari Barri) application of B and S together significantly improved the grain and haulm yields of soybean (*Glycine max*) over control (Table 4). Grain yield increased from 740 kg ha^{-1} (FP) to 1340 kg ha^{-1} (B+S+FP) over FP. Haulm yield increased from 980 kg ha^{-1} (FP) to 1700 kg ha^{-1} (BS + FP). There was significant residual effect of B+S applied to soybean to following chickpea (*Cicer arietinum*) (Table 5). Grain yield of chickpea increased from 1050 kg ha^{-1} (FP) to 1550 kg ha^{-1} (with B+S+FP). While haulm yield increased from 1510 kg ha^{-1} to 1790 kg ha^{-1} with B+S+FP treatment. The yield increase was 48% in grain and 18% in haulm with B+S+FP over FP.

Genotypic variations in chickpea response to Zn and S

In the Madhusudangadh watershed (Guna, Madhya Pradesh) effect of balanced nutrition was tested with five chickpea varieties (Table 6) (Local, KAK-2, ICCV-2, ICCV-10 and ICCV-37) during post rainy season of 2002 and 2003. Higher grain yield (2150 kg ha^{-1}) and straw yield (2230 kg ha^{-1}) were obtained in case of KAK-2 as compared to other three genotypes with Zn, B, S + FP. Even under FP, KAK-2 gave higher yield than the other three chickpea cultivars.

Table 2. Extractable (available) Zn, B and S status of soil in 1617 farmers fields in different watersheds in six states of India.

State/ Location	No of farmers' fields	Zn (μg g^{-1})		B (μg g^{-1})		S (μg g^{-1})	
		Min	Max	Min	Max	Min	Max
Madhya Pradesh							
Vidisha	12	0.16	0.96	0.65	1.20	3.20	5.35
(% deficient fields)		(92)*		(0)		(100)	
Dewas	24	0.12	0.56	0.20	0.80	3.90	9.50
(% deficient fields)		(100)		(96)		(100)	
Guna	18	0.24	1.74	0.60	2.20	2.60	14.20
(% deficient fields)		(78)		(0)		(89)	
Rajasthan							
Bundi	36	0.20	1.80	0.10	0.98	3.20	50.90
(% deficient fields)		(67)		(72)		(72)	
Dungarpur	99	0.88	14.10	0.28	1.50	4.00	31.30
(% deficient fields)		(2)		(31)		(72)	
Udaipur	44	0.70	3.92	0.22	1.50	3.20	274.0
(% deficient fields)		(5)		(25)		(48)	
Karnataka							
Dharwad	135	0.28	4.72	0.12	2.44	1.80	118.2
(% deficient fields)		(34)		(54)		(83)	
Haveri	217	0.20	2.32	0.08	1.58	1.80	60.70
(% deficient fields)		(79)		(63)		(81)	
Kolar	408	0.06	5.50	0.04	1.44	0.50	155.8
(% deficient fields)		(64)		(90)		(87)	
Tumkur	269	0.14	2.34	0.06	0.98	1.10	59.6
(% deficient fields)		(88)		(96)		(93)	
Chitradurga	231	0.08	3.40	0.04	4.08	1.20	601.4
(% deficient fields)		(93)		(75)		(82)	
Gujarat							
Baruch	82	0.20	2.45	0.06	0.49	1.10	150.4
(% deficient fields)		(85)		(100)		(40)	
Haryana							
Gurgaon	30	0.20	0.87	0.09	0.85	0.30	90.8
(% deficient fields)		(89)		(93)		(60)	
Tamilnadu							
Tirunelvelli	12	<0.20	<0.20	0.08	0.26	0.3	3.4
(% deficient fields)		(100)		(100)		(100)	

* Percent deficient

Table 3. Response of different crops to Zn, B, and S in Karnataka watersheds (2005-06).

Crop/Treatment	Yield		
	Stover	Grain	Total biomass
Finger millet (16)*			
FP	4630	2142	6772
FP+ZnBS	6654 (44)**	3354 (56)	10008 (48)
CD (0.05)	694	252	826
Maize (9)			
FP	4619	4000	8619
FP+ZnBS	5919 (28)	6091 (52)	12010 (39)
CD (0.05)	962	395	910
Sunflower (11)			
FP	2531	901	3432
FP+ZnBS	4368 (72)	2309 (156)	6678 (94)
CD (0.05)	555	307	730
Soybean (6)			
FP	1254	2029	3282
FP+ZnBS	2151 (71)	3469 (70)	5620 (71)
CD (0.05)	350	664	1001
Groundnut (8)			
FP	2803	774	3576
FP+ZnBS	4079 (45)	1200 (55)	5279 (47)
CD (0.05)	625	330	733

FP= Farmers' practice (only N+P)
* = No of trials; ** percent increase over FP.

Table 4. Effect of B + S + FP on grain and haulm yields of soybean in Guna district of Madhya Pradesh.

Treatment	Kailashpura		Barada Kala		Banjari Barri		Pooled yield	
	G	H	G	H	G	H	G	H
FP	660	920	840	1050	710	960	740	980
B+S+FP	1080	1630	1350	1580	1590	1880	1340	1700
CD (0.05)	280	250	220	310	300	290	260	280

G = Grain yield; H = Haulm yield.

Economics of Zn, B and S application

Significant grain and straw yields of chickpea were obtained due to Zn+B+S+FP treatment in the Guna district of Madhya Pradesh. Similarly, higher gross and net returns were obtained with balanced nutrient treatments. The benefit: cost ratio increased from 2.18 (FP) to 2.63 (Zn + B + S + FP) for chickpea production.

Table 5. Residual effect of B + S + FP applied to soybean on grain and haulm yield of chickpea in Guna district of Madhya Pradesh (2002-03).

Treatment	Yield (kg ha^{-1})		% Yield increase over FP	
	Grain	Haulm	Grain	Haulm
FP	1050	1510	-	-
B+S+FP	1550	1790	48	18

Table 6. Genotypic variations in chickpea in response to Zn + S + B + FP at Guna district of Madhya Pradesh (2002-03).

Treatment	Local		ICCV-2		ICCV-10		ICCV-37		KAK-2	
	G	S	G	S	G	S	G	S	G	S
FP	880	1150	1200	1340	1200	1390	970	1210	1260	1590
ZN+B+S+FP	1170	1640	1730	1750	1630	1840	1650	1580	2150	2230
CD (0.05)	Grain: 143; Straw; 245									

G = Grain; S = Straw.

Table 7. Effect of Zn + B + S + FP on grain and straw yields of chickpea and economics of micronutrient application at Guna district of Madhya Pradesh (2002-2003).

Treatment	Grain (kg ha^{-1})	Straw (kg ha^{-1})	Cost of cultivation (Rs ha^{-1})	Gross returns (Rs ha^{-1})	Net returns (Rs ha^{-1})	Benefit: Cost ratio
FP	1330	1650	10480	22920	12440	2.18
Zn+B+S+FP	2180	2590	14210	37390	23180	2.63
CD (0.05)	187	143	-	280	215	0.13

Uptake of Zn, B and S by different crops

Uptake of Zn, B and S by different rainfed crops in farmers' fields in five districts of Karnataka (Table 8) indicates the significant increases in uptake of Zn, B an S with balanced nutrition over farmers' practice of only NP application. However extent of increases varied among nutrients as well as crops. Zn, B and S uptakes increased by 66%, 22% and 59% in finger millet, 76%, 11% and 38% in maize, 165%, 93% and 68% in sunflower, 113%, 60% and 125% in soybean and 125%, 64% and 55% in groundnut.

Discussion

Our results indicate a widespread deficiency of S, B and Zn in farmers' fields in the semi-arid regions of India. The extensive Zn, B and S deficiencies was due to poor organic carbon status of soils (Srinivasarao et al., 2006) and depletion under continuous cropping without application of these plant nutrients (Rego et al., 2007). Srinivasarao et al. (2006) showed that soils in 16 of 21 locations under rainfed systems were low in organic carbon content of soils. Low levels of organic carbon in these soils were primarily due to high temperatue and low rainfall in these regions (Jenny and Raychaudhuri, 1960) and also due to low or little organic matter additions (El-Swaify et al., 1985; Rego et al., 2003). The extent of deficiency of Zn B and S, as revealed from our analysis, are comparable to these reported from well endowed and intensive irrigated production systems (Takkar et al., 1989; Takkar, 1996). Coarse textured, calcareous, alkaline or sodic soils having high pH and low organic matters are generally low in available Zn.

Table 8. Uptake of Zn, B and S by different crops in farmers's fields in Karnataka watersheds (2005-06).

Crop/Treatment	Total uptake		
	Zn (g/ha)	B (g/ha)	S (kg/ha)
Finger millet (16)*			
FP***	193	17.0	9.9
FP + ZnBS	322 (66) **	20.8 (22)	15.8 (59)
CD (0.05)	117	3.7	2.5
Maize (9)			
FP	82	26.9	5.5
FP + ZnBS	145 (76)	29.5 (11)	7.6 (38)
CD (0.05)	63	2.5	0.9
Sunflower (11)			
FP	113	82.4	6.3
FP + ZnBS	300 (165)	159.2 (93)	10.6 (68)
CD (0.05)	83	39.1	2.0
Soybean (6)			
FP	45	73.2	5.2
FP + ZnBS	96 (113)	117.1 (60)	11.7 (125)
CD (0.05)	30	47.9	2.3
Groundnut (8)			
FP	44	38.5	4.2
FP + ZnBS	99 (125)	63.3 (64)	6.5 (55)
CD (0.05)	31	13.5	0.9

* No of on farm trials
** Percent increase over FP
*** FP= Farmers' practice (only N+P)

Our results clearly demonstrated significant yield responses of different rainfed crops due to application of Zn, B and S + FP over farmers' practice (NP). The crop responses to applied nutrients greatly vary with seasonal rainfall and its distribution during the cropping season (El-Swaify et al., 1985). The responses of crops to the application of Zn, B and S varied across crops; the crop yields and nutrient uptake responses are clearly significant and are of similar magnitude to those reported for field crops under irrigated agriculture (Takkar 1996; Scherer, 2001; Fageria et al., 2002; Katyal and Rattan, 2003; Rego et al., 2007). Clearly, the deficiencies of Zn, B and S assume critical importance for increasing and sustaining crop productivity of rainfed systems in the Indian SAT. Our results from on-farm trials conducted during 2002-2006 at different watersheds in various states of India clearly demonstrated that under rainfed conditions, application of Zn, B and S is essential to increase the productivity. The best results are achieved when the application of Zn, B and S combined with the application of N+P.

Besides direct effect of these nutrients, there was considerable residual effect on succeeding crops. Under B and S deficient conditions in soil, there was about 50% grain yield of post-rainy chickpea on Vertisols of Central India due to B applied to rainy season soybean. Results emphasize the need for better management strategies to utilize residual effects more efficiently under farmers' conditions. These studies also underline the need to study the frequency of application of Zn, B and S. We can apply these micro and secondary nutrients regularly, alternative years or once in three years.

Results demonstrate that different genotypes of rainfed crops responded differently to the application of Zn, B and S. Among 5 varieties of chickpea, KAK-2 gave significantly higher response compared to other four genotypes. Even under farmers' practice (N+P), KAK-2 gave higher grain and straw yields than other cultivars. Similar genotypic variations in B and Zn response in chickpea were reported by Ali et al. (2002) and these genotypic variations were related to root size and morphology. Evaluating 20 chickpea genotypes on multi-nutrient deficient Inceptisol, Srinivasarao et al. (2006a) indicated variability in Zn uptake response and these uptake levels were influenced by P application.

Significant increase in gross returns, net returns and B:C ratio were obtained with balanced nutrition treatment (2:63) than under farmers' practice treatment (2:18). This indicates that applications of Zn, B and S were economical and this practice can be recommended for large scale adoption where Zn, B and S are deficient. Higher B:C ratio were also obtained with micronutrient application on soils deficient in these nutrients (Sakal et al., 1996).

In all the crops, significant increase in uptake of Zn, B and S were obtained in different rainfed crops. Increase in Zn uptake was more than 100% in sunflower, soybean and groundnut. The percent increase in B uptake ranged from 11 to 93% while increase in S uptake ranged from 38 to 125%. Substantial nutrient uptake with the application of Zn, B and S were earlier reported by Rego et al. (2007).

Thus, our results show that for sustained increase in productivity, the rainfed crops need application of Zn, B and S along with N and P. Best results in systems' productivity was achieved when efficient cultivar is chosen along with balanced nutrition.

Acknowledgements

We thank Sir Dorabji Tata Trust, Asian Development Bank, World Bank for special fund for watershed development and Government of Karnataka for the financial support of various projects under which these studies are undertaken. We sincerely thank the farmers who actively collaborated for undertaking Participatory Research and Development trials.

References

Ali, Y.M., Krishnamurthy, L., Saxena, N.P., Rupela, O.P., Kumar, J., Johansen, C., Rengel, Z., 2002. Scope for genetic manipulation of mineral acquisition in chickpea. Plant Soil 245,123-134.

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

Fageria, N.K., Baligar, V.C., Clark, R.B., 2002. Micronutrients in crop production. Adv. Agron. 77,185-26.

Jenny, H., Raychaudhuri, S.P., 1960. Effect of climate and cultivation on nitrogen and organic matter resources in Indian soils. Indian Council of Agricultural Research, New Delhi.

Katyal, J.C., Rattan, R.K., 2003. Secondary and micronutrients: Research gaps and future needs. Fert. News 48, 9-14, 17-20.

Keren, R., 1996. Boron. In: Sparks, D. L. (Ed.), Methods of Soil Analysis. Part 3. Chemical Methods—Soil Science Society of America Book Series no. 5. SSSA and ASA, Madison, Wisconsin, pp 603-626.

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

Mills, H.A., Jones, Jr., J.B., 1996. Plant analysis handbook II: A practical sampling, preparation, analysis, and interpretation guide. GA: Micro—Macro Publishing, Athens.

Nelson, D.W., Sommers, L.E., 1996. Total carbon, organic carbon, and organic matter. In: Sparks, D. L. (Ed.), Methods of Soil Analysis. Part 3. Chemical Methods—Soil Science Society of America Book Series no. 5. SSSA and ASA, Madison, Wisconsin, pp: 961-1010.

Rego, T.J., Rao, V.N., Seeling, B., Pardhasaradhi, G., Kumar Rao, J.V.D.K., 2003. Nutrient balances—a guide to improving sorghum and groundnut-based dryland cropping systems in semi-arid tropical India. Field Crops Res. 81, 53-68.

Rego, T.J., Sahrawat, K.L., Wani, S.P., Pardhasaradhi, G., 2007. Widespread deficiencies of sulphur, boron and zinc in Indian semi arid tropical soils: on farm crop responses, J. Plant Nutr. 30: 1569-1583.

Sahrawat, K.L., 2002. Plant nutrient sufficiency and requirements. In: Lal, R., (Ed.), Encyclopedia of Soil Science. Marcel Dekker, Inc., New York, NY, pp 1000-1004.

Sahrawat, K.L., Ravi Kumar, G., Rao, J.K., 2002. Evaluation of triacid and dry ashing procedures for determining potassium, calcium, magnesium, iron, zinc, manganese, and copper in plant materials. Commun. Soil Sci. Plant Anal. 33, 95-102.

Sakal, R., Singh, A.P., Sinha, R.B., Bhogal, N.S., 1996. Twenty five years of research on micro and secondary nutrients in soils and crops of Bihar. RAU, Pusa, Bihar.

Scherer, N.W., 2001. Sulphur in crop production. European J. Agron. 14, 81 -111.

Singh, H.P., Sharma, K.L., Venkateswarlu, B., 1999. Fertilizer use in rainfed areas. Fert. News 44, 27-30 & 33-38.

Srinivasarao, Ch., Vittal, K.P.R., Ravindra Chary, G., Gajbhiye, P.N., Venkateswarlu, B., 2006. Characterization of available major nutrients in dominant soils of rainfed crop production systems of India. Indian J. Dryland Agric. Res. Dev. 21, 105-113.

Srinivasarao, Ch., Ganeshamurthy, A.N., Ali, M., Venkateswarlu, B., 2006a. Phosphorus and micronutrients nutrition of chickpea genotypes in a multi-nutrient-deficient typic Ustochrept. J. Plant Nutr. 29, 747-763.

Tabatabai, M.A., 1996. Sulfur. In: Sparks, D.L. (Ed.), Methods of Soil Analysis. Part 3. Chemical Methods—Soil Science Society of America Book Series no. 5. SSSA and ASA, Madison, Wisconsin, pp: 921-960.

Takkar, P.N., 1996. Micronutrient research and sustainable agricultural productivity. J. Indian Soc. Soil Sci. 44, 563-581.

Takkar, P.N., Chhibba, I.M., Mehta, S.K., 1989. Twenty years of coordinated research on micronutrients in soils and plants. Bulletin no.1. Indian Institute of Soil Science Bhopal, India.

Wani, S.P., Pathak, P., Jangawad, L.S., Eswaran, H., Singh, P., 2003. Improved management of Vertisols in the semiarid tropics for increased productivity and soil carbon sequestration. Soil Use Manage.19, 217-222.