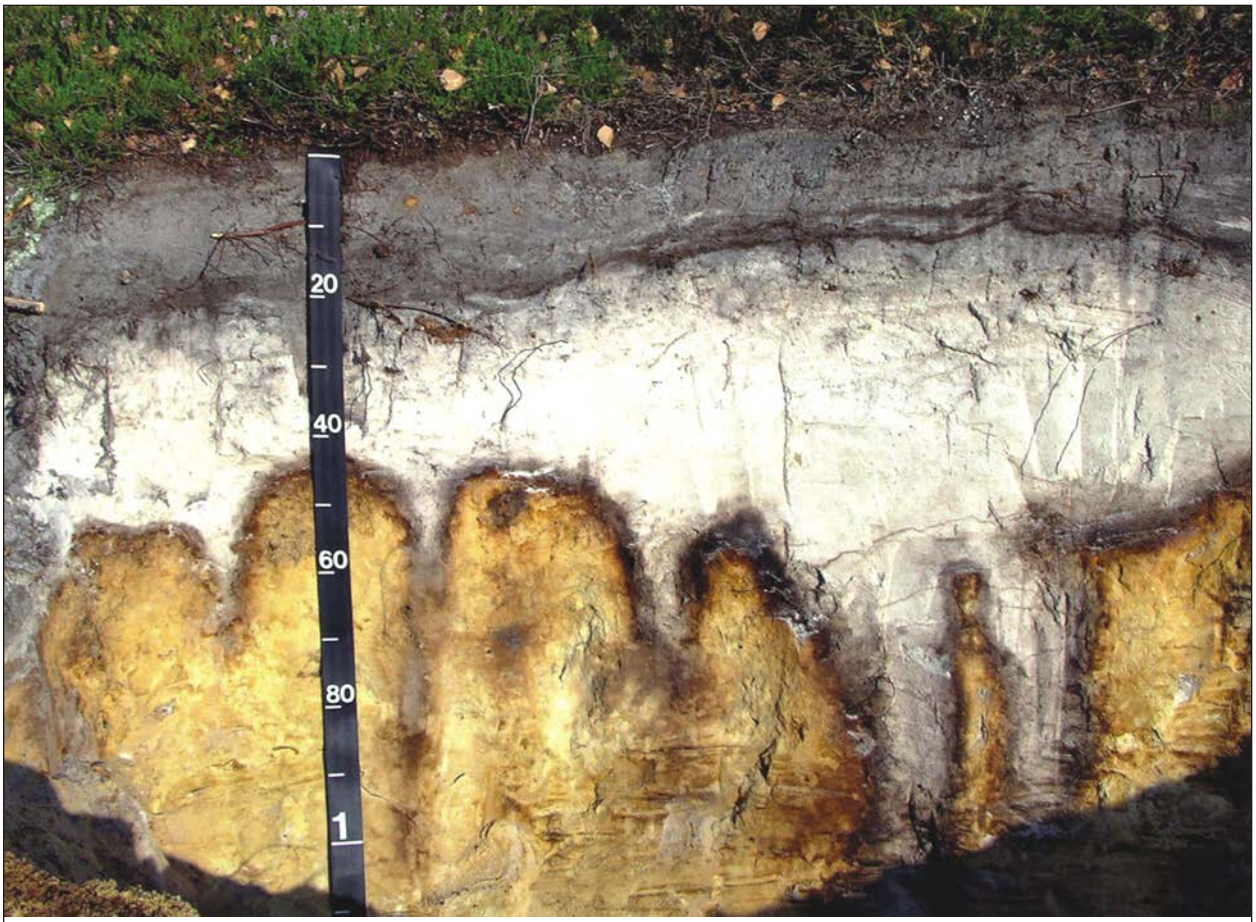

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Integrated Nutrient Management to Enhance On-Farm Productivity of Rain Fed Maize in India

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Abstract: On-farm trials were conducted in the central Karnataka of India, over 3 years, with the objectives of quantifying the effects of applying balanced nutrition to rain fed maize with regard to yield response, plant nutrition, profitability and rain water use efficiency under multi-nutrient deficient conditions. Maize grain yield was significantly increased by the soil application of Farmers' Inputs (FI) plus additional quantities of nitrogen and phosphorus (NP), FI+sulfur, boron and zinc (SBZn) and FI+NP+SBZn treatments compared to maize receiving no fertilizer inputs or FI. Optimizing limiting soil nutrients significantly ($p<0.05$) enhanced grain productivity by an average of 67.1% and stover yields by 76.6% under farm situations. Also the treatment NP+SBZn over the FI treatment significantly increased the uptake of N, P, K, S and Zn in the grain and above-ground maize parts. Use of SBZn, along with the FI's enhanced partial factor productivity and agronomic efficiency by 202 and 96.8%, respectively. However, the benefit: cost ratio (2.9: 1) of SBZn treatment was not encouraging and it was most lucrative (6.4: 1) in FI+NP treatment. Maize fertilized with balanced nutrition (FI+NP+SBZn) showed greater rain water use efficiency (almost increased by 50%), over the farmer's practice of fertilization. Integrated application of additional quantities of NP and correcting SBZn deficiencies in rain fed maize are critical for not only to enhance the productivity and profitability but also to maintain sustainable soil resource base.

Key words: Integrated nutrient management, nutrient deficiencies, productivity efficiency, rain fed maize, rain water use efficiency

INTRODUCTION

In many parts of the Semi-arid India, lower productivity of rain fed crops was linked to the water shortage. Erratic rainfall and cultivation of crops without balanced nutrient inputs has led to decline in productivity of rain fed staple cereals such as maize (*Zea mays*) and sorghum (*Sorghum bicolor*) (Rego *et al*., 2007). Due to low productivity of the dry lands, it was assumed that the mining of nutrients is much less than under the irrigated systems. However, in the Indian rain fed regions, negative balances of nitrogen and phosphorous (Rego *et al*., 2003) and recently, wide spread deficiency of other nutrient elements such as sulfur (S), zinc (Zn) and boron (B) have been reported in the rain fed areas of India (Sahrawat *et al*., 2007).

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Generally, the use of mineral and organic fertilizers in the rain fed production systems is minimal compared to the irrigated production systems. Most of the fertilizer used in India is confined to irrigated production systems (Katyal, 2001). In the rain fed production systems, the deficiency of nutrients are increasing in spread due to little amounts of organic manures used, poor recycling of crop residues and low use of N and P nutrients. In the recent years, there is a set back to the use of single super phosphate and now fertilizer materials like di ammonium phosphate and several grades of complex fertilizers are being used as major nutrients sources by the farmers (Tandon, 2002) and as a consequence soils are increasingly becoming deficient in sulfur (S) and other micronutrients.

Rain fed, agro ecosystems constitute 67% of the net cultivated area and occupy an important place in Indian agriculture (Singh *et al*., 2000). Among the states of India, Karnataka is the second largest state with respect to the geographical area under rain fed crops. Maize in Karnataka is mostly under rain fed production and cultivated by hybrid seeds with high yield potential. Average maize productivity of Karnataka is above 3.1 t ha^{-1} which is threatened by water stress, improper nutrient management and zinc deficiency (Joshi *et al*., 2005). Under rain fed agro-ecosystems best results in terms of crop productivity increase can be achieved when holistic approach involving conservation and judicious use of rain water are accomplished through proper nutrient management (Wani *et al*., 2003). Low rain water use efficiency in a marked character of rain fed agriculture and is mainly due to water and other biogeochemical constraints (Huxman *et al*., 2004) which includes soil nutrient. The objectives of the present study were to quantify on-farm effects of applying different nutrients simultaneously through synthetic sources under multi nutrient deficient conditions on (1) yield, (2) nutrient uptake, (3) rain water use efficiency and (4) profitability as compared with the maize receiving sole N and P fertilizers and farmers traditional inputs.

MATERIALS AND METHODS

The experiments were established during 2005-07, under rain fed conditions in farmers' fields of Haveri district in the central part of Karnataka state, India. For the purpose of crop trials two villages (Aremallapur and Chikkalingadahalli) were identified before the cropping season in the Haveri District. This intensively farmed area is situated in the central part of Karnataka with geographical location between latitude 14°16'18" to 15°00'36" N and longitudes 75°00'36" to 75°49'30" E. The long-term mean annual rainfall is 820 mm and the area experiences four distinct seasons: hot season (from the middle of February to the end of May), South-West Monsoon (from June to September), North-East Monsoon (October and November) and Winter (December to first half of February). The cropping is mostly prevalent during the South-West Monsoon.

The number of participating farmers was 9 in 2005, 20 in 2006 and 17 in 2007 season (Table 1). Each farmer was treated as a replication. The experimental design was a randomized complete block design with every farmer having a set of five treatments (AC-T3). The treatments used for the experiments are presented in Table 1.

In trials, farmers were free to decide on variety and their crop management practices such as planting method, weeding were the same in all treatments. Farmers'Iinput (FI) of fertilizers was recorded for each trial and it ranged widely (Table 2). In brief, N, P and K fertilizer applied by farmers (FI) was far lesser than the recommended dosage for maize in the region. In 2005 each treatment plots were 500 m^2 in size. During 2006 and 2007 seasons, only two treatments (FI and T3) were retained after increasing the trial plot size to 2000 m^2. The treatments thus verified were (1) farmers' nutrient input and (2) FI+ NP+ SBZn. Di Ammonium Phosphate

Table 1: Treatments and treatment structures used for the experiments

Treatments	Treatment structure	Goal of the treatment
AC	Absolute control (No inputs of fertilizers)	-
FI	Farmer's inputs	Assess the comparative advantage of FI over absolute control, if any
T_1	FI+NP (80 kg N, 30 kg P_2O_5 ha^{-1})	Use of N and P is to make up for the sub-optimal levels of application practiced by farmers'
T_2	FI+SBZn (30 kg S, 0.5 kg B, 10 kg Zn ha^{-1})	Assess the performance of deficient nutrients, which are not generally used in maize production by the farmers
T_3	FI+NP+SBZn (80 kg N, 30 kg P_2O_5 ha^{-1}, 30 kg S, 0.5 kg B, 10 kg Zn ha^{-1})	Test the influence of integrated supply of NP and SBZn under on-farm conditions

Table 2: Number of participating farmers, planting and harvesting of maize in Julian day numbers, and application rates of N, P_2O_5 and K_2O in the Farmers' Input (FI) treatment, with maximum and minimum values given in parenthesis

				Fertilizer rates in FI (kg ha^{-1})		
Year	No. of farmers	Planting period	Harvest period	N	P_2O_5	K_2O
2005	9	166-185	285-312	18.3 (11.5-23.5)	15.0 (11.5-23.5)	4.4 (0-10.0)
2006	20	154-170	270-291	15.3 (11.5-55.0)	13.5 (5.0-23.5)	3.8 (0-30.0)
2007	17	161-175	283-305	17.4 (7.5-23.5)	14.3 (7.5-23.5)	4.3 (0-30.0)

(DAP) was used to supply 30 kg P_2O_5. Urea was used as N source to supply 80 kg N ha^{-1}. In the S, B, Zn treatment these nutrients were provided through 200 kg gypsum (30 kg S ha^{-1}), 2.5 kg borax (0.5 kg B ha^{-1}) and 50 kg zinc sulfate (10 kg Zn ha^{-1}). The NP+SBZn treatment consisted of application of SBZn along with N and P. All fertilizer materials were mixed thoroughly, surface broadcast and mixed with soil at the time of final tillage. Forty days after planting, 50% of N was supplied as top dressing. Maize was grown with an inter-row spacing of 0.5 m and a plant to distance of 0.3 m corresponding to a planting density of 66,666 plants ha^{-1}. Plots were weeded three times using ox-drawn implements. At the time of harvest of the crops, plant samples were collected from three sub plots in each treatment plot. Each subplot measuring 2.0×1.80 m was harvested in the centre of each treatment plot. Cobs were removed from the harvested plants and fresh weight of vegetative parts and cobs were recorded. Then three sub samples of known weight of maize stalks, empty spindles and grain were used for dry matter determination and were analyzed at the ICRISAT center in Patancheru Andhra Pradesh (India). The plant samples were dried at 60°C for 48 h and dry weight of grain and stover were computed.

Soil and Plant-Sampling and Analysis

Before the onset of the experiment participatory soil sampling of the representative farmer's fields were conducted in trial villages according to the procedure explained by Rego *et al.* (2007) and Sahrawat *et al.* (2008). About 10-12 soil cores were taken in each farmer's field, composited and sufficient sample material was transported to further processing and analysis to Central Analytical Services Laboratory of the ICRISAT, Patancheru, India. The composite soil samples were processed-air dried and powdered with wooden hammer to pass through a 2 mm sieve. For the analyses of organic C, the soil samples were finely powdered to pass through a 0.25 mm sieve and Organic Carbon (OC) content estimated by Walkley-Black method (Nelson and Sommers, 1996). Available phosphorous (P) was extracted with $NaHCO_3$ and sulfur (S) by extracting with 0.15% calcium chloride, potassium (K) with ammonium acetate, Zn with DTPA, available boron (B) with hot water (Rego *et al.*, 2007) and estimated using an ICP-AES. 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.

For plant analyses, sub samples of grain and straw were ground in a mill and analyzed for total N, P, K, S, B and Zn. Total N, P and K in plant materials were determined by sulfuric acid-selenium digestion. Nitrogen and P in the digests were determined by an auto analyzer and K in digests was analyzed by atomic absorption spectrophotometer as explained by Sahrawat *et al.* (2002a). Zinc content of the plant sample was estimated by triacid digestion and atomic absorption spectrophotometer method (Sahrawat *et al.*, 2002b). For the total S and B in plant samples were digested in nitric acid and an ICP-AES was used for measurements (Mills and Jones, 1996).

Productivity Efficiency Parameters

Crop yield obtained were converted to kg ha^{-1} and factor productivity information were generated for individual case and mean values were computed. The Partial Factor Productivity (PFP), Agronomic Efficiency (AE) and benefit: cost (B:C) ratio were calculated according to the procedure of Bhattacharyya *et al.* (2008). The PFP is the ratio of the grain yield to the applied nutrients, is a useful measure of nutrient use efficiency as it provides an integrative index that quantifies total economic out put relative to the utilization of all nutrient resources in the system, including native soil nutrients and nutrients from applied fertilizers. The AE is the incremental efficiency from applied fertilizers over the control. The efficiency parameters were determined taking in to consideration of all nutrients used in different treatments. The PFP is calculated from the equation:

$$Y = (Y_0 + \Delta Y)\, F_n^{-1} \qquad (1)$$

where, Y is the grain yield of a fertilized plot, Y_0 is the grain yield in Absolute Control (AC) plots, ΔY is the yield increment due to treatments and F_n is the amount of nutrients applied.

The incremental efficiency of applied nutrients to produce grain ($\Delta Y\, F_n^{-1}$) is termed as the Agronomic Efficiency (AE). Farmers' are concerned mostly with overall profit and the marginal B:C ratio from investment in labor and fertilizer input. The cost of labor and cultivation, excluding that of nutrient input, was considered to be similar in all plots. Therefore, the ratio of the cost of incremental yield, ΔY or $(Y-Y_0)$ due to nutrient application, to that of the cost of nutrient inputs may be referred to as the marginal B:C ratio of nutrient application:

$$\text{B:C ratio} = \{(Y-Y_0)\,(Py)\}\ \{(F_n)\,(P_n)\}^{-1} \qquad (2)$$

where, Y is the grain yield of a fertilized plot, Y_0 is the grain yield in Farmers' Input (FI) plots, P_y is the price of grain, F_n is the amount of nutrient applied and P_n is the cost of the applied nutrient input.

The value of P_y for maize was taken as US\$ 130 Mg^{-1} for maize grain. Cost of N application through urea was US\$ 0.23 kg^{-1}, unit cost of N through DAP US\$ 1.24 kg^{-1} and P_2O_5 unit price was US\$ 0.48 kg^{-1}. Price of Zn was US\$ 3.34 kg^{-1}, which of S was US\$ 0.26 kg^{-1} and of B was US\$ 8.89 kg^{-1}. Average prices of fertilizers and the maize grain prevailed over 3 years was used for calculation of yearly B:C ratio.

The experimental sites were monitored with Hobo rain gauges for daily rainfall. The experimental plots were within 500 m from the rain gauge stations. Rainfall use efficiency was calculated by dividing grain yield over total rainfall occurred during the growing season (seasonal rainfall).

The data on crop yield, nutrient uptake, productivity efficiency parameters and rainfall use efficiency were subjected to statistical test of significance using the KyPlot 2.0 (beta 15) software. When the F values were significant for treatments, means were compared using Least Significant Difference (LSD) test at 0.05 level of probability.

RESULTS

Site characteristics revealed that 18-62% farmers' fields were low in nitrogen (as assessed from organic carbon content of the soil), 66-92% fields in available P, 59-80% in available S, 69-78% in hot water soluble B and 78-87% fields in DTPA extractable Zn (Table 3). Apart from limitations of these nutrients, no other soil fertility related problems could be diagnosed from the study. In general, K availability was medium to adequate in majority of farmers' fields. About 18% of the farmer's fields in Aremallapur village were deficient in available K. The most striking observation made on results of soil testing was the considerable extent of deficiency of available S, B and Zn and low levels of available soil N and P.

In the maize crop, FI+NP+SBZn significantly ($p \leq 0.05$) improved the grain yield and total biomass yields in 2005, over the yields obtained in absolute control plots (Table 4). In the 2005 season, SBZn treatment on average gave 24% more grain yield and N plus P treatment gave 31% more grain yield than FI plot. Stover yield of maize, in FI+NP+SBZn treatment was 28% higher than the FI plot which was statistically on par with each other. In subsequent years (2006 and 2007 seasons), the addition of N and P along with SBZn resulted in 42 and 53% more grain yield, 35 and 29% more stover yield, 39 and 40% more total biomass

Table 3: Soil chemical characteristics of 89 soil samples collected from farmers' fields in two villages of Karnataka

Villages and No. of fields tested	pH (1: 2)	E.C. (dS m^{-1})	Org C (g kg^{-1})	Olsen-P (mg kg^{-1})	Exch. K (mg kg^{-1})	Extractable elements (mg kg^{-1}) S	B	Zn
Aremallapur (39)								
Range	5.1-9.0	0.03-1.0	3.1-8.9	1.2-12.7	39-267	1.8-60.7	0.1-1.6	0.2-2.3
Mean	7.58	0.21	5.3	3.67	113	7.93	0.56	0.61
Deficiency (%)			62	92	18	59	69	87
Chikkalingadahalli (39)								
Range	6.3-8.8	0.06-0.8	4.0-8.0	0.6-46.0	52-204	3.8-49.6	0.28-1.04	0.24-1.44
Mean	7.48	0.18	5.8	9.7	108	8	0.5	0.59
Deficiency (%)			18	66	0	80	78	78

The fertility ratings used for delineation of deficiency are: <5 g kg^{-1} organic carbon; <5 mg kg^{-1} for P and <50 mg kg^{-1} K are considered as low. Critical limits considered are 8-10 mg kg^{-1} for calcium chloride extractable S; 0.58 mg kg^{-1} for hot water soluble B; 0.75 mg kg^{-1} for DTPA extractable Zn

Table 4: Yield response of maize crop to different nutrient management regimes in Karnataka, India, 2005-07

Treatments	Grain yield (t ha^{-1})	Stover yield (t ha^{-1})	Total dry matter (t ha^{-1})	Harvest index (% dry matter)
2005				
Absolute control	3.65	4.38	8.03	45.5
Farmer Input (FI)	4.00	4.62	8.62	46.5
FI+NP	5.25	5.48	10.74	48.9
FI+SBZn	5.00	5.65	10.65	47.9
FI+NP+SBZn	6.09	5.92	12.01	50.7
LSD (0.05)	0.49	0.54	0.63	1.2
2006				
FI	3.77	3.80	7.57	49.8
FI+NP+SBZn	5.37	5.12	10.49	51.2
LSD (0.05)	0.56	0.52	0.62	1.2
2007				
FI	5.10	4.84	9.94	47.2
FI+NP+SBZn	6.32	5.82	12.14	51.3
LSD (0.05)	0.65	0.77	0.77	1.6

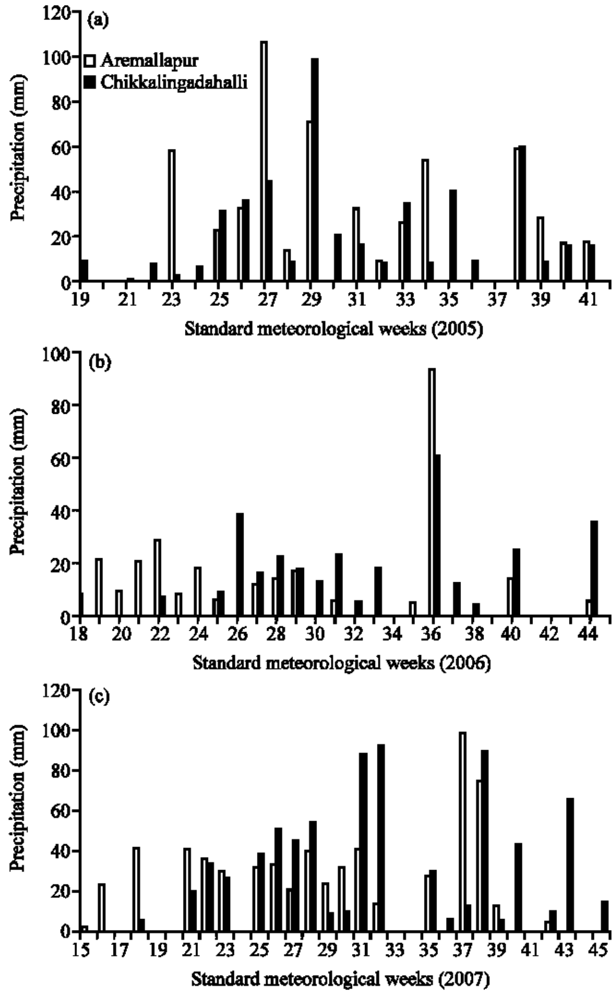

Fig. 1: (a-c) Weekly rainfall in 2005-2007

yield, respectively. Also mean harvest index was increased by the application of treatments consisting of NP, SBZn and NP+SBZn. Thus, both an enhanced dry matter production and a higher harvest index contributed to the greater grain yield observed in plots receiving NP, SBZn and NP+SBZn over the FI. This suggests that, sub optimal level of N and P application by the farmers seems to be relatively important yield-limiting nutrients, while, factors such as deficiencies of S, B and Zn played minor role. The differences between absolute control and farmer's practice of fertilization were non significant with respect to grain yield, straw yield, above-ground plant parts and harvest index (Table 4). Large year to year variation in productivity of maize in FI treatment could be partially due to rainfall distribution, quantity of total and seasonal rainfall (Fig. 1a-c). Differences in inherent fertility of the FI plots could also contribute to yield variability over 3 years of experimentation. However, the seasonal rain fall in 2006, was just 398.3 mm, compared to the 453.8 mm in 2005 and 552 mm in 2007.

As in the case of grain yields, the application of nutrient treatment NP+SBZn over the FI treatment significantly increased the uptake of N, P, K, S, B and Zn in the above-ground

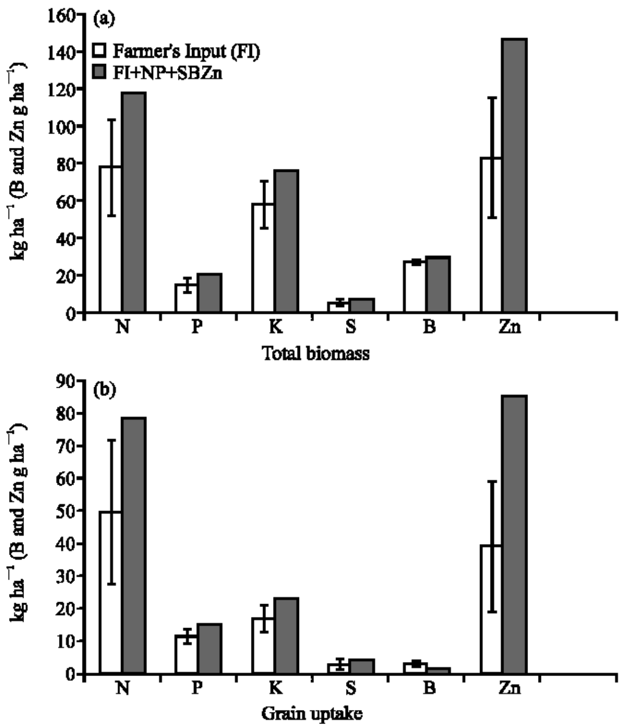

Fig. 2: (a, b) Nutrient uptake pattern in maize grain and total biomass, in response to nutrient management practices. Error bars shown in FI treatment series indicates values of Least Significant Difference (LSD) at $p \leq 0.05$

Table 5: Partial factor productivity, agronomic efficiency and benefit: cost ratio of improved nutrient management in rain fed maize

	Treatments			
*Production efficiency parameters	FI	FI+NP	FI+SBZn	FI+NP+SBZn
Partial factor productivity (kg grain kg^{-1} of nutrients)	40.8	57.3 (40.4)	123.4 (202)	48.4 (18.6)
Agronomic efficiency (kg grain kg^{-1} of nutrients)	12.5	14.0 (12.0)	24.6 (96.8)	16.0 (28.0)
Benefit: cost ratio	3.2	6.4 (100)	2.9 (-9.4)	4.6 (43.8)
Rain water use efficiency (kg grain mm^{-1} of rain)	9.8	11.6 (18.7)	11.1 (13.6)	14.6 (49.2)

*Calculated from mean values of 2005, 2006 and 2007; For FI+NP and FI+SBZn treatments, the mean values of 2005 are presented. Values in parenthesis indicate percent increase or decrease in each parameter due to treatments over the FI

maize parts (Fig. 2a, b). Total uptake of nutrients in maize plot receiving NP+SBZn treatment was greater with respect to N by 50, 28% in P, 31% in K, 36% in S, 9% in B and 76% in Zn compared to FI treatment. Partial factor productivity and agronomic efficiency of maize among different nutrient application treatments was highest for FI+ SBZn plot with 123.4 kg grain kg^{-1} applied nutrients and 24.6 kg grain kg^{-1} nutrients, respectively (Table 5). Application of additional doses of NP was the best option to maximize profits with B:C ratio of 6.4:1 followed by 4.6:1 in NP+SBZn received plots and 2.9: 1 in SBZn treatment. In rain fed maize, application of SBZn over NP and NP+SBZn treatments was efficient as evidenced by the two-fold higher values of partial factor productivity and agronomic efficiency. Rain water efficiency in the rain fed maize was significantly enhanced due to balanced use of N, P, S, B and Zn nutrient carriers (Table 5). Additional amounts of N and P fertilizers along with S, B and Zn nutrients, increased grain production to the tune of about 67% in comparison to FI treatment.

DISCUSSION

As expected, wide spread deficiency of N, P, S, B and Zn were noticed in the maize fields' selected for on-farm trials in the central part of Karnataka. The tentative critical limits of nutrients, used for separating deficient fields from non-deficient fields for available S, B and Zn are: 8-10 mg kg^{-1} for calcium chloride extractable S; 0.58 mg kg^{-1} for hot water soluble B; 0.75 mg kg^{-1} for DTPA extractable Zn. Available P status below 5 mg kg^{-1} in soil was categorized as low or deficient (Sahrawat, 2002). Nutrient status above the critical limits was categorized in to sufficient in a particular nutrient. The soil chemical analysis, revealed findings similar to previous studies. Deficiency of S, B, Zn and low levels of P in maize fields was in conformity with the findings of Rego *et al*. (2007). Deficiency of S, B and Zn are indicative of exhaustion of nutrient reserves through continuous cropping and low recycling of crop residues in maize production system. Even under situations of farmers' management, crop mining of S, B and Zn was significant in the present study (5.6 kg ha^{-1}, 26.9, 82.5 g ha^{-1}, respectively) (Fig. 2a, b). Generally, in maize growers do not apply these nutrient elements on regular basis and recycling of crop residues and manure application was minimal in the region. Possibility of replenishment is meager, through organic sources in the rain fed systems of India due to scarce availability of organic inputs such as animal manures, poor recycling of crop residues, free roaming ruminants in rain fed agro-ecosystems (Franke *et al*., 2008). Farmers often tend to use small quantities of organic manures available on-farm, for their irrigated crops and availability of organic matter in large quantities for recycling purpose is a constraint (Chhonkar, 2003). While, low availability of P in the soils of the study region may be due to sub optimal levels of phosphate fertilizer used to maize by the farmers (Rego *et al*., 2003). In the on-farm trials, application of S, B and Zn significantly increased grain yield, straw yield, total dry matter production and harvest index of maize. Similar results were observed when Zn (Potarzycki and Grzebisz, 2009) and sulphur (Soliman *et al*., 1992) were applied separately to the maize. B fertilization was reported to have negative effects on maize especially when supplied under inadequate P conditions (Aydin and Mehmet, 2000). However, in present study no such deleterious effects of B on grain yield or straw yield could be noticed, as the treatments involved application of other nutrients (S and Zn) along with B. NP+SBZn treatment significantly enhanced ($p<0.05$) nutritional quality of maize grain and straw with respect to N, P, K, S and Zn. Apparently, grain samples from the plots receiving NP+SBZn treatment showed 48% less uptake of B than the FI plots.

Results from the on-farm trials clearly demonstrated that maize responded well to the combined application of fertilizer nutrients. The response seen in the rain fed maize is of similar magnitude reported in SAT regions of Andhra Pradesh, India (Rego *et al*., 2007). Farmers' in the study region use considerable quantity of mineral fertilizers for supplying N and P nutrients. Present study clearly shows that rain fed maize productivity can be significantly boosted by alleviating the deficiencies of S, B and Zn coupled with optimum fertilization of N and P. Addition of S, B and Zn, known to enhance absorption of native as well as added major nutrients such as N and P, there by increases efficiency of production (partial factor productivity and agronomic efficiency) (Bhattacharyya *et al*., 2008; Yadav, 2003). Greater harvest index in the treatment, receiving NP+SBZn, could be due to reduced water stress during grain formation, which may be due to better developed root system. Data on rain use efficiency confirmed that plots receiving NP+SBZn produced more grains $unit^{-1}$ of rainfall received. Appropriate plant nutrient management is reported to enhance rain water use efficiency in rain fed production systems mainly due to formation of better root system which enhances water and nutrient uptake by the crop, thus decreasing water loss through soil evaporation, run off, through-flow and deep drainage (Turner, 2004).

Greater productivity of rain fed maize can be sustained by the integrated soil nutrient resource management through the use of mineral fertilizer materials such as gypsum, borax and zinc sulfate, with appropriate additional dose of nitrogen and phosphorous. Although, in the SBZn treatment, efficiency of production was enhanced to greatest tune, the major limitation in the farm-scale use and scaling out of the technology would be the benefit: cost factor. Lowest cost: benefit ratio of the SBZn treatment, compared to other options of nutrient management, could result in overlooking of the production efficiency benefits by the farmers. In the Indian sub-continent, the comparative cost of zinc sulfate and borax are quite high and these fertilizer materials are not subsidized, while, N and P fertilizers are subsidized. This policy creates imbalance in the use pattern of different fertilizer nutrients. Therefore, efforts must be made to evolve a governance policy which encourages farmers to manage soil nutrients. The basis of developing such policy should relay on the scientific approach of supplying balanced nutrition.

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