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Integrated Plant Genetic and Balanced Nutrient Management Enhances Crop and Water Productivity of Rainfed Production Systems in Rajasthan, India

Short title: Plant genetic & nutrient management enhances yield

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ABSTRACT

Analysis of soils from 421 farmers' fields in eastern districts of Rajasthan, India revealed widespread deficiencies of sulfur (S; 43 to 87% fields deficient), boron (B; 25 to 100%), zinc (Zn; 0 to 94%) in addition to phosphorus (P; 10 to 73%) and soil organic carbon (1 to 84%). Integrated approach of application of deficient sulphur, boron and zinc along with nitrogen and phosphorus to high yielding crop cultivars increased yield over farmers' practice of nitrogen and phosphorus application to local cultivars by 92 to 204% in maize, 115 to 167% in pearl millet and 150% in groundnut. Benefit to cost ratio of the integrated strategy varied from 3.33 to 8.03 in maize, 2.92 to 3.40 in pearl millet and 1.15 in groundnut. Integrated approach effectively utilized scarce water in food production and increased rainwater use efficiency at 67 to 145 kg mm^{-1} ha^{-1} from 21 to 50 kg mm^{-1} ha^{-1} under farmers' practice.

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Keywords: Crop yields, high yielding crop cultivars, micronutrients, sulphur, water productivity.

INTRODUCTION

Along with water shortages, low soil fertility hold back the potential to enhance productivity of rainfed systems in the semi arid tropics (SAT). Despite the shortages of water, much of available water is not utilized efficiently mainly due to nutrient imbalances and use of low yielding crop cultivars. Rainfed agriculture in India is practiced on about 60% of the cultivated area (Wani et al. 2008), and Rajasthan state in India has the largest area under rainfed agriculture. Current productivity of the rainfed agriculture is quite low (1 to 1.5 t ha^{-1}) as against a potential of 2.5 to 7.0 t ha^{-1} (Wani et al. 2003; Bhatia et al. 2009; Fischer et al. 2009; Wani et al. 2011). In view of looming climate change (Zhang et al. 2007; IPCC 2007), producing more food with less water through improved crop, water and nutrient management is the way forward to achieve food security and improve livelihoods of rural communities (Wani et al. 2009). Earlier research showed that SAT soils are critically deficient in micronutrients and macronutrients (Rego et al. 2005; Srinivasarao et al. 2008; Sahrawat et al. 2010; Girish Chander et al. 2012), leading to current lower yields. We hypothesized that rainfed areas in eastern Rajasthan, where water really is not a constraint due to assured rainfall in rainy season, could be used to bridge the yield gaps between current farmers' crop yields and achievable yields through soil test based nutrient management practice and by using improved crop cultivars. The specific objectives of this study were, (i) to assess the nutrient deficiencies in soil samples from the farmers' fields in the target districts of Rajasthan, (ii) to conduct farmer participatory action research trials with high yielding

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crop cultivars with and without soil test based balanced nutrient management recommendations, and (iii) to assess effect of integrated crop genetic and balanced nutrient management practices on crop productivity, rainwater use efficiency (RWUE) and economic viability.

MATERIALS AND METHODS

On-farm Sites, Soil Sampling and Testing

The on-farm trials were conducted in the districts of eastern Rajasthan in India during the rainy seasons of 2009 (Table 1). The predominant soils in Rajasthan are Aridisols, which are well drained and suited to cultivation of maize, pearl millet and groundnut during the rainy season. In eastern parts of Rajasthan, water is not a real constraint for crop production due to assured rainfall particularly during the rainy season. Table 1 shows the rainfall received during 2009 rainy season crop growth phase from June through September.

To diagnose soil fertility related constraints, soil samples were collected from 421 farmers' fields in 9 semi-arid districts in eastern part of Rajasthan state of India by stratified soil sampling method (Sahrawat et al. 2008). The collected samples were air dried, ground and passed through 2 mm sieve. For organic carbon, the soil samples were ground to pass through 0.25 mm sieve. The processed samples were analyzed for pH, organic carbon (OC), available - sulfur (S), boron (B), zinc (Zn), phosphorus (P), and potassium (K) in the Charles Renard Analytical Laboratory in ICRISAT center based at Patancheru, India. Soil reaction (pH) was measured with the help of glass electrode using soil to water ratio of 1:2 and organic carbon by Walkley-Black method (Nelson and Sommers 1996). Available P was extracted using the sodium bicarbonate

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($NaHCO_3$) method (Olsen and Sommers 1982), exchangeable K using the ammonium acetate method (Helmke and Sparks 1996) and available S using 0.15% calcium chloride ($CaCl_2$) as an extractant (Tabatabai 1996). Available Zn was extracted by diethylenetriaminepentaacetic acid (DTPA) reagent (Lindsay and Norvell 1978) and available B by hot water (Keren 1996). As regards determination, available P was determined using colorimetric method, while K by Atomic Absorption Spectrophotometer (AAS). Estimation of S, B, and Zn were made using the Inductively Coupled Plasma Atomic Emission Spectroscopy (ICP-AES).

On-farm Trials

Based upon soil analysis results, the farmer participatory research and development trials were conducted in the rainfed target districts of Rajasthan during the 2009 rainy season (Table 1). The treatments were: (i) Farmer's practice (FP) = application of nitrogen (N) and P + local low yielding crop cultivar (ii) Improved cultivar (IC) = application of N and P + high yielding crop cultivar (iii) Best bet (IC+BN) = application of N and P plus S, B and Zn as balanced nutrition (BN) + high yielding crop cultivar. The N and P at the rate of 60 and 20 kg ha^{-1}, respectively were only fertilizers applied in FP and IC treatments for both maize and pearl millet crops, but groundnut received 20 kg N ha^{-1} along with the same quantities of P. In best bet treatment, in addition to the application of N and P as in FP and IC treatments, the deficient secondary and micronutrients were also added to all crops at the rate of 30 kg S ha^{-1}, 0.5 kg B ha^{-1} and 10 kg Zn ha^{-1}. The sources of nutrients were urea for N, DAP (diammonium phosphate) for P, MOP (muriate of potash) for K, gypsum for S, borax for B and zinc sulphate for Zn. Application of all the nutrients except N was made as basal. Fifty per cent N to non-legumes was added as basal

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and the remaining in two equal splits at one-month intervals, while all N to leguminous crop groundnut was added as basal. The treatments were imposed on 2000 m^2 plots, side by side and uniform crop management practices were ensured in all the treatments.

Crop Yields Rainwater use Efficiency and Economic Analysis

At maturity, the yields were recorded from three sub-plots in a treatment measuring 3X3 m^2 and the average of which was taken as final yield. Per ha additional cost on input seed for improved cultivar was worked out at Rs. 1250/- or \$ 27.6 for maize (25 kg seed ha^{-1}), Rs. 180/- or \$ 3.97 for pearl millet (6 kg seed ha^{-1}), and Rs. 6000/- or \$ 132.5 for groundnut (150 kg seed ha^{-1}). Per ha additional cost on fertilizer application in best bet treatment was taken at Rs. 3000/- (\$ 66.2). Additional return was calculated based on per kg farm gate price for grain/seed/pod produce at the rate of Rs. 9/- or \$ 0.20 for maize, Rs. 8/- or \$ 0.18 for pearl millet, and Rs. 23/- or \$ 0.51for groundnut. The benefit to cost (B:C) ratio of adopting the technology was worked out by dividing additional returns with additional costs over and above the farmers practice. The economic value of maize fodder was worked at market price of Rs. 2/- (\$ 0.04) per kg.

The total amount of water received through rainfall was used to work out the RWUE, which is kg of food grain produced per mm of water per ha. Economic returns per mm of water were also worked out from RWUE based on the farm gate price of seed/grain/pod produce.

The data recorded was subjected to statistical analysis using the Genstat 13th statistical package (VSN International Ltd, UK) (Ireland 2010).

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RESULTS AND DISCUSSION

Soil Analysis

The soil analysis of 421 farmers fields in the target districts revealed widespread deficiencies of S (43-87%), B (25-100%) and Zn (0-94%) in addition to P (10-73%) and OC (1-84%), which are apparently holding back the realization of existing yield potential and efficient utilization of inputs including water and which still have not caught the attention of stakeholders in the SAT (Table 2). On an average 71, 56 and 46% fields were deficient in S, B, and Zn while 38 and 45% in organic carbon and P, respectively. And only 18% of the fields sampled across target region were deficient in available K. Out of 9 target districts, 5 to 7 had majority (>50%) farmers fields deficient in S, B and Zn, but only 3 districts had P deficiency in majority farmers fields. The Rajasthan soils are, in general, rich in K and majority of the farmers' fields are rather sufficient in it. Such deficiencies of micro and secondary nutrients have earlier been identified in other rainfed SAT regions of India (Rego et al. 2005; Srinivasarao et al. 2008; Sahrawat et al. 2010; Girish Chander et al. 2012). The arid and semi-arid climate of the target regions results into rapid mineralization and Aridisols with poor retaining capacity facilitates leaching losses of nutrients in addition to crop removals and thereby subsequent manifestation of deficiencies in low crop yields.

Occurrence of widespread deficiencies of secondary and micronutrients is apparently one of the major reasons for low productivity in the target districts and formed the basis of nutrient

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management decision to include deficient secondary and micro nutrients in addition to N and P to combat land degradation and boost crop productivity and water use efficiency.

Crop Productivity, Profitability and Rain Water use Efficiency

Maize Crop

Across the districts, the farmers' practice of using local cultivars and application of only N and P fertilizers produced maize grain yield in the range of 1150 to 2990 kg ha^{-1} (Table 3). Replacement of local cultivars with improved ones increased maize grain yield in the range of 22 to 68%. However, the best bet practice of adopting improved cultivars along with balanced nutrient management recorded the highest increase in grain yield, which varied from 92 to 204% over the farmer's practice. The increase in the realized maize yield with best bet practices, 41 to 105% increase over improved cultivar, is attributable to applications of the deficient nutrients S, B and Zn. Thus, it is evident from the findings that improved cultivars alone can not realize the yield potential in the hungry rainfed soils of Rajasthan. The B: C ratio of the best bet technology in maize crop varied from 3.33 to 8.03 indicating economic viability for adoption at farm level. The net profit in adopting best bet varied from Rs. 9910/- ($ 219) to Rs. 29890/- ($ 660) per ha. Other rainfed crops in SAT regions have also shown beneficial response to balanced nutrition (Rego et al. 2005; Srinivasarao et al. 2008; Sahrawat et al. 2010; Girish Chander et al. 2012).

Water is a scarce resource and chief determinant of poverty and hunger in rural areas in Rajasthan. So improving RWUE is important for achieving food security and better livelihoods. The RWUE of existing farmers' cultivars with applied N and P in maize varied from 3.36 to 7.39

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mg kg^{-1} ha^{-1} (Table 3). The introduction of improved cultivar in on-farm trials in target districts increased it from 5.43 to 10.8 mg kg^{-1} ha^{-1}, and thereby proved the ability of improved cultivar to best utilize the limiting water resources. The integrated approach involving soil test based addition of secondary and micronutrients to improved cultivar, however, recorded the maximum RWUE (8.20 to 16.2 mg kg^{-1} ha^{-1}). Therefore, integrated soil and crop management involving improved crop cultivars and soil fertility management, with a purpose to increase proportion of water balance as productive transpiration, are one of the most important rainwater management strategies to improve yields and water productivity (Rockstrom et al. 2010). In economic terms, the returns realized per mm of water with best bet (Rs. 74/- or $ 1.63 to Rs. 145/- or $ 3.20 mm^{-1} water) were far better than farmers practice (Rs. 30/- or $ 0.67 to Rs. 67/- or $ 1.48 mm^{-1} water).

The benefits of best bet practice are not only in grain yield, but stover yield as well which increased by 58 to 165% over the farmer's practice (Figure 1). Stover is generally not traded in the region, but as the farmers, in addition to crop production, depend upon livestock economies, increased fodder availability is bound to beneficially impact their livelihoods. Improvement in stover productivity in monetary terms ranged from Rs. 3500/- ($ 77.3) to Rs. 8100/- ($ 179) with average of Rs. 6300/- ($ 139) per ha.

Pearl Millet and Groundnut Crops

Similarly, the replacement of local pearl millet cultivar with improved one increased grain yield by 46% in Tonk district and 54% in Sawai Madhopur district (Table 4). The adoption of best bet, however, enhanced pearl millet yield by 166% in Tonk and 115% in Sawai Madhopur. The best bet yields are up over the improved cultivar with applied N and P treatment by 83% in Tonk and

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39% in Sawai Madhopur indicating the role of deficient secondary and micronutrients. Similar yield improvement (150%) was also recorded with best bet in groundnut as compared with the farmers practice in the Tonk district. However, the groundnut yield was quite low probably because of low rainfall (288 mm) recorded during the crop growth period. By contrast, pearl millet, which is a drought tolerant and early maturing crop, recorded good yields in the same district. Taking into consideration the net additional returns and B:C ratio, pearl millet seems the best crop compared to groundnut for Tonk and Sawai Madhopur region because of low rainfall. The net returns under best bet varied from Rs. 6110/- ($ 136.5) to Rs. 7620/- ($ 170.2) in case of pearl millet and Rs. 1350/- ($ 30.2) for groundnut cultivation.

As in the maize crop, the RWUE in pearl millet also increased from 2.72 to 2.90 kg mm^{-1} ha^{-1} under farmers' practice to 6.27 to 7.20 kg mm^{-1} ha^{-1} under best bet management (Table 4). In groundnut, RWUE increased from 0.92 kg mm^{-1} ha^{-1} under farmers practice to 2.28 kg mm^{-1} ha^{-1} under best bet. Singh and Chaudhary (2006) also recorded the role of cultivar and application of deficient S in increasing water use efficiency in chickpea. In monetary terms, the integrated approach recorded the highest economic returns per mm of water varying from Rs. 50/- ($ 1.10) to Rs. 58/- ($ 1.28) mm^{-1} water in pearl millet and Rs. 52/- ($ 1.15) mm^{-1} water in groundnut. The returns per mm of water under farmers' practices were only Rs. 22/- ($ 0.49) to Rs. 23/- ($ 0.51) in pearl millet and Rs. 21/- ($ 0.46) mm^{-1} water in farmer's practice, respectively. The results proved very precisely and firmly that a strategy based on integrated soil and crop management optimizes resource utilization resulting maximum water productivity or returns per unit of water.

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A relative analysis of RWUE by crop plants in Rajasthan revealed that C4 crop plants (Maize, and pearl millet) are more efficient in contrast to counterpart C3 plants (Groundnut) in bringing in better water productivity.

CONCLUSIONS

Majority of the smallholder farmers in the rainfed production systems in Rajasthan use low yielding crop cultivars and their replacement with improved high yielding cultivars increased on-farm productivity. Improved cultivars alone, however cannot realize the yield potential of rainfed soils of Rajasthan where widespread deficiencies of S, B and Zn along with N and P are holding back the realization of potential yield of crops. This study demonstrated the need for an integrated approach using improved crop cultivars and balanced nutrient management for enhancing crop productivity, rainwater use efficiency and economic returns.

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Table 1. Rainfall received during the growing season and detail of on-farm trials in Rajasthan, rainy season 2009

District	Rainfall (mm)	No. of trials	Crop
Tonk	288	19	Maize (*Zea mays*)
Sawai Madhopur	330	11	Maize (*Zea mays*)
Bundi	367	20	Maize (*Zea mays*)
Bhilwara	341	20	Maize (*Zea mays*)
Jhalawar	605	9	Maize (*Zea mays*)
Udaipur	570	8	Maize (*Zea mays*)
Tonk	288	14	Pearl millet (*Pennisetum* spp.)
Sawai Madhopur	330	13	Pearl millet (*Pennisetum* spp.)
Tonk	288	6	Groundnut (*Arachis hypogaea*)

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Table 2. pH, organic C and available nutrient status of farmers' fields in Rajasthan state of India

District	No. of farmers	pH	% deficiency[a] (Range of available contents[b])					
			OC	P	K	S	B	Zn
Dungarpur[c]	99	6.2-8.0	1 (0.48-1.99)	48 (1.0-28.2)	8 (34-240)	72 (4.0-31.3)	31 (0.28-1.50)	0 (0.88-14.10)
Tonk	78	6.8-10.2	72 (0.09-1.11)	55 (0.2-28.2)	32 (14-243)	79 (2.3-29.8)	64 (0.08-2.46)	94 (0.06-11.92)
Sawai Madhopur	44	7.8-9.4	84 (0.16-0.70)	73 (0.2-11.8)	7 (44-438)	86 (3.1-26.6)	52 (0.20-2.18)	41 (0.34-28.60)
Bundi[c]	36	6.2-8.7	39 (0.18-1.17)	53 (0.9-20.1)	50 (23-563)	72 (3.3-51.0)	72 (0.10-0.98)	67 (0.20-1.78)
Bhilwara	30	7.2-8.9	17 (0.32-1.87)	40 (0.8-27.0)	17 (33-460)	43 (4.0-44.9)	47 (0.32-1.30)	37 (0.16-2.30)
Jhalawar	30	8.0-8.6	7 (0.46-1.15)	30 (0.9-22.6)	0 (51-1358)	87 (1.9-78.0)	77 (0.22-1.36)	60 (0.40-3.40)
Udaipur[c]	44	7.3-9.0	25 (0.25-2.37)	18 (2.6-41.0)	0 (52-288)	48 (3.2-274)	25 (0.22-1.50)	5 (0.70-3.92)
Alwar	30	7.9-8.8	67 (0.33-0.66)	10 (0.5-44.0)	0 (53-515)	63 (4.5-17.2)	87 (0.20-0.68)	83 (0.20-2.00)
Banswara	30	6.3-8.1	43 (0.28-1.05)	50 (1.0-35.0)	17 (31-418)	70 (2.4-22.0)	100 (0.10-0.54)	80 (0.26-2.60)
Rajasthan Total	**421**		**38**	**45**	**15**	**71**	**56**	**46**

[a]Critical value adopted for delineating % deficiency are - 0.50% for OC, 5 mg kg^{-1} for P, 50 mg kg^{-1} for K, 10 mg kg^{-1} for S, 0.58 mg kg^{-1} for B and 0.75 mg kg^{-1} for Zn

[b]Figures in parentheses indicate the range of available contents

[c]Source: Sahrawat et. al. 2008

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Table 3. Integrated improved crop cultivar and balanced nutrient management enhances maize grain yield and RWUE in different districts of Rajasthan during rainy season 2009

District	Yield (kg ha^{-1})			LSD (5%)	B:C ratio	RWUE (kg mm^{-1} ha^{-1})			LSD (5%)
	FP	IC	IC+BN			FP	IC	IC+BN	
Tonk	1150	1930	3160	280	4.26	3.36	5.52	9.13	0.73
Sawai Madhopur	1430	2030	3000	420	3.33	4.09	5.77	8.59	0.95
Bundi	1380	2180	4240	714	6.05	3.59	5.68	10.93	1.68
Bhilwara	2990	4340	6510	860	7.45	7.39	10.76	16.15	1.69
Jhalawar	2550	3520	4960	316	5.11	4.21	5.82	8.20	0.52
Udaipur	2530	3090	6320	509	8.03	4.45	5.43	11.11	0.89

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Table 4. Integrated improved crop cultivar and balanced nutrient management enhances crop grain yield and RWUE in different districts of Rajasthan during rainy season 2009

District	Crop	Yield (kg ha^{-1})			LSD (5%)	B:C ratio	RWUE (kg mm^{-1} ha^{-1})			LSD (5%)
		FP	IC	IC+BN			FP	IC	IC+BN	
Tonk	Pearl Millet	810	1180	2160	212	3.40	2.72	3.93	7.20	0.59
	Groundnut	300	550	750	140	1.15	0.92	1.69	2.28	0.38
Sawai Madhopur	Pearl Millet	1010	1560	2170	225	2.92	2.90	4.49	6.27	0.51

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Figure 1. Effects of cultivar and balanced nutrition on stover yield of maize in different districts of Rajasthan, rainy season 2009.