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Balanced plant nutrition enhances rainfed crop yields and water productivity in Jharkhand and Madhya Pradesh states of India

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Abstract

Two hundred and thirty six soil samples from farmers' fields in the Gumla and Saraikela districts of Jharkhand, and Jhabua and Mandla districts of Madhya Pradesh were analyzed for soil chemical fertility. Results showed deficiencies of sulphur (43 to 100% of samples), boron (69 to 98%), and zinc (5 to 73%). Majority of the farmers' fields, except for those in the Saraikela district, fell in the normal range of soil carbon, phosphorus, and potassium. Soil samples from Jharkhand were relatively poor in fertility. In on-farm trials conducted during 2009 and 2010 in Jharkhand, balanced nutrition (NPK+ S+B Zn) increased yields by 27 to 56% for paddy (*Oryza sativa*), maize (*Zea mays*), and groundnut (*Arachis hypogaea*). Similarly, in Madhya Pradesh, productivity improved by 14 to 57% for soybean (*Glycine max*), paddy, groundnut, blackgram (*Vigna mungo*), and greengram (*Vigna radiata*). The benefits of balanced nutrition included effective utilization of scarce water and increased rainwater use efficiency (1.02 to 13.3 kg mm^{-1} ha^{-1}), compared with farmers' practice (0.92 to 9.67 kg mm^{-1} ha^{-1}). Balanced nutrition provided net returns ranging from Rs. 7155 to 12375 ha^{-1} in Jharkhand and Rs. 1475 to 12735 ha^{-1} in Madhya Pradesh. A favourable benefit-to-cost ratio in Jharkhand (7.36 to 12.0) and Madhya Pradesh (1.97 to 9.35) demonstrated the economic viability of balanced nutrition.

Keywords: Soil fertility, Micronutrients, Productivity, Farm-income, Rainwater use efficiency.

Introduction

With the growing population, food security has become a cardinal issue in India. The country will need more than 300 Tg (million tonnes) of food grains annually to feed the 1.4 billion people expected to populate it by 2025 (Tiwari, 2002). Productivity of the irrigated area has already reached a plateau and any additional food grain production has to come largely from the 89 million hectares of rainfed lands (Wani et al., 2008). Current productivity of rainfed agriculture, however, is quite low: 1 to 1.5 Mg ha^{-1}, against a potential for two to four fold increase (Wani et al., 2012). Rainfed soils are multi-nutrient deficient and need proper nutrient management strategies to bridge the yield gaps (Sahrawat et al., 2010). Wani et al. (2009) also reported that rainfed regions have low rain water use efficiency (RWUE). In the context of economic and environmental limitations to increase water supply to meet the increased demand, water scarcity is increasing. The looming climate related risks and increased probability of occurrence of extreme events (Zhang et al., 2007) call for increasing RWUE. Soil fertility management aimed to increase the proportion of 'productive transpiration', is also one of the most important rainwater management strategies to improve water productivity (Rockstrom et al., 2010). The rainfed areas in Madhya Pradesh and Jharkhand could be sustainably used to bridge

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the yield gaps between current farmers' crop yields and achievable yields through soil test-based nutrient management. The specific objectives of this study were, (i) to assess the nutrient deficiencies in the farmers' fields in selected districts of Jharkhand and Madhya Pradesh, (ii) to conduct farmer participatory action research trials (FPART) using soil test based balanced nutrient management recommendations, and (iii) to assess the effect of balanced nutrient management practices on crop productivity, rainwater use efficiency (RWUE), and economic viability.

Materials and Methods

On-farm sites, soil sampling, and analysis

The participatory on-farm trials were conducted in Gumla and Saraikela districts of Jharkhand state and Jhabua and Mandla districts of Madhya Pradesh during the rainy seasons of 2009 and 2010. The predominant soils were Vertisols and Vertic Inceptisols along with Entisols and Alfisols. Table 1 shows the rainfall received during the crop growth phase from June through September. Soil samples were collected from 236 farmers' fields adopting a stratified soil sampling method (Sahrawat et al., 2008). The farmers were selected from different topographic, soil colour, soil textural, crop management, and socioeconomic strata. The samples were air-dried, and ground to pass through a 2 mm sieve. For organic carbon, the soil samples were ground to pass through 0.25 mm sieve. The processed samples were analysed in the Charles Renard Analytical Laboratory at the ICRISAT following standard methods. Soil pH was measured by glass electrode using soil to water ratio of 1:2 and organic carbon (OC) following the Walkley-Black method. Available phosphorus (P), potassium (K), sulphur (S), boron (B) and zinc (Zn) were extracted as described in Sahrawat et al. (2010). Available P was determined using colorimetry and K by Atomic Absorption Spectrophotometry. Estimation of S, B, and Zn were made using Inductively Coupled Plasma Atomic Emission Spectroscopy (ICP-AES).

Table 1. Rainfall received in target districts in Jharkhand and Madhya Pradesh states of India during crop growth phase in rainy season 2009 and 2010.

State	District	Rainfall (mm)	
		2009	2010
Jharkhand	Gumla	934	368
	Saraikela	407	361
Madhya Pradesh	Jhabua	563	382
	Mandla	800	620

On-farm trials

Based on soil test results, farmer participatory trials were conducted to evaluate the effects of S, B, and Zn (diagnosed to be deficient) in the rainfed districts of Gumla, Saraikela, Jhabua, and Mandla in Jharkhand and Madhya Pradesh states of India during 2009 and 2010 rainy (June to September) seasons (Table 2). The treatments were, (i) farmers practice (FP) of application of N (nitrogen), P, and K only and (ii) balanced nutrition (BN). FP received 60 kg N ha^{-1} and 20 kg ha^{-1} each of P and K for all crops except legumes which received 20 kg N ha^{-1} basally along with same quantities of P and K. The sources of N, P and K were urea and DAP (diammonium phosphate) and MOP (Muriate of potash) respectively. The BN treatment, in addition to farmers' inputs, contained the deficient secondary and micronutrients through 25 kg ha^{-1} zinc sulphate (20% Zn) plus 2.5 kg ha^{-1} Agribor (20% B). Gypsum (15% S) at the rate 200 kg ha^{-1} was also added in the BN treatment in Madhya Pradesh as a source of S. The treatments were imposed on adjacent 2000 m^2 plots, and uniform crop management practices were adopted.

Crop yield, benefit-to-cost ratio, and rainwater use efficiency

At maturity, crop yields were recorded from three subplots measuring 3 x 3 m, the average of which was taken as the final yield. Costs of fertilizer application was worked out based on the prevailing average market prices of fertilizers viz. Rs. 29 per

Table 2. Details of farmer participatory research for development trials on balanced nutrition conducted in Jharkhand and Madhya Pradesh states of India during rainy season 2009 and 2010.

Crop	District	Season	No. of trials
Jharkhand			
Paddy (*Oryza sativa)*	Gumla	Rainy, 2009	21
Groundnut (*Arachis hypogaea*)	Gumla	Rainy, 2009	35
Maize (*Zea mays*)	Gumla	Rainy, 2009	11
Paddy (*Oryza sativa)*	Gumla	Rainy, 2010	39
Maize (*Zea mays*)	Gumla	Rainy, 2010	15
Maize (*Zea mays*)	Saraikela	Rainy, 2010	17
Madhya Pradesh			
Soybean (*Glysine max*)	Jhabua	Rainy, 2009	12
Paddy (*Oryza sativa)*	Jhabua	Rainy, 2009	6
Greengram (*Vigna radiata*)	Jhabua	Rainy, 2009	10
Blackgram (*Vigna mungo*)	Jhabua	Rainy, 2009	4
Soybean (*Glycine max*)	Jhabua	Rainy, 2010	36
Paddy (*Oryza sativa)*	Mandla	Rainy, 2010	11
Groundnut (*Arachis hypogaea*)	Mandla	Rainy, 2010	46
Blackgram (*Vigna mungo*)	Mandla	Rainy, 2010	8

kg for zinc sulphate, Rs. 120 per kg for Agribor, and Rs. 2 per kg for gypsum. Returns were calculated for maize, groundnut, paddy, soybean, greengram, and blackgram based on per kg farm gate price of Rs. 9 for maize, Rs. 23 for groundnut, Rs. 10 for paddy, Rs. 16 for soybean, Rs. 50 each for blackgram and greengram. The benefit to cost ratio of adopting the technology was worked out by dividing returns with costs exceeding the farmers practice. The total amount of water used in crop production through rainfall in all trials was used to work out the water use efficiency as kg of food grain produced per mm of water per hectare. The data were subjected to statistical analysis using Genstat 13th edition (Ireland, 2010). Famers' fields in a cluster of villages in a district were treated as replications for the statistical analysis of the data.

Results and Discussion

Soil analysis

Soil analyses of the farmers' fields in selected districts of Jharkhand and Madhya Pradesh (Table 3) revealed serious mining of S, B, and Zn. In Jharkhand state, 69 to 100% farms were low in S, 93 to 98% low in B, and 71 to 73% low in Zn. Similarly in Madhya Pradesh, 43 to 95% farms were low in S, 69 to 91% farms low in B, and 5 to 19% farms low in Zn. Some farmers' fields also showed low levels of soil C and available P and K; however, most fields in general had normal levels. Saraikela district by contrast had majority farms with low levels of P (80%) and K (58%). The results revealed relatively serious land degradation in Jharkhand, compared to Madhya Pradesh. Going by the essentiality of nutrients, the smallest amounts of micronutrients required were potent enough to affect crop yields. The results thus indicate that widespread deficiencies of S, B, and Z are apparently holding back the realization of the productivity potential and there is a need to include them in the fertilizer management practices. Similar micro and secondary nutrient deficiencies have been reported earlier in the rainfed regions of India (Sahrawat et al., 2010).

Table 3. Soil fertility status of farmers' fields in target districts in Jharkhand and Madhya Pradesh states of India.

State	District	No. of farmers	pH	% deficiency[a] (Range of available contents[b])					
				OC	P	K	S	B	Zn
Jharkhand	Gumla	30		33	23	27	100	93	73
			5.0–7.1	(0.28–1.13)	(1.4–72.4)	(29–247)	(2.0–9.6)	(0.06–0.80)	(0.30–2.90)
	Saraikela	85		45	80	58	69	98	71
			4.5–7.4	(0.19–0.99)	(0.0–18.2)	(8–194)	(1.3–50.0)	(0.06–0.80)	(0.24–2.50)
Madhya Pradesh	Jhabua	22		0	45	0	95	91	5
			6.4–7.4	(0.58–1.53)	(0.2–42.2)	(88–506)	(2.7–28.2)	(0.26–0.76)	(0.66–3.18)
	Mandla	99		3	32	0	43	69	19
			5.9–7.4	(0.45–2.62)	(1.0–147.5)	(82–1846)	(2.0–74.2)	(0.06–1.02)	(0.40–5.50)

[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 (% for OC and mg kg^{-1} for P, K, S, B and Zn).

Crop yield, income, and rain water use efficiency in Jharkhand

In Gumla district during the 2009 rainy season, soil test based BN brought in significant yield advantages, compared to that under FP; i.e., 39% for lowland paddy, 33% for groundnut, and 27% for maize (Table 4). The 2010 growing season in Gumla witnessed only 39% rains as that of 2009. As a result, maize yields were affected adversely,

Table 4. Balanced nutrition enhances crop yields and RWUE in Jharkhand and Madhya Pradesh during rainy seasons 2009 and 2010.

District/season	Crop	Crop yield (kg ha^{-1})		Additional return on BN (Rs.)	Additional cost on BN (Rs.)	B:C ratio	RWUE (kg ha^{-1} mm^{-1})	
		FP	BN				FP	BN
Jharkhand								
Rainy season 2009								
Gumla	Paddy	3325	4615*	12900	1125	11.5	3.56	4.94*
Gumla	Groundnut	1465	1950*	11155	1125	9.92	1.57	2.09*
Gumla	Maize	5500	7000*	13500	1125	12.0	5.89	7.49*
Rainy season 2010								
Gumla	Paddy	3560	4910*	13500	1125	12.0	9.67	13.3*
Gumla	Maize	2530	3950	12780	1125	11.4	6.87	10.7
Saraikela	Maize	2070	2990*	8280	1125	7.36	5.73	8.28*
Madhya Pradesh								
Rainy season 2009								
Jhabua	Soybean	1530	1750*	3520	1525	2.31	2.72	3.11*
Jhabua	Paddy	2800	3550*	7500	1525	4.92	4.97	6.31*
Jhabua	Greengram	725	875*	7500	1525	4.92	1.29	1.55*
Jhabua	Blackgram	550	695*	7250	1525	4.75	0.98	1.23*
Rainy season 2010								
Jhabua	Soybean	1460	1660*	3200	1525	2.10	3.82	4.35*
Mandla	Paddy	2070	2910	8400	1525	5.51	3.34	4.69
Mandla	Groundnut	1090	1710*	14260	1525	9.35	1.76	2.76*
Mandla	Blackgram	570	630	3000	1525	1.97	0.92	1.02

*Significant at 5% level; FP = farmers' practice; BN = balanced nutrition while lowland paddy yields remained unaffected. A comparison of the maize yields under similar management practices in Gumla showed more (54%) yield loss under FP and relatively less (44%) under BN during the year 2010 compared with that of 2009, indicating that BN contributes to building up resilience in the rainfed systems. During 2010, BN increased yields in Gumla by 56% for maize and 38% for lowland paddy. Similarly, in Saraikela district of Jharkhand, maize yields increased by 44% with the adoption of BN during the rainy season 2010. Rainfed crops in other parts of India have also shown beneficial response to balanced nutrition (Sahrawat et al., 2010; Rao et al., 2009).

The real indicator of on-farm acceptability and sustainability of any technology, however, lies in the economics. In this context, the B:C ratio for adopting BN in Jharkhand state during 2009 and 2010 seasons varied from 11.5 to 12.0 for paddy, 7.36 to 12.0 for maize, and 9.92 for groundnut. The soil test based balanced nutrition brought in per ha additional net returns varying from Rs. 11775 to 12375 in paddy, Rs. 7155 to 12375 in maize, and Rs. 10030 in groundnut during 2009 and 2010 seasons which indicated the economic viability of the technology.

The RWUE also increased under BN (2.09 to 13.3 kg ha^{-1} mm^{-1}) treatment as compared with FP (1.57 to 9.67 kg ha^{-1} mm^{-1}) for paddy, groundnut, and maize crops (Table 4). BN by virtue of enhanced root and shoot biomass effectively utilized the scarce water resources and converted unproductive evaporation into productive transpiration. The results particularly during the drought year of 2010 showed that BN helps to increase drought tolerance of crops through increased RWUE. In economic terms, each mm of rainwater in the target regions during 2009 and 2010 seasons generated crop produce worth Rs. 36 to 97 per ha under FP. The corresponding figures were Rs. 48 to 133 under BN, with a meagre additional cost of Rs. 1.20 to 3.12 per mm of rainwater per ha. Put simply, it means gaining more benefits with less water under balanced nutrient management practices.

Crop yield, income and rain water use efficiency in Madhya Pradesh

In Jhabua district during the 2009 rainy season, BN compared to FP increased crop productivity (Table 4) in soybean (14%), paddy (27%), greengram (21%) and blackgram (26%). Similar productivity improvements were also recorded in Mandla district during the 2010 rainy season in paddy (41%), groundnut (57%), and blackgram (11%) crops. The B:C ratio for adopting balanced nutrition in Jhabua and Mandla districts of Madhya Pradesh were profound and it ranged from 2.10 to 2.31 for soybean, 4.92 to 5.51 for paddy, 1.97 to 4.75 for blackgram, 4.92 for greengram, and 9.35 for groundnut. Net returns (per ha) also varied from Rs. 1675 to 1995 in soybean, Rs. 5975 to 6875 in paddy, Rs. 1475 to 5725 in blackgram, Rs. 5975 in greengram, and Rs. 12735 in groundnut.

RWUE of crops increased under BN both during 2009 and 2010 (1.02 to 6.31 kg ha^{-1} mm^{-1}) over FP (0.92 to 4.97 kg ha^{-1} mm^{-1}). Overall, every mm of rainwater produced food worth Rs. 47 to 78 per ha against Rs. 40 to 65 under farmers practice, with additional investments of Rs. 1.91 to 3.99 per mm of water per ha only. The results also showed clearly that soil fertility management, with a purpose to increase the proportion of water balance as productive transpiration, is one of the most important rainwater management strategies to improve yields and water productivity (Rockstrom et al., 2010).

A diagnosis of soil fertility related constraints in rainfed regions of Jharkhand and Madhya Pradesh revealed widespread deficiencies of S, B, and Zn. Soil test based balanced nutrient management involving application of S, B, and Zn along with major nutrients increased crop yields and water productivity. Balanced nutrient management also proved to be economically remunerative.

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