Evaluation of Nutrient Management Options for Yield, Economics, and Nutrient Use Efficiency

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Sustainable high yield agriculture is India's top-most agenda for food security and environmental safety. But there is need to refine most farming situations, if not all, to sustain productivity and prevent the ever-increasing problems related to soil fertility deterioration. This paper evaluates the nutrient management options for cereals, pulse, oilseed, and fodder-based cropping systems in order to diversify crop production, maximise economic gain, and sustain optimal nutrient use efficiency and soil fertility.

Site-specific nutrient management (SSNM) considers indigenous nutrient supply of the soil and productivity targets capable of sustained high yields on one hand, and assured restoration of soil fertility on the other. With this approach, the present food grain production could be achieved from half of the presently irrigated area (Tiwari et al., 2006; Gill et al., 2008). Meanwhile, the remaining half could be better utilised in crop diversification efforts involving legumes, pulses, vegetable, and other high value crops.

After breaking current yield barriers by attaining 12 to 16 t/ha within rice-rice and rice-wheat cropping systems at 17 locations in India under IPNI-supported research projects on SSNM with Project Directorate for Cropping System Research (PDCSR)(Tiwari et al., 2006), it was planned to devise SSNM schedules for pulse, oilseed, and fodder-based cropping systems. An on-station experiment was conducted during 2007-08 in Meerut to evaluate the performance of five nutrient management options including: (1) Farmers' fertiliser practice (FFP), (2) State fertiliser recommendation (SR), (3) Improved state recommendation (ISR; uses a 25% higher dose of N and 50% higher doses of P and K than the SR), (4) state soil testing laboratory recommendation (SSTR), and (5) SSNM within five important cropping systems (i.e., sesamum-wheat, groundnut-wheat, pigeon pea-wheat, maize-wheat, sorghum (fodder)-wheat vis-à-vis a rice-wheat cropping system).

The climate of Meerut is semi-arid sub-tropical, with hot, dry summers and cold winters. The average annual rainfall is 810 mm, 75% of which is received between July and September. The soil of the experimental site was sandy loam in texture (160 g clay/kg, 190 g silt/kg, and 630 g sand/kg), alkaline in reaction (pH 8.2), low in organic C (0.48%), high in P (29 ppm), low in available K (166 kg/ha), and low in S (5.6 ppm). The available micronutrient (i.e., Zn, Mn, Cu, Fe, and B contents were 0.55, 12.3, 2.39, 47.3, and 0.41 ppm, respectively.

The experiment was conducted in split plot design with three replications. The treatment detail for the kharif crops is depicted in **Table 1**. Wheat was grown in the same layout, using NPK fertilisers only, to assess the carryover effect of the secondary and micronutrient applications. Fertiliser sources included urea, diammonium phosphate, potassium chloride, gypsum, zinc sulphate, and sodium tetra-borate.

Economics of the various fertiliser scheduling were calculated on the basis of cost of cultivation **(Table 4)** plus fertiliser cost. For net return, the total cost of cultivation was deducted from the gross return of the system. Gross return calculations used both procurement prices and local prices where applicable (e.g., sorghum fodder value based on local price).

Abbreviations and notes: ISR = improved state recommendation; SR = state recommendation; FFP = farmers' fertilisation practices; N = nitrogen; P = phosphorus; K = potassium; S = sulphur; Zn = zinc; Mn = manganese; Cu = copper; Fe = iron; B = boron; C = carbon; CD = Critical Difference, equivalent to Least Significant Difference.

Yield and System Productivity

The yields of kharif crops varied with nutrient management options, but maximum economic yields were registered under SSNM in all crops **(Table 2)**. The ISR gave the second highest economic yield. Higher yields in these two treatments is ascribed to better yield attributes due to adequate and balanced supply of nutrients as per crop demand through better consideration of the indigenous nutrient supply capacity of soil (Shukla et al, 2004). Response to nutrient management options varied with fertiliser treatment. The SR and STLR produced comparable results for most crops, but were inferior to either ISR or SSNM, highlighting the effects of inadequate nutrients supply. Improved nutrient management also enhanced the yields of sorghum fodder through enhanced leafstalk ratio and diameter of stem.

Grain yield of wheat rose after these kharif crops on same layout without application of secondary and micronutrients. Wheat yields after rice, maize, pigeon pea, groundnut, sesamum, and sorghum fodder followed much the same trend as was observed in the preceding crops. Wheat yields were highest under SSNM and lowest under FFP. The highest wheat yield under SSNM (6.57 t/ha) was registered after maize harvest, while the lowest production (5.81 t/ha) was recorded after sorghum fodder harvest. Enhanced wheat yields under SSNM and ISR is attributed to longer ear size, greater number of grains/ear, and higher numbers of effective tillers (data not shown). Although the magnitude of the response varied with cropping system, the application of secondary and micronutrients in most kharif crops caused significant residual effects on succeeding wheat crops

System productivity across treatments, in terms of wheat equivalent yield [WEY-{(kg yield of other crop in wheat based system x unit price of that crop)/unit price of wheat) + actual wheat yield}], was highest in the rice-wheat (9,709 kg/ha) followed by maize-wheat (9,122 kg/ha), groundnut-wheat (7,976 kg/ha), pigeon pea-wheat (7,619 kg/ha), sesamum-wheat (7,069 kg/ha), and was lowest in sorghum fodder-wheat (6,504 kg/ha). Across cropping systems, system productivity (WEY) was 10.1, 20.4, 11.1, and 26.3% higher in the SR, ISR, STLR, and SSNM compared to the FFP. On average, SSNM had a 6% edge over the ISR. This improvement is attributed to secondary and

Table 1. Treatment details of different crops/cropping system.

Treatments	N	P_2O_5	K_2O	S	$ZnSO_4$	Borax
	Grain/dry fodder yield, kg/ha					
Sesamum						
FFP	25					
SR	35	30	30			
ISR	43.75	37.5	30			
STLR	43.75	22.5	30			
SSNM	60	45	45	40	25	
Pigeon pea						
FFP	22.5	58				
SR	15	4520				
ISR	18.75	56.25	30			
STLR	18.75	33.75	25			
SSNM	30	60	90	40	25	
Groundnut						
FFP	22.5	58				
SR	20	30	45	25		
ISR	25	37.5	68	31.25		
STLR	25	22.5	56	31.25		
SSNM	40	60	90	45	25	5.0
Rice						
FFP	180	60		25		
SR	180	75	60		25	
ISR	187.5	93.75	90		31.5	
STLR	187.5	56.25	75		31.5	
SSNM	180	60	90	45	40	5.0
Maize						
FFP	120	58				
SR	120	60	90			
ISR	150	75	90			
STLR	150	45	75			
SSNM	150	75	90	40	40	
Sorghum						
FFP	35	11.5				
SR	120	60				
ISR	150	75				
STLR	150	45				
SSNM	120	60	60	30	25	

Note: Wheat is grown after each crop with the same treatment structure following the recommendation of wheat crop.

micronutrient application within the SSNM treatment, which is supported by the IPNI-PDCSR collaborative programme on SSNM (Tiwari et al., 2006) and long-term experiments conducted at PDCSR (Shukla et al., 2009).

The largest gap between the SSNM and FFP was recorded in sorghum fodder-wheat (38%), followed by sesamum-wheat (33%), rice-wheat (30%), and groundnut-wheat (28%). The smallest gaps were recorded in maize-wheat (24%), and in pigeon pea-wheat (24%). The increase over SR, ISR, and STLR varied from 14 to 20%, 5 to 8%, and 12 to 18%, respectively **(Figure 1)**.

Nutrient Uptake

The total NPK uptake varied across nutrient management options depending on system productivity and the nutrient content in the grain and straw of the different crops **(Table 3)**. On average, the greatest NPK uptake was recorded in the maize-wheat system (681 kg/ha) followed by rice-wheat (651 kg/ha), pigeon pea-wheat (516 kg/ha), sorghum fodder-wheat (461 kg/ha), sesamum-wheat (426 kg/ha), and lastly groundnut-wheat (408 kg/ha). However, the nutrient content in groundnut

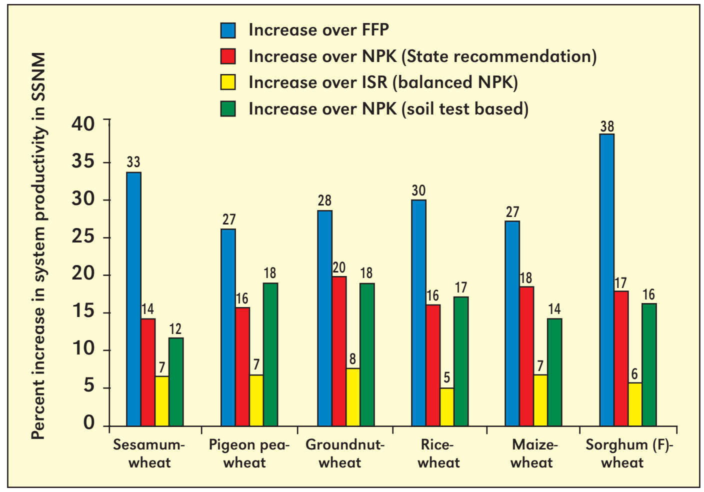

Figure 1. Percent increase in system productivity in SSNM treatment over other nutrient management options under different cropping systems.

seed (and foliage) was very high despite relatively lower seed yields. Stalk yield of sesamum was much higher than that of groundnut, which contributed to greater total N and K uptake in sesamum.

Maximum NPK accumulation was registered in SSNM, followed by ISR, and was lowest in FFP. The STLR and SR options were statistically comparable, but both were superior to FFP. The effect of secondary and micronutrient application was clearly visible on NPK uptake – observed by comparing the ISR (with adequate NPK only) against SSNM (adequate NPK plus S, Zn, and B). This increase could be accredited to better crop metabolism of NPK. Since FFP lacked K fertiliser, the practice not only adversely affected K uptake, but also uptake of N and P, because of low yields and reduced NP metabolism.

Accordingly, NPK use efficiency was much higher in SSNM compared to FFP. Addition of micronutrients in the SSNM schedule also increased internal nutrient use efficiency over the ISR. However, the magnitude of this increase varied among cropping systems **(Figure 2)**.

Effect on Soil Fertility

Soil nutrient status after one crop cycle was measured for available N, P, K, and S (data not shown). Trends found little effect on soil pH or electrical conductivity, but other parameters varied with nutrient management option and cropping system. Available N status was lowest in sorghum fodder-wheat, which was on a par with the maize-wheat system. Since N is the most mobile element in soil, its available status is highly unstable. However, available N status was invariably greater in the upper soil layer (0 to 15 cm) in all cropping systems. In sorghum, the available N status in lower layer (15 to 30 cm) was lowest among all the cropping systems. The ISR treatment showed higher available P contents in surface soils compared to other treatments. However, lower P contents in surface soils under SSNM over ISR revealed that P utilisation was better in SSNM due to secondary and micronutrient application. The P content in deep-rooted legume and fodder-based cropping systems was usually less than in cereal crops, owing to higher utilisation of P by legume and fodder crops. The treatment receiving fertiliser as per STLR had identical P contents as the SR in most cropping systems. The lowest soil K content was recorded in the

Table 2. Crop yields and system productivity as influenced by nutrient management options in different cropping systems.

Nutrient manage-ment options	System productivity (kg/ha) as wheat equivalent yield (WEY)																	
	Rice	Wheat	RWS*	Sesamum	Wheat	SWS*	Pigeon pea	Wheat	PWS	Groundnut	Wheat	GWS	Maize	Wheat	MWS	Sorghum (F)	Wheat	S(F)WS
FFP	6,971	4,571	8,422	713	4,252	5,950	1,526	4,867	6,916	1,351	5,143	7,099	5,766	5,114	8,079	41,619	4,390	5,381
SR	7,467	5,333	9,458	804	5,030	6,945	1,582	5,410	7,534	1,362	5,571	7,543	6,045	5,581	8,690	51,429	5,095	6,320
ISR	8,343	5,771	10,380	850	5,392	7,416	1,878	5,690	8,212	1,624	6,076	8,427	6,913	6,038	9,593	57,905	5,629	7,007
STLR	7,619	5,143	9,351	776	5,248	7,096	1,588	5,257	7,390	1,456	5,619	7,727	6,383	5,714	8,997	49,905	5,200	6,388
SSNM	9,257	5,819	10,933	998	5,564	7,940	2,144	5,876	8,756	1,934	6,286	9,085	7,732	6,276	10,253	67,810	5,810	7,424
Mean	7,931	5,328	9,709	828	5,097	7,069	1,744	5,420	7,619	1,545	5,739	7,976	6,568	5,745	9,122	53,733	5,225	6,504
CD $(p < 0.05)$	528	265	536	85	244	463	106	211	481	89	232	412	529	198	543	1,095	231	321

RWS = Rice-wheat system; SWS = sesamum-wheat system; PWS = pigeon pea-wheat system; GWS = groundnut-wheat system; MWS = maize-wheat system; and S(F)WS= sorghum (fodder)-wheat system.

Table 3. Total NPK uptake as influenced by nutrient management options under different cropping systems.

Nutrient manage-ment options	Total NPK uptake[1], kg/ha																	
	Rice-wheat			Sesamum-wheat			Pigeon pea-wheat			Groundnut-wheat			Maize-wheat			Sorghum (F)-wheat		
	N	P	K	N	P	K	N	P	K	N	P	K	N	P	K	N	P	K
FFP	203	64	267	129	30	199	155	43	224	138	41	168	212	64	286	82	30	180
SR	239	80	298	152	38	224	182	53	256	149	46	183	234	77	329	178	40	239
ISR	276	92	341	165	43	237	218	64	297	180	58	211	254	96	374	211	51	271
STLR	244	76	305	159	37	231	178	49	247	158	49	184	251	80	348	175	39	237
SSNM	301	101	363	182	48	256	233	67	314	188	61	225	292	100	400	222	53	300
Mean	253	83	315	157	39	230	193	55	268	163	51	194	249	84	348	174	42	245
CD $(p < 0.05)$	22.8	7.5	19.6	13.2	4.1	18.5	15.3	5.2	18.9	12.8	4.2	20.7	13.4	6.8	24.0	17.8	3.4	14.3

[1]Plant uptake values are presented as elemental forms.

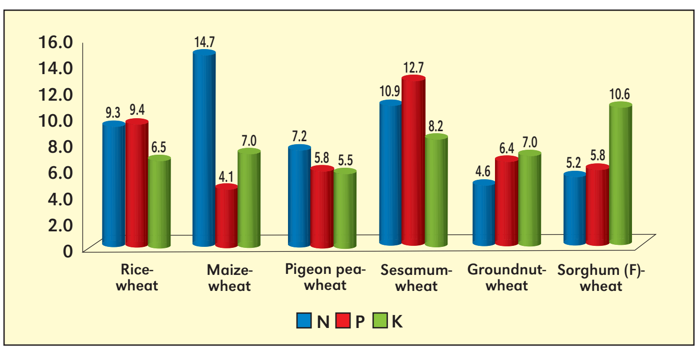

Figure 2. Percent increase in internal nutrient use efficiency in SSNM treatment over other nutrient management options.

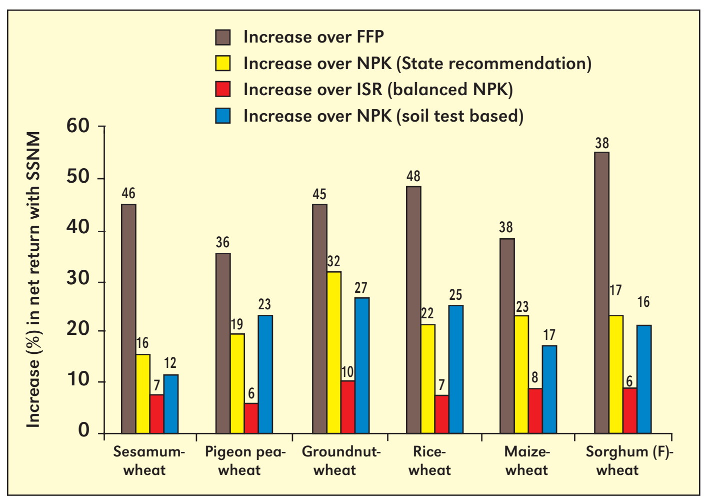

Figure 3. Percent increase in net return with SSNM treatment over other nutrient management options.

pigeon pea-based system and sorghum fodder-based system. The higher soil K status in cereal-based systems is possibly due to higher application and reduced K uptake compared to the pulse-based systems. The available S content of surface soil in the maize-wheat, sorghum-wheat, and sesamum-wheat cropping systems was either below or near the critical limit. Application of gypsum in groundnut has resulted in enhanced available S status in all the treatments. SSNM had the highest soil S content after one crop cycle, although the magnitude of this increase was not very high as the succeeding crop of wheat was grown without secondary and micronutrient application. The available S content at the lower depth was usually less than the surface soil in all cropping systems except the pigeon pea-wheat system. Interestingly, a slight S build up was noted under SSNM, while K status sharply declined in the STLR, SR, ISR, and FP treatments.

Economic Return

Economics is the dominant factor influencing the adoption of cropping systems. Across all options, the highest return (Rs.56,327) was recorded for the rice-wheat system, while

Table 4. Effect of nutrient management options on total net return of different cropping systems.

Nutrient management options	Sesamum-wheat	Pigeon pea-wheat	Ground nut-wheat	Rice-wheat	Maize-wheat	Sorghum fodder-wheat
	Total cost of cultivation, Rs./ha					
FFP	30,020	33,967	35,982	43,432	41,488	26,589
SR	30,830	34,408	38,078	45,115	41,956	29,267
ISR	31,758	35,421	39,301	46,570	43,456	30,542
STLR	30,940	34,442	38,399	45,269	42,279	29,477
SSNM	33,950	37,836	41,258	47,692	45,541	31,950
Mean	31,499	35,215	38,604	45,616	42,944	29,565
	Total net return, Rs./ha					
FFP	32,452	38,655	38,560	45,002	43,347	29,916
SR	42,091	44,697	41,123	54,192	49,284	37,090
ISR	46,112	50,809	49,181	62,418	57,274	43,034
STLR	43,565	43,149	42,735	52,922	52,191	37,599
SSNM	49,426	54,102	54,139	67,099	62,112	46,003
Mean	42,729	46,282	45,147	56,327	52,842	38,728
CD ($p<0.05$)	2,665	2,815	2,690	3,212	3,254	2,358

Note: Prices for N, P_2O_5, K_2O, S, Zn, and B were Rs.10.5, 16.5, 7.5, 26.5, 20, and 34 per kg. Prices for rice, sesamum, pigeon pea, groundnut, maize, and sorghum (fodder) were Rs.5.80, 15.60, 14.10, 15.20, 5.40, and 0.25 per kg. Labour cost = Rs105 per labourer per day. In addition, land lease cost (rental value), irrigation cost, and pesticides costs are included in the total cost.

the lowest (Rs.38,728) was registered in the sorghum fodder-wheat system **(Table 4)**. The cost of cultivation was lowest in sesamum-wheat and this was comparable with the sorghum fodder-wheat system. Under SSNM, 8.1 to 17%, 6.3 to 11.3%, 2.6 to 7.7%, and 5.9 to 11.5% additional investment was accrued compared to FFP, SR, ISR, and STLR treatments, respectively. Similarly, the total net returns for the different systems were also greater by 36 to 55%, 16 to 32%, 6.0 to 10%, and 12 to 27%, respectively, over FFP, SR, ISR, and STLR **(Figure 3)**. As for adoption of nutrient management options, the highest return was from SSNM, which furnished Rs. 67,099, 62,112, 54,139, 54,102, 49,426, and 46,003 in rice-wheat, maize-wheat, groundnut-wheat, pigeon pea-wheat, sesamum-wheat, and sorghum fodder-wheat, respectively. BC INDIA

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The International Certified Crop Adviser (ICCA) program of the American Society of Agronomy (ASA) is coming to India in 2010. The ICCA program is a voluntary initiative that certifies candidates who successfully complete an exam which tests their knowledge on principles and practices associated with crop management, integrated pest management, nutrient management, and soil and water management.

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