Effect of site-specific nutrient management on yield, profit and apparent nutrient balance under pre-dominant cropping systems of Upper Gangetic Plains

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Effect of site-specific nutrient management on yield, profit and apparent nutrient balance under pre-dominant cropping systems of Upper Gangetic Plains

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ABSTRACT

A field experiment was conducted on a Typic Ustochrept soil at Project Directorate for Farming Systems Research Modipuram (29^{0}4' N, 77^{0}46' E, 237m asl), for three consecutive years (2007-08 to 2009-10) to evaluate the site-specific nutrient management (SSNM) option against existing farmers fertilizer practices (FFP), state recommendation (SR), improved SR (ISR) (i.e. 25% higher than SR), and soil testing laboratory recommendation (STLR) in six pre-dominant wheat based cropping systems of Upper Gangetic Plains, in terms of yield gain, economics, nutrient harvest index, soil fertility, and apparent nutrient balances. SSNM improved system wheat equivalent yield over SR, ISR, STLR and FFP by 19%, 8%, 17% and 29%, respectively. SSNM involved additional cost of ₹ 5 097 to 7 938 /ha over SR and FFP under different cropping systems but it gave higher added net return of ₹ 13 649 to 58 776 /ha and ₹ 25 030 to 68 980 /ha over SR and FFP, respectively. The output: input ratio and nutrient harvest index were also highest in SSNM. At the end of the experiment, soil available N, Olsen-P and available K content were either maintained or improved over its initial values in SSNM treatments, whereas these parameters declined or marginally increased over the initial contents under FFP and SR in 0-15 cm soil profile depth. After 03-crop cycles, apparent N and P balances were positive in most of the cropping systems and fertilizer treatments, except a negative N balance was noticed in pigeonpea [*Cajanus cajan* (L.) Millsp]–wheat (*Triticum aestivum* L.) and groundnut (*Arachis hypogaea* L.)–wheat systems under SR and SSNM treatments. The apparent K balances were negative across all the cropping systems and nutrient management options but the magnitude was lower under SSNM.

Key words: Apparent nutrient balance, Economics, Nutrient harvest index, Output: input ratio, Site-specific nutrient management, System equivalent yield, Soil fertility

Recent diagnostic surveys in intensively cultivated areas of Indo-Gangetic Plains (IGP) revealed that farmers often apply greater than recommended rates of fertilizer N and P, but ignore the sufficient application of other limiting nutrients (Singh *et al*. 2013). Such an unbalanced and inadequate fertilizer use not only aggravates the deficiency of K, S and micronutrients in the soil, but also proves uneconomic and environmentally unsafe (Dwivedi *et al*. 2003, Singh *et al*. 2005). Under these circumstances, high yield potential of modern varieties can never be exploited with existing fertilizer practice which fail to provide adequate and balanced doses needed for the crops.

Attainable yield of crops under farmers fertilizer practices (FFP) in the Western Indo-Gangetic Plains vary with inherent soil fertility level, crop residue and fertilizer use management, organic materials input, rate of applications, method and schedule of fertilizer application, and variation in nutrient requirements by cultivars etc (Shukla *et al*. 2004, Singh *et al*. 2013). In contrast, blanket application of plant nutrients in RWS across large areas is typical in the Upper Gangetic Plains (UGP) of IGP. One standard recommendation, developed before 50 years is promoted at state-level without considering the above factors however, drastic changes in crop cultivars and other agronomic management has witnessed during this period. This leads to inefficient use of added nutrients as application rates do not consider the spatial variability in nutrient requirements among the fields (Buresh *et al*. 2010). Site-specific nutrient management (SSNM) has been proposed as an approach to tailor fertilizer application to match field-specific needs of crops to improve productivity and profitability (Witt *et al*. 1999, Buresh *et al*. 2010). This could be done by utilizing available information on indigenous nutrient supplying capacity, nutrient contributions from organic manures, irrigation water, rain fall and crop residue pools and finally crop nutrient demand for targeted yield of crops/cropping systems. With these considerations, the present investigation was undertaken to

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identify the best nutrient management strategy for various production systems in UGP for achieving maximum attainable yields and profits, and to see its effect on important soil fertility parameters, nutrient harvest index and apparent nutrient balance.

MATERIALS AND METHODS

A field experiment was carried out during 2007-08 to 2009-10 on a Typic Ustochrept soil of the research farm of Project Directorate for Farming Systems Research, Modipuram, Meerut, India, located at 29° 4' N latitude, 77° 46' E longitude and at elevation of 273 m above mean sea level. Modipuram falls under a semi-arid sub-tropical climate zone with very hot summers and cool winters. The average annual rainfall is 810 mm and potential evapo-transpiration is 1500 mm. The experimental site represents irrigated, mechanized and input intensive cropping areas of UGP of the IGP region. The soil of the experimental site was sandy loam (160 g clay/kg, 190 g silt /kg and 630 g sand/kg) of Gangetic alluvial origin, very deep (>2 m), well-drained, flat (about 1% slope), and represented an extensive soil series, i.e. Sobhapur series of north-west India. The top soil (0-15 cm) of the experimental field at the start of experiment was non-saline (EC 0.35 dS/m) and mildly alkaline (pH 8.2), CEC (8.8 mol/kg) and contained 0.48% organic carbon, 169 kg/ha available N, 29.1 kg/ha Olsen-P, 166 kg/ha available K, 9.6 mg/kg sulphur, 0.55 mg/kg zinc and 0.41 mg/kg boron.

The site-specific nutrient management doses for the different cropping systems were worked out based on plant nutrient demand for a targeted yield. On-farm data from field experiments conducted under All India Coordinated Research Project on Integrated Farming Systems (AICRP-IFS) were used to estimate the Reciprocal Internal Efficiencies (RIE) expressed as kilogram plant nutrient uptake per tonne grain production (Witt *et al.* 1999) for rice, wheat, maize, pigeonpea, sorghum, groundnut and sesamum crops. These values were subsequently combined with information on indigenous nutrient supply (INS) and yield gains from added nutrients to determine nutrient requirements for these crops for a pre-determined yield target. The components of INS calculations included nutrient (N, P and K) contributions from soil available pool, irrigation water, and rainfall and their availability (%, efficiency) to the crop. The following equation was used to estimate the nutrient (N, P and K) balance under different crops.

$$B_{n\ (c)} = \{(IW_n \times Eff) + (CR_n \times Eff) + (RF_n \times Eff) + (S_n \times Eff)\} - \{(GY_c \times RIE_{nc})\} \quad (1)$$

where, B_n is the nutrient balance (N or P or K; kg/ha), and the IW_n, CR_n, RF_n and S_n are the nutrient (N or P or K) contribution from irrigation water, crop residue, rainfall and soil during entire crop cycle. The term "Eff" is the efficiency (%) of different nutrients from various pools of INS in terms of their availability to the crops. GY_c and RIE_{nc} are attainable grain yields (tonnes/ha) and the reciprocal internal efficiencies (N or P or K) of a crop in the system.

The nutrient contributions from IW and RF (kg/ha) were estimated using total amount of irrigation water applied/rainfall received (ha-cm) during the crop cycle, and their N, P, K content. Average available soil N, P and K content (kg/ha) at the start of the study was used as contribution from soil. The nutrient input from residues of a crop (CR_n) was determined from the amount and nutrient content of the above ground crop biomass retained in the field after harvest and expressed in kg/ha. The total fertilizer nutrient requirement (kg/ha) for the crop ($F_{n\ (c)}$) was worked out as:

$$F_{n(c)} = B_{n(c)}\ RE_{n(c)}^{-1} \quad (2)$$

where, $F_{n(c)}$ and $RE_{n(c)}$ are the fertilizer nutrient (N or P or K) requirement (kg/ha) and recovery efficiency (%) of nutrient N, P and K of a crop, respectively.

On the basis of above, SSNM (N-P-K) doses were calculated as 180-26-75 kg/ha, 150-33-75 kg/ha, 150-33-75 kg/ha, 30-26-75 kg/ha, 40-26-75 kg/ha, 120-26-50 kg/ha and 60-20-37 kg/ha for hybrid rice, wheat, maize, pigeon-pea, groundnut, sorghum (f) and sesamum, respectively.

The experiment comprising six cropping system namely rice-wheat (R-W), maize-wheat (M-W), pigeon-pea-wheat (P-W), groundnut-wheat (G-W), sesamum-wheat (S-W) and sorghum (f)- wheat (Sg-W) in main plot and five nutrient management options, viz. farmers fertilizer practice (FFP), ad-hoc recommendation (SR), improved state recommendation, i.e. 25% higher than SR (ISR), soil testing lab recommendations (STLR) and site-specific nutrient management (SSNM) in sub-plots were evaluated in split plot design with 03 replications. Nutrient application under FFP for different crops were decided based on farmers' participatory survey conducted with farmers growing the respective cropping systems, and highest mode value for N, P, K and Zn application were used for FFP at each cropping system. Except for fertilizer application, standard crop management practices were followed in all the crops. Grain and straw yields of all the crops were determined from 20 m^2 area in each plot. After sun-drying for three days in the field, the total biomass (grain + straw) was weighed and threshed with a plot thresher, except sorghum fodder (f) which was weighed as green fodder.

Soil samples (0-15 cm depth) were collected from four places from experimental fields using a core sampler of 8 cm diameter before commencement of the experiment in 2007 and after completion of 03 cropping system cycles (i.e. post wheat season 2010). Soil samples collected from each field were mixed thoroughly, and a sub-sample was pulverized using a wooden pestle and mortar and passed through a 100 mm sieve. Soils were analyzed for extractable N by the alkaline $KMNO_4$ method (Subbiah and Asija 1956), Olsen- P (0.5*M* $NaHCO_3$, pH 8.5 extraction) (Olsen *et al.* 1954) and exchangeable K (1*M* NH_4OAc, pH 7.0 extraction) (Helmke and Sparks 1996).

Representative sub-samples of grain and straw of rice and wheat were dried at 70°C, ground in a stainless steel Wiley mill, and then wet-digested with concentrated H_2SO_4

for determination of total N, or digested with concentrated HNO_3 and $HClO_4$ (mixed in 1:4 ratio) for determination of total P and K. The N content was determined by the Kjeldahl method using an auto analyzer, P was determined by the vanadomolybdate yellow colour method (Piper 1966), and total K content was determined by flame photometry.

Nutrient harvest index (NHI) for N, P and K was computed as:

$$NHI_{N\ or\ P\ or\ K} = [G_u / (G_u+S_u)] \times 100 \quad (3)$$

where G_u and S_u are the N or P or K uptake in economic and straw/ halm part of different crops, expressed in kg/ha.

Added net return with different treatments relative to FFP was determined using the minimum support price (MSP) fixed by the government for rice, wheat, maize, groundnut and sesamum grain plus straw prices for these crops and fodder cost of sorghum as per local market, and the cost of fertilizers on a nutrient basis (FAI 2011). The total cost of fertilizer for a treatment was computed as the sum of cost for each applied nutrient.

An apparent nutrient balance sheet at the end of the 03 year experiment were calculated by subtracting the nutrient removed in the crops from those added in the fertilizer, crop residue, irrigation water and rainfall.

RESULTS AND DISCUSSION

Effect on crop productivity

Monsoon Crop

The productivity gain under SSNM treatment over FFP was of 33.46%, 38.1%, 45.6%, 31.9%, 30.9% and 17.5% for rice, maize, pigeonpea, sesamum, groundnut and sorghum (f) (Table 1), respectively. Higher productivity under SSNM was accrued due to sufficient nutrient supply as per crop demand and indigenous soil nutrient supplying capacity, whereas in FFP with excess N use, sub-optimal P and no- K application led to the insufficient and imbalanced plant nutrient supply and resulted in lowest productivity gain.

The ISR option of nutrient management ranked second in terms of yield performance and had edge over SR and STLR method of fertilizer application. The increase in yield under ISR over SR and STLR was to the tune of 0.75 to 1.00 tonne/ha in rice, 0.70 to 0.93 tonne/ha in maize, 0.24 tonne/ha in pigeonpea, 0.03 to 0.09 tonne/ha in sesamun, 0.14 to 0.21 tonne/ha in groundnut and 0.79 to 0.92 tonnes/ ha in sorghum (f) crop (Table 1). The yield obtained in SR and STLR fertilizer treatment had almost similar trend for different monsoon crop but with an edge over FFP.

Effect on wheat crop

The grain yields of wheat, raised on same layout were also highest under SSNM treatment followed by ISR, and the lowest in FFP (Table 1). Among the cropping system, highest wheat yield with SSNM was registered after maize (6.3 tonnes/ha), which was closely followed by wheat grown after pigeonpea and groundnut. Yield gain under SSNM over FFP and SR was in the range of 11.5 to 38.5% and 10.5 to 21.3%, respectively in various cropping system. The enhanced wheat yield in SSNM and ISR treatment options is attributed to larger spike length, longer spike, more number of grains/spike and greater number of effective tillers/m^2 (data not reported).

Table 1 Productivity (tonnes/ha) of different crops and cropping systems as influenced by various nutrient management options

Nutrient management options	Rice-wheat	Maize-wheat	Pigeonpea-wheat	Sesamum-wheat	Groundnut-wheat	Sorghum-wheat	Mean
Monsoon crop							
FFP	6.80	5.64	1.49	0.72	1.36	16.73	5.46
SR	7.28	6.00	1.64	0.82	1.40	17.89	5.84
ISR	8.28	6.93	1.88	0.85	1.61	18.68	6.37
STLR	7.53	6.23	1.64	0.76	1.47	17.76	5.90
SSNM	9.11	7.79	2.17	0.95	1.78	19.66	6.91
Mean	7.80	6.52	1.76	0.82	1.52	18.14	-
Winter crop							
FFP	4.33	5.66	5.18	4.54	5.15	4.23	4.85
SR	5.13	5.62	5.51	5.34	5.54	4.83	5.33
ISR	5.48	5.80	5.77	5.77	5.91	5.50	5.71
STLR	4.96	5.62	5.37	5.53	5.59	5.05	5.36
SSNM	5.67	6.31	6.21	5.99	6.20	5.86	6.04
Mean	5.11	5.80	5.61	5.43	5.68	5.09	-
Systems wheat equivalent yield (SWEY)							
FFP	10.04	9.96	9.48	6.43	8.00	5.53	8.24
SR	11.24	10.20	10.23	7.50	8.47	6.22	8.98
ISR	12.45	11.09	11.18	8.02	9.29	6.96	9.83
STLR	11.29	10.38	10.09	7.55	8.68	6.43	9.07
SSNM	13.33	12.26	12.46	8.51	9.95	7.39	10.65
Mean	11.67	10.78	10.69	10.60	8.88	6.51	-

CD (P=0.05)

	Cropping System (C)	*Nutrient management options* (N)	*C × N*
Monsoon crop	0.68	0.44	0.92
Winter crop	0.37	0.59	0.84
SWEY	0.73	1.05	1.31

System productivity

Comparing the system productivity, in terms of wheat equivalent yield indicated that SSNM out yielded different nutrient management options across the cropping systems. System wheat equivalent yield (SWEY) in SR, ISR, STLR and FFP treatments was 19%, 8%, 17%, and 29%, lower than that of SSNM (Table 1). Averaged over the nutrient management options, the highest system productivity was recorded in R-W (11.67 tonnes/ha) followed by M-W (10.8 tonnes/ha), P-W (10.7 tonnes/ha), G-W (8.9 tonnes/ha), S-W (7.60 tonnes/ha) and Sg-W (6.50 tonnes/ha) cropping system. Among the studied cropping systems, highest increase due to SSNM option over FFP was recorded in R-W system (3.29 tonnes/ha) followed by P-W system (2.98 tonnse/ha). These results clearly showed that the generalized recommendations at state level and recommendations made by soil testing laboratory based on initial soil status (i.e. high, medium and low) may not help to achieve high yield target. On the other hand, SSNM recommendations, which take into account of indigenous nutrients supplying capacity of soil (INS), targeted yield and nutrient use efficiency together, proved to be an efficient nutrient management option for attaining high yields under different crops and cropping systems. The significantly higher system productivity in SSNM over SR may partially be ascribed to the inclusion of S and Zn in SSNM fertilizer schedule. It is pertinent to mention here that the high yielding cultivars of different crops were grown in this study, and their nutrient uptake demands were considerably higher compared with commonly grown cultivars in the region. Theoretically, as the yield goals move up, the nutrient basket demanded by crop not only grows bigger but also became more varied and complex leading to multiple nutrient deficiencies (Singh *et al*. 2012). Therefore, nutrient harvest index (NHI) computed for N, P and K in rice and wheat was highest under SSNM, implying that the balanced nutrient supply through SSNM regulated efficient nutrient utilization towards the sink (Fig 1).

Effect on nutrient harvest index

Nutrient harvest index for N, P and K were highest under SSNM in all the cropping system followed by SR and FFP (Fig 1). Increased NHI for N, P and K values under SR and SSNM may be ascribed due to inclusion of K under fertilizer application schedule. Physiologically, potassium helps in regulating the activity of several enzymes leading to control of diseases, building up resistance in plant towards invading pathogens and several abiotic stress (Aulakh and Malhi 2004). On the other hand, excessive accumulation of N compounds in plants disrupts the phloem transport and thus restricts P absorption under K deficient conditions. Thus, increasing K levels in fertilizer prescription, can be utilized advantageously for protecting the crop from several health hazards and consequently for enhancing nutrient use efficiency.

Changes in soil fertility status

Available N content

In general, available N content in soil was more under legume based system as compared to other cropping system (Table 2). Averaged across the nutrient management options, the available N content was maximum under P-W system (280 kg/ha) followed by G-W (259 kg/ha), M-W (241 kg/ha), R-W (234 kg/ha), Sg-W (195 kg/ha) and S-W system (167 kg/ha). The higher N content in legume based system may be ascribed to sizeable additions of N through BNF and leaf litter fall and its subsequent decomposition enriching different pools of N. In addition, relatively greater amount of wheat residues recycled owing to higher yield of wheat after legume also had added advantage in enriching the N pools (Singh *et al*. 2002). Averaged over the cropping system, ISR had highest soil N content (259 kg/ha) followed by SSNM option (253 kg/ha) and the lowest N content was recorded with FFP. The lower N content under FFP, SR and STLR indicates potential N loss from soil caused by imbalance or insufficient nutrient applications (Dwivedi *et al*. 2003). After three crop cycles, available N content in the soil increased under all the nutrient management options but the magnitude of increase was more under ISR (53%) and SSNM (50%) options. Increased soil N availability may be corroborated with earlier reports of Dwivedi *et al*. (2003) and Singh *et al*. (2005), wherein better root foraging caused by balanced nutrition helps to trap NO_3-N losses and made it available in upper soil profile. Balancing the N P K ratio by increasing fertilizer K input is practical way to improve agronomic N efficiency (Zhu and Chin 2002).

Olsen-P content

After 03 crop cycle, Olsen-P content of the soil (0-15 cm depth) increased over the initial content, consequent to different fertilizer management options under R-W system (6.1%) and M-W system (4.3%) (Table 2). On the contrary, a depletion of available P content, compared to the initial value was observed under other cropping systems and the magnitude of depletion was more under P-W and G-W system. Lower P content in the soil under legume based cropping system may be due to higher P demand of legumes and better P utilization efficiency as indicated in NHI_P (Fig 1) due to its deeper root system (Singh *et al*. 2005). The higher P content of soil in R-W system corroborated with the earlier studies by Dwivedi *et al*. (2003), wherein continuous P application at 26 kg/ha to both the crops resulted in build up of P content in the soils.

Among nutrient management options, ISR treatment showed superiority over all other treatments as far as Olsen-P content of 0-15 cm profile depth is concerned. Relatively lower P under SSNM may be ascribed to the higher P utilization efficiency in this treatment as indicated by NHI_P (Fig 1). Further, soil P content under STLR treatment was identical under all the cropping system indicating that recommendations of soil testing laboratory needs a fresh look in the view of changing management practices, cultivars yield potential and indigenous soil nutrient supply.

Available K content

Soil K content varied among the cropping systems and it ranged between 152 to 179 kg/ha (Table 2). In general, available K content increased over initial K status under different crop sequences with exception of S-W (-8.0 %) and Sg-W system (-9.7%). Negative K content under these system may be ascribed as relatively lower K application rate to the sesamum and sorghum crops, almost nil-K recycling through residues + stubbles and greater K uptake demand by the crops (Fig 1).

Averaged over the cropping systems, highest soil K content was recorded under SSNM followed by ISR, STLR, SR and least under FFP. After 03 crop cycle, SSNM and ISR could only contribute by 21% and 8% to the available

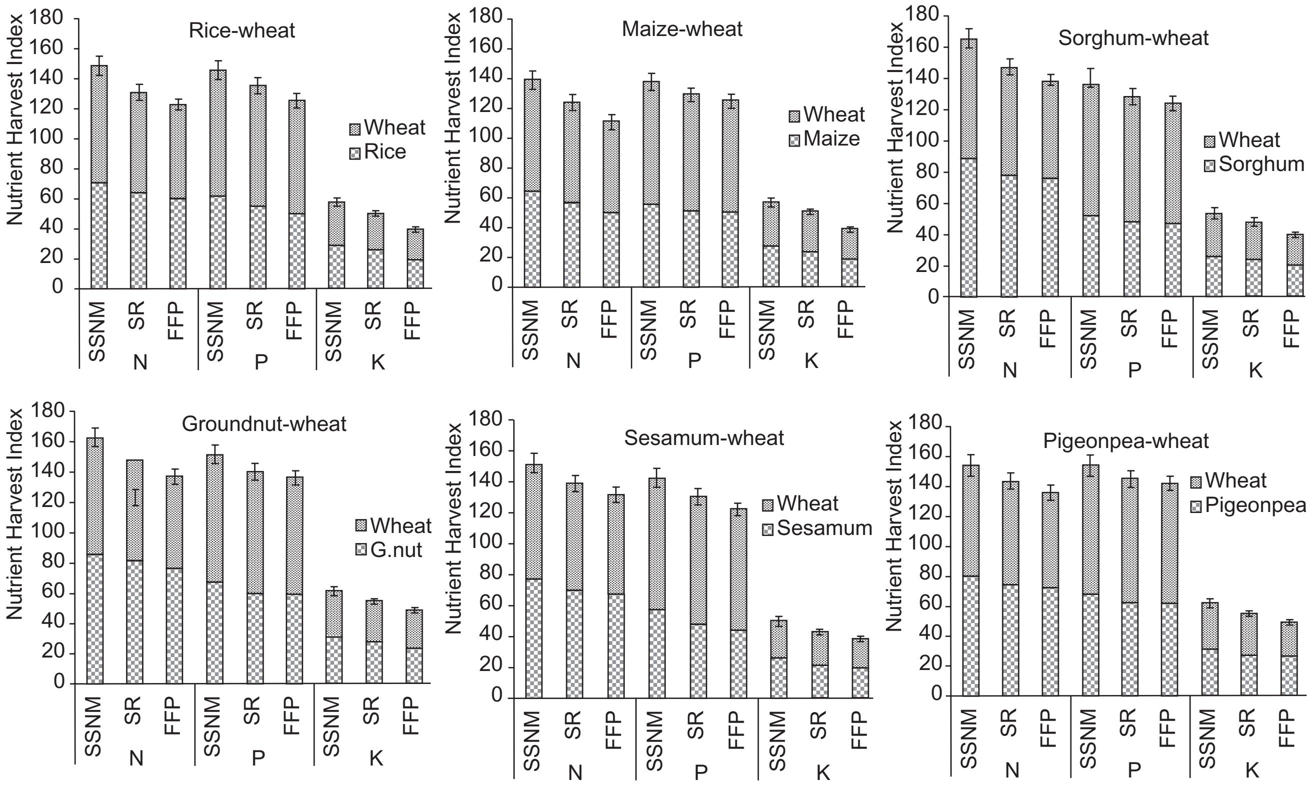

Fig 1 Nutrient harvest index (NHI) of N, P and K as influenced by different nutrient management options. @ Bar indicates standard error of mean (n=9)

soil K pool, whereas maximum soil K depletion was noted under FFP. Here it may be argued that the higher K rates under SSNM and 25% additional K use in ISR led to greater crop yields and residue recycling and resulted in improved K status in these plots. These results further underline the significance of SSNM, which not only improves crop productivity but also take care of soil sustainability.

Apparent nutrient balance sheet and output: input ratio

During the experiment, nitrogen additions through fertilizer, residues, irrigation water and rainfall under different nutrient management option were 932 to 1064 kg N/ha in R-W, 741 to 924 kg N/ha in M-W, 557 to 718 kg N/ha in P-W, 489 to 662 kg N/ha in S-W, 519 to 672 kg N/ha in G-W and 746 to 842 kg N/ha in Sg-W system (Table 3). The apparent balance sheet, computed as nutrient addition from different sources less nutrient off take in the crops, revealed positive N balances under all the treatments of different cropping systems, whereas the N balance were negative in P-W and G-W system and had wider output: input ratios.

The negative N balance under P-W and G-W system may be explained in two ways: (i) the N addition through fertilizer to pigeonpea and groundnut was much lower (only 20 kg N/ha as starter dose) than the other crops, though the N removal in former case was invariably greater (data not reported) and (ii) the contribution of BNF in pigeonpea and groundnut was not measured while computing apparent N balance. Literature indicates that legumes may derive 54-70% of their N requirement through BNF (Awonaike *et al*. 1990). Thus, considering possible contribution from BNF, the extent of negative N balance could be lower than what is reported here and may not reflect depletion in soil N reserve. The excessive N balance under FFP as compared to SSNM indicates the inefficient use of N by the crops caused by imbalanced fertilizer use.

All the crop sequences revealed a positive P balance, which was comparatively greater in S-W followed by R-W system (Table 3). Since component crops of these crop sequences removed less P than the additions through fertilizers and other sources, the P balances were positive. In AICRP on long-term fertilizer experiments, continuing on diverse soil, the application of P at recommended rate led to positive balance in intensive production system (Swarup and Wanjari 2000). The positive P balance computed in the study was reflected on the available P content of soil only under R-W and M-W cropping system, which increased after 03 crops cycle (Table 2). The variable soil P content after 03 crop cycle even after positive P balance may be visualized as different crop (P) demand. The higher input: output ratio and comparatively smaller apparent P balance under SSNM in all the cropping system reveals that the SSNM treatment facilitated judicious P use and its higher accumulation in the crops. Whereas, lower output: input ratio under FFP shows the inefficient P fertilizer use by the crops.

In contrast to P, the apparent balances for K were

Table 2 Available N , Olsen P and available K content after 03-crop cycles in 0-15 cm soil profile as influenced by different nutrient management option and cropping systems

Treatment	Initial	Sesamum-wheat		Groundnut-wheat		Pigeonpea-wheat		Sorghum-wheat		Maize-wheat		Rice-wheat		Average over C	
		After 03 cycle	% change over initial	After 03 cycle	% change over initial	After 03 cycle	% change over initial	After 03 cycle	% change over initial	After 03 cycle	% change over initial	After 03 cycle	% change over initial	After 03 cycle	% change over initial
Available N (kg/ha)															
FFP	169	146	–13.61	221	30.77	234	38.46	137	–18.93	204	20.71	194	14.79	189.33	12.03
SR	169	151	–10.65	246	45.56	251	48.52	184	8.88	218	28.99	212	25.44	210.33	24.46
ISR	169	184	8.88	288	70.41	308	82.25	218	28.99	288	70.41	266	57.40	258.67	53.06
STLR	169	176	4.14	269	59.17	286	69.23	201	18.93	236	39.64	244	44.38	235.33	39.25
SSNM	169	179	5.92	273	61.54	321	89.94	235	39.05	259	53.25	252	49.11	253.17	49.80
Mean		167.2	–1.07	259.4	53.49	280	65.68	195	15.38	241	42.60	233.6	38.22	229.37	35.72
Olsen P (kg/ha)															
FFP	29.1	29.2	0.34	31.8	9.28	30.6	5.15	21.6	–25.77	31.2	7.22	30.8	5.84	29.20	0.34
SR	29.1	26.6	–8.59	24.2	–16.84	25.4	–12.71	31.4	7.90	30.4	4.47	31.2	7.22	28.20	–3.09
ISR	29.1	33.4	14.78	25.7	–11.68	24.3	–16.49	33.1	13.75	32.8	12.71	33.5	15.12	30.47	4.70
STLR	29.1	23.5	–19.24	23.6	–18.90	22.1	–24.05	27.3	–6.19	26.1	–10.31	29.6	1.72	25.37	–12.83
SSNM	29.1	29.6	1.72	28.4	–2.41	28.4	–2.41	30.2	3.78	31.2	7.22	29.3	0.69	29.52	1.43
Mean		28.46	–2.20	26.74	–8.11	26.16	–10.10	28.72	–1.31	30.34	4.26	30.88	6.12	28.55	–1.89
Available K (kg/ha)															
FFP	166	141	–15.06	132	–20.48	146	–12.05	144	–13.25	142	–14.46	138	–16.87	140.50	–15.36
SR	166	155	–6.63	154	–7.23	158	–4.82	138	–16.87	160	–3.61	152	–8.43	152.83	–7.93
ISR	166	149	–10.24	188	13.25	174	4.82	133	–19.88	208	25.30	222	33.73	179.00	7.83
STLR	166	145	–12.65	176	6.02	164	–1.20	141	–15.06	174	4.82	179	7.83	163.17	–1.71
SSNM	166	174	4.82	209	25.90	221	33.13	202	21.69	196	18.07	204	22.89	201.00	21.08
Mean		152.8	–7.95	171.8	3.49	172.6	3.98	151.6	–8.67	176	6.02	179	7.83	167.30	0.78
CD (P=0.05)															
				Cropping system (C)				*Nutrient management options (N)*				*C × N*			
Available N				24.4				27.1				21.6			
Olsen P				1.7				2.2				1.4			
Available K				14.7				18.9				134			

Table 3 Effect of nutrient management options on apparent nutrient balance sheet and out put: input ratio under different cropping system after 03 year of cropping

Treatments	Nitrogen						Phosphorus						Potassium					
	Addition (kg/ha)			Removal (kg/ha)	Apparent balance (kg/ha)	Output: input ratio	Addition (kg/ha)			Removal (kg/ha)	Apparent balance (kg/ha)	Output: input ratio	Addition (kg/ha)			Removal (kg/ha)	Apparent balance (kg/ha)	Output: input ratio
	Fertilizer	Other sources@	Total				Fertilizer	Other sources@	Total				Fertilizer	Other sources@	Total			
Rice-wheat system																		
FFP	1038	26	1064	620	(+) 444	0.58	161	9	170	110	(+) 60	0.65	0	72	72	724	(-) 652	10.05
SR	900	32	932	731	(+) 201	0.78	177	14	191	122	(+) 68	0.64	273	84	357	899	(-)543	2.52
SSNM	900	38	938	872	(+) 66	0.93	157	16	173	148	(+) 24	0.86	540	90	630	1012	(-) 382	1.61
Mean	946	32	978	741	(+) 237	0.77	165	13	178	127	(+) 51	0.71	271	82	353	878	(-) 525	4.72
Maize-wheat system																		
FFP	864	18	882	714	(+) 168	0.81	160	8	168	106	(+) 62	0.63	0	36	36	735	(-) 699	20.41
SR	720	21	741	737	(+) 4	0.99	157	11	168	126	(+) 42	0.75	273	39	312	860	(-) 548	2.76
SSNM	900	24	924	883	(+) 41	0.96	177	14	191	177	(+) 14	0.93	515	41	556	971	(-) 415	1.75
Mean	828	21	849	778	(+) 71	0.92	165	11	176	136	(+) 39	0.77	263	39	301	855	(-) 554	8.30
Pigeonpea-wheat system																		
FFP	572	146	718	700	(+) 18	0.975	160	23	183	138	(+) 45	0.7	0	32	32	407	(-) 375	12.73
SR	405	152	557	780	(-) 223	1.400	138	28	166	145	(+) 21	0.87	164	38	202	457	(-) 255	2.26
SSNM	540	158	698	1045	(-) 347	1.497	157	31	188	166	(+) 22	0.88	515	41	556	514	(+) 43	0.92
Mean	506	152	658	842	(-) 184	1.29	152	27	179	150	(+) 29	0.84	226	37	263	459	(-) 196	5.30
Sesamum-wheat																		
FFP	579	21	600	375	(+) 225	0.625	84	14	98	57	(+) 40	0.59	0	39	39	388	(-) 349	9.94
SR	465	24	489	447	(+) 42	0.91	118	17	135	72	(+) 63	0.53	191	40	231	505	(-) 274	2.18
SSNM	630	32	662	635	(+) 27	0.96	138	19	157	95	(+) 61	0.61	393	43	436	451	(-) 15	1.03
Mean	558	26	584	486	(+) 98	0.83	113	17	130	75	(+) 55	0.57	195	41	235	448	(-) 212	4.38
Groundnut-wheat system																		
FFP	572	94	666	591	(+) 75	0.89	160	27	187	110	(+) 77	0.5	0	37	37	439	(-) 402	11.87
SR	420	99	519	688	(-)169	1.33	118	35	153	124	(+) 29	0.81	232	41	273	493	(-)220	1.80
SSNM	570	102	672	882	(-) 210	1.31	157	38	195	180	(+) 15	0.92	515	54	569	537	(+) 33	0.94
Mean	521	98	619	720	(-) 101	1.18	145	33	178	138	(+) 40	0.77	249	44	293	489	(-) 196	4.87
Sorghum-wheat system																		
FFP	819	21	840	417	(+) 423	0.50	125	10	135	92	(+) 43	0.68	0	38	38	473	(-) 435	12.45
SR	720	26	746	548	(+) 198	0.73	157	14	171	122	(+) 49	0.71	109	151	260	581	(-) 430	2.24
SSNM	810	32	842	723	(+) 119	0.86	157	17	174	141	(+) 33	0.81	434	487	921	681	(-) 195	0.74
Mean	783	26	809	563	(+) 247	0.70	146	14	160	119	(+) 42	0.74	181	225	406	579	(-) 353	5.14

@Includes nutrient addition through rainfall, irrigation water and root+ stubbles during the course of study

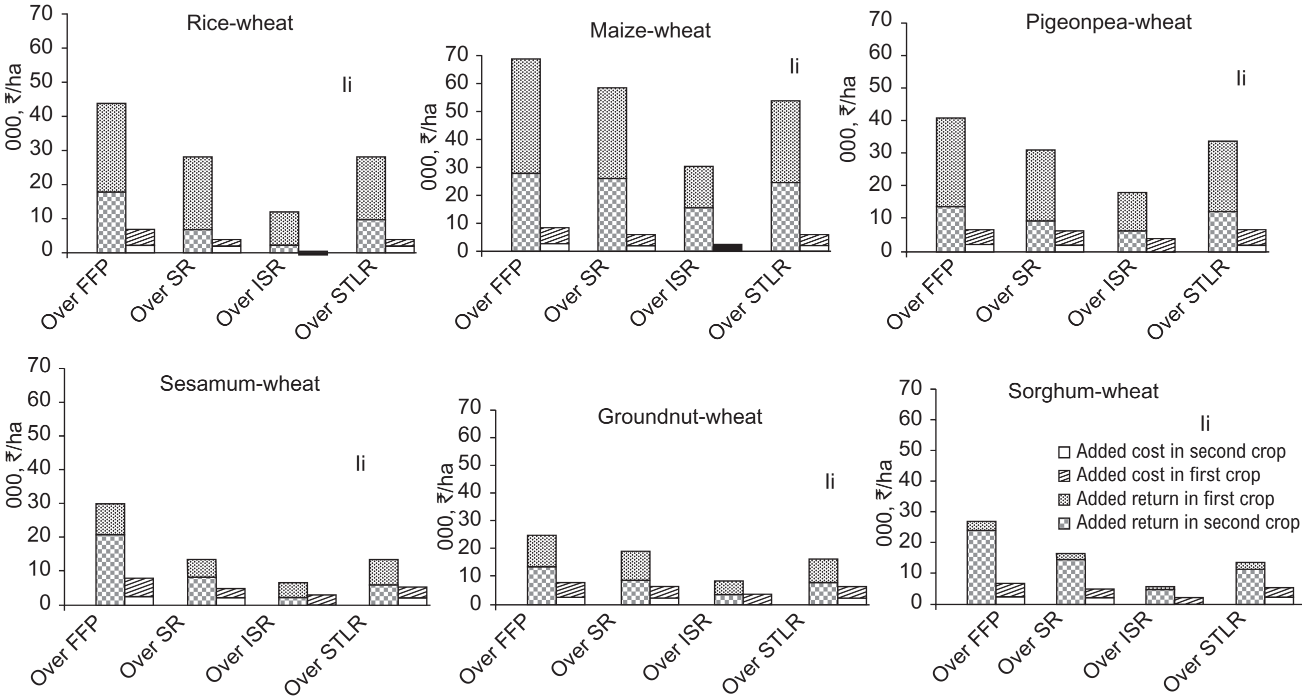

Fig 2 Added cost and net return in SSNM treatment over FFP, SR, ISR and STLR; Ii - indicates CD at 0.05 for added cost and added return of the system, respectively.

negative in all the crop sequences and the magnitude was more under cereal-cereal system. Among the different nutrient management options highest negative apparent K balance was noticed with FFP followed by SR and least in SSNM (Table 3). Relatively higher negative K balance under FFP and SR indicates the lack of K use in existing farmer fertilizer practices and sub-optional K recommendations at state level are not sustainable for modern high yielding cultivars in intensive cropping systems. Further, these results cautioned to develop fertilizer recommendations based on crop demand for a specified yield targeted and indigenous soil nutrient supplying capacity.

Economics of SSNM

Economic return varied with the cropping systems and within the systems as per nutrient management options. In rice-wheat system, on average across the treatment, the cost of cultivation (₹ 41 816) as well as total net returns (₹ 60 127) was recorded highest while lowest total net return (₹ 40 528) was registered in Sg-W system (Fig 2). The cost of cultivation was lowest in S-W system which was comparable with Sg-W system. The additional fertilizer input cost accrued for SSNM treatment was in the range of 8.1 to 17.0, 6.3 to 11.3, 2.6 to 7.7 and 5.9 to 11.5% as compared FFP, SR, ISR and STLR treatments in different cropping system. Comparing the net return from different nutrient management options, the SSNM was the premier option among the treatments, which gave ₹ 112 716, 109 789, 83 363, 73 328, 72 485 and 54 948 as profit in R-W, M-W, P-W, S-W, G-W and Sg-W systems, respectively. The added net return in SSNM over other nutrient management options depended upon grain and straw yield and their prices in each cropping systems, and it varied from ₹ 25 030 to 68 980 (mean ₹ 47 005) over FFP, ₹ 13 650 to 58 776 (mean ₹ 36 213) over SR, ₹ 6 559 to 30 463 (mean ₹ 18 511) over ISR and ₹ 13 509 to 53 830 (mean ₹ 33 670) over STLR. The favourable economics of SSNM over FFP, SR, ISR and STLR underlines the significance of balanced nutrition to counter the stagnation in crop yield as well as low farm profitability due to increasing fertilizer cost, which is a major challenge towards sustainability of intensive cropping systems (Singh *et al.* 2013).

The existing nutrient management options, i.e. SR and STLR posing a constant threat of long-term deterioration in soil fertility due to greater drain of native nutrient reserves, particularly in intensive production system. The recommendation emerging from state soil testing labs could be useful, only if they are specific to the site and per as yield target. Otherwise, the yield grains with STLR may not be different from local Ad-hoc state recommendations. The SSNM based on indigenous nutrient supply capacity, nutrient use efficiency and target yield, is a promising nutrient management option for attaining higher productivity and sustaining soil health. There is need to develop SSNM option for other locations and rice based cropping system too as rice and wheat comprises the major food basket of the country.

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