

Site-Specific Nutrient Management under Rice-Based Cropping Systems in Indo-Gangetic Plains: Yield, Profit and Apparent Nutrient Balance

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Abstract High fertilizer use efficiency in rice (*Oryza sativa* L.)-based cropping systems in Indo-Gangetic Plains (IGP) is not achieved because farmers' fertilizer practices (FFP) and blanket state recommendations (BSR) do not take into account the site-specific variability of nutrient availability in the soil. We evaluated the site-specific nutrient management (SSNM) option against existing FFP, blanket state recommendation (BSR), improved BSR (IBSR i.e., 25 % higher than BSR), and state soil testing laboratory recommendation (STLR) in six pre-dominant rice-based cropping systems namely wheat–rice (W–R), mustard–rice (M–R), potato–rice (P–R), garlic–rice (G–R), chickpea–rice (C–R) and berseem fodder–rice (B–R) in terms of yield gain, economics, nutrient harvest index, soil fertility, and apparent nutrient balances. System rice equivalent yield (SREY) improved by 15.7, 9.5, 13.9 and 30 %, in SSNM over BSR, IBSR, STLR and FFP, respectively. SSNM involved additional cost of ₹ 2940–5291 ha⁻¹ over BSR and ₹ 5492–10120 ha⁻¹ over FFP under different cropping systems but contributed higher added net return of ₹ 23236–75056 ha⁻¹ and ₹ 39577–143899 ha⁻¹ over BSR and FFP, respectively. The output: input ratio and nutrient harvest index for N, P, K 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 their initial values in SSNM treatments, whereas soil available K in FFP declined by -1.65 % and increased over initial content in BSR and STLR in 0–15 cm soil profile depth. After three crop cycles, apparent N and P balances were positive in all the cropping systems and fertilizer treatments; only exception was a negative N balance in C–R and B–R systems in different fertilizer treatments. The apparent K balances were negative in all the cropping systems irrespective of nutrient management options. But, the magnitude of negative balance was lower in plots received SSNM treatment as compared to other nutrient management strategies, indicating a potential for improving yields, nutrient use efficiency and farm profit without deteriorating soil fertility in different rice based systems in IGP.

Keywords Site-specific nutrient management · Nutrient harvest index · Economics · Apparent nutrient balance · Farmers' fertilizer practices · Rice-based cropping systems

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Abbreviations

IGP: Indo-Gangetic Plain; FFP: Farmers' fertilizer practices; BSR: Blanket state recommendations; SSNM: Site-specific nutrient management; STLR: Soil testing laboratory recommendation; SREY: System rice equivalent yield; UGP: Upper Gangetic Plain; RIE: Reciprocal Internal Efficiency; AICRP: All India Coordinated Research Project; INS: Indigenous nutrient supply; IBSR: Improved blanket state recommendation; MSP: Minimum support price; NHI: Nutrient harvest index

Introduction

Different rice based cropping systems are practiced depending on soil types, ecologies and resource available for crop management across the Asia and important systems for livelihood of millions of people in India [10]. These production systems are of paramount significance to provide food, income and employment, and to ensure livelihood security for millions of rural and urban producers and consumers in the region. Recent reports reveals that intensively cultivated rice based system is levelling off annual growth in production [10] over the past decade. The prospects of area expansion are very narrow with burgeoning population of the country. Intensification of cropping systems has often over-exploited natural resources [27] and resulted in depletion of soil fertility and emergence of multi-nutrient deficiencies [5]. Consequently, the annual productivity of the different pre-dominant cropping systems has been declining for the past one decade. Decline in crop yields and factor productivity has become a common phenomenon, because the ratios of nutrients applied to crops do not match the ratios in which they are removed from the soils. 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 [18]. 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 [6, 13, 20]. Excess N application can also enhance emission of nitrous oxide arising from nitrification–denitrification nexus [29]. Under these circumstances, high yield potential of modern varieties cannot ever be exploited with existing fertilizer practice, which fail to provide adequate and balanced doses needed for the crops. Therefore, agronomic management has to be improved for greater efficiency of applied inputs to sustain yields [22]. In this context, site-specific nutrient management (SSNM) based on crop nutrient demand and variability in indigenous nutrient supplying capacity of the soil could serve as an ideal tool to enhance nutrient use efficiency.

Attainable yield of crops under farmers' fertilizer practices (FFP) in the IGP 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. [15, 18]. In contrast, one standard recommendation (popularly known as blanket fertilizer recommendation) of plant nutrients in rice-based systems across large areas exists in the IGP. 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 [3]. SSNM has been proposed as an approach to tailor fertilizer application to match field-specific needs of crops to improve productivity and profitability [3, 4, 28]. This could be done by utilizing available information on indigenous nutrient supplying capacity, nutrient contributions from organic manures, irrigation water, rainfall 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 identify the best nutrient management strategy for various production systems in Upper Gangetic Plains (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

Study Site

A field experiment was carried out during 2007–2008 to 2009–2010 on a Typic Ustochrept soil of the research farm of Indian Institute of 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 evapotranspiration is 1500 mm. The experimental site represents irrigated, mechanized and input intensive cropping areas of IGP region. The soil of the experimental site was sandy loam (164 g clay kg⁻¹, 196 g silt kg⁻¹ and 640 g sand kg⁻¹) 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 [6]. The top soil (0–15 cm) of the experimental field at the start of experiment was non-saline (EC 0.35 d S m⁻¹) and mildly alkaline (pH 8.4), CEC (8.6 mol kg⁻¹) and contained 0.46 % organic carbon, 23.4 kg ha⁻¹ Olsen-P, 172 kg ha⁻¹ available K, 12.2 mg kg⁻¹ sulphur, 0.54 mg kg⁻¹ zinc and 0.39 mg kg⁻¹ boron.

Computation of SSNM Doses

The site-specific nutrient management doses for the different cropping systems were worked out based on plant nutrient demand for a targeted yield considering the indigenous nutrients supplying capacity of soil and nutrient use efficiency. 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 [28] for rice, wheat, mustard, chickpea, garlic, potato and berseem 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.

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

where, B_n is the nutrient balance (N or P or K; kg ha^{-1}), 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 (t ha^{-1}) 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^{-1}) 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^{-1}) 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^{-1} . The total fertilizer nutrient requirement (kg ha^{-1}) for the crop ($F_{n(c)}$) was worked out as:

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

where, $F_{n(c)}$ and $\text{RE}_{n(c)}$ are the fertilizer nutrient (N or P or K) requirement (kg ha^{-1}) 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 for hybrid rice, wheat, potato, chickpea, mustard, garlic and berseem, and being given in Table 1.

Treatments and Crop Management Practices

The experiment comprising of six cropping system namely wheat–rice (W–R), mustard–rice (M–R), potato–rice (P–

R), garlic–rice (G–R), chickpea–rice (C–R) and berseem (f)–rice (B–R) in main plot and five nutrient management options viz. farmers fertilizer practice (FFP), blanket state

Table 1 Crop wise fertilizer rates under different nutrient management options

Treatments	Nutrient use (kg ha^{-1})		
	N	P ₂ O ₅	K ₂ O
Rice			
FFP	178	59	
BSR	150	75	60
IBSR	187.5	93.75	75
STLR	137.5	56.25	70.5
SSNM	150	75	99
Wheat			
FFP	168	64	
BSR	150	60	40
IBSR	187.5	75	50
STLR	134	45	57
SSNM	150	60	99
Potato			
FFP	250	150	40
BSR	180	80	100
IBSR	225	100	125
STLR	198	60	103
SSNM	210	99	150
Garlic			
FFP	80	58	
BSR	125	60	60
IBSR	156.3	75	75
STLR	136.5	45	62
SSNM	150	90	99
Chickpea			
FFP	22.5	58	
BSR	20	50	30
IBSR	25	62.5	37.5
STLR	24.5	37.5	45
SSNM	30	75	75
Mustard			
FFP	85	60	
BSR	120	50	40
IBSR	150	62.5	50
STLR	132.5	37.5	64
SSNM	125	75	90
Berseem (fodder crop)			
FFP	75	50	
BSR	20	50	0
IBSR	25	62.5	
STLR	37.5	41.5	
SSNM	40	60	75

recommendation (BSR), improved blanket state recommendation i.e., 25 % higher than BSR (IBSR), soil testing lab recommendations (STLR) and site-specific nutrient management (SSNM) in sub-plots were evaluated in split plot design with three 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. Crop wise fertilizer rates applied under different treatments are given in Table 1. 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 m² area in each plot. After sun-drying for 3 days in the field, the total biomass (grain + straw) was weighed and threshed with a plot thresher, except potato and berseem (f) which were weighed as tuber and green fodder, respectively.

Soil and Plant Analysis

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 rice 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 KMNO₄ method [25], Olsen- P (0.5 M NaHCO₃, pH 8.5 extraction) [11] and exchangeable K (1 M NH₄OAc, pH 7.0 extraction) [8].

Representative grain and straw sub-samples of crops were dried at 70 C, ground in a stainless steel Wiley mill, and then wet-digested with concentrated H₂SO₄ for determination of total N, while for total P and K, samples were digested with concentrated HNO₃ and HClO₄ (mixed in 1:4 ratio). The N content was determined by the Kjeldahl method using an auto analyzer, P was determined by the vanadomolybdate yellow colour method [12], and total K content was determined by flame photometry.

Computations and Economic Analysis

Nutrient harvest index for N, P and K (NHI_{N or P or K}) was computed as

$$\text{NHI}_{\text{N or P or K}} = \left[\frac{G_u}{G_u + S_u} \right] \times 100 \quad (3)$$

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⁻¹.

Added net return with different treatments relative to FFP was determined using the minimum support price

(MSP) fixed by the government for rice, wheat, mustard and chickpea grain plus straw prices for these crops as per local market. The price of garlic, potato and berseem fodder was taken as per local market, and the cost of fertilizers on a nutrient basis [7]. 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 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

Effect on Winter Crop

The productivity gain under SSNM treatment over FFP was of 30.8, 41.8, 67.3, 70.1, 42.1 and 24.1 % for wheat, mustard, potato, garlic, chickpea and berseem (f) (Table 2), respectively. Higher productivity under SSNM was observed due to sufficient nutrient supply as per crop demand through external application as well as indigenous soil nutrient supplying capacity. On the other hand, in FFP treatment, with excess N use, sub-optimal P and no- K application led to the inadequate and imbalanced plant nutrient supply, and resulted in lowest productivity among all the nutrient management options.

The IBSR option of nutrient management wherein 25 % extra N, P and K over BSR was applied, had edge over BSR and STLR method of fertilizer application, underlining necessity for an upward revision in fertilizer recommendations. These findings corroborate the reports of long-term experiments which suggested inadequacy of current fertilizer recommendation to sustain high productivity under intensive cropping systems [16]. The increase in yield under IBSR over BSR and STLR was to the tune of 0.31–0.41 t ha⁻¹ in wheat, 0.08–0.11 t ha⁻¹ in mustard, 1.8–2.7 t ha⁻¹ in potato, 0.37–0.48 t ha⁻¹ in garlic, 0.25–0.30 t ha⁻¹ in chickpea and 1.9–6.9 t ha⁻¹ in berseem (f) crop (Table 2). The yield obtained in different monsoon crop under BSR and STLR fertilizer treatment was almost similar in but had an edge over FFP.

Effect on Rice Crop

Irrespective of the previous crop grown, the grain yields of rice, raised on same layout were also the highest under SSNM treatment followed by IBSR, and the lowest in FFP (Table 2). Among the cropping system, the highest rice yield with SSNM was registered after potato (9.5 t ha⁻¹),

which was closely followed by rice grown after berseem, chickpea, garlic and mustard crops. Although, BSR proved its superiority over FFP for rice crop but it exhibited 17.1–25.1 % lower yield as compared to SSNM in various cropping system. The enhanced rice yield in SSNM and IBSR treatment options is attributed to larger ear length, more number of grain ear⁻¹, higher grain weight ear⁻¹ and greater number of effective tillers m⁻² (data not reported), obviously due to better nutrient management i.e. improved nutrient supplies [23].

Effect on System Productivity

Comparing the system productivity, in terms of rice equivalent yield indicated that SSNM out yielded different nutrient management options across the cropping systems. System rice equivalent yield (SREY) in BSR, IBSR, STLR and FFP treatments was 15.7, 9.5, 13.9, and 30.0 %, lower than that of SSNM option (Table 2). These results clearly showed that the generalized adhoc 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. Further, significantly higher system productivity in SSNM over BSR 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 goal moves up, the nutrient demand of the crops increases but also becomes more varied and complex leading to multiple nutrient deficiencies [24]. Therefore, nutrient harvest index (NHI) computed for N, P and K in different rice-based systems was highest under SSNM, implying that the balanced nutrient supply through SSNM regulated efficient nutrient utilization towards the sink (Fig. 1). Averaged over the nutrient management options, the highest system productivity was recorded in G–R (31.74 t ha⁻¹) followed by P–R (21.69 t ha⁻¹), W–R (13.42 t ha⁻¹), C–R (13.33 t ha⁻¹), M–R (12.47 t ha⁻¹) and B–R

Table 2 Productivity (t ha⁻¹) of different crops and cropping systems as influenced by various nutrient management options (Mean over 03 years)

Nutrient management options	Wheat–rice	Mustard–rice	Potato–rice	Garlic–rice	Berseem–rice	Chickpea–rice	Average over cropping system
Winter crop							
FFP	4.91d	1.65c	16.8e	4.46d	75.1e	1.9e	17.47d
BSR	5.63bc	2.1ab	22.5c	6.52bc	85.4d	2.26c	20.74bc
IBSR	6.04ab	2.21ab	24.3b	7ba	87.3c	2.51b	21.56b
STLR	5.73b	2.13ab	21.6d	6.63b	80.4b	2.21cd	19.78c
SSNM	6.42a	2.34a	28.1a	7.62a	93.2a	2.7a	23.40a
Mean	5.75tu	2.09u	22.66s	6.45t	84.28r	2.32u	
Monsoon crop							
FFP	6.77c	6.8c	7.29c	7.06cd	7.2c	6.84c	6.99d
BSR	7.24bc	7.23bc	8.13bc	7.3c	8.01bc	7.91bc	7.64c
IBSR	7.73ba	8.16ba	8.47ba	8.2bc	8.53ba	8.14b	8.21b
STLR	7.28b	7.74b	8.4b	8.51b	8.41b	8.04bc	8.06bc
SSNM	8.48a	9.02a	9.5a	9.13a	9.4a	9.32a	9.14a
Mean	7.50st	7.79s	8.36r	8.04rs	8.31r	8.05rs	
System rice equivalent yield (SREY)							
FFP	11.82d	10.50d	17.17d	23.46d	9.96d	11.17d	14.01d
BSR	13.04c	11.94c	21.37c	31.27c	11.15c	13.06c	16.97c
IBSR	13.95b	13.12b	22.76b	33.94b	11.74b	13.86b	18.23b
STLR	13.18bc	12.52bc	21.11cd	32.89bc	11.37bc	13.08bc	17.35bc
SSNM	15.09a	14.27a	26.03a	37.14a	12.83a	15.47a	20.14a
Mean	13.42t	12.47tu	21.69s	31.74r	11.41u	13.33t	

Within a column values of the same group (except mean) with the same letter are not significantly different at $P < 0.05$

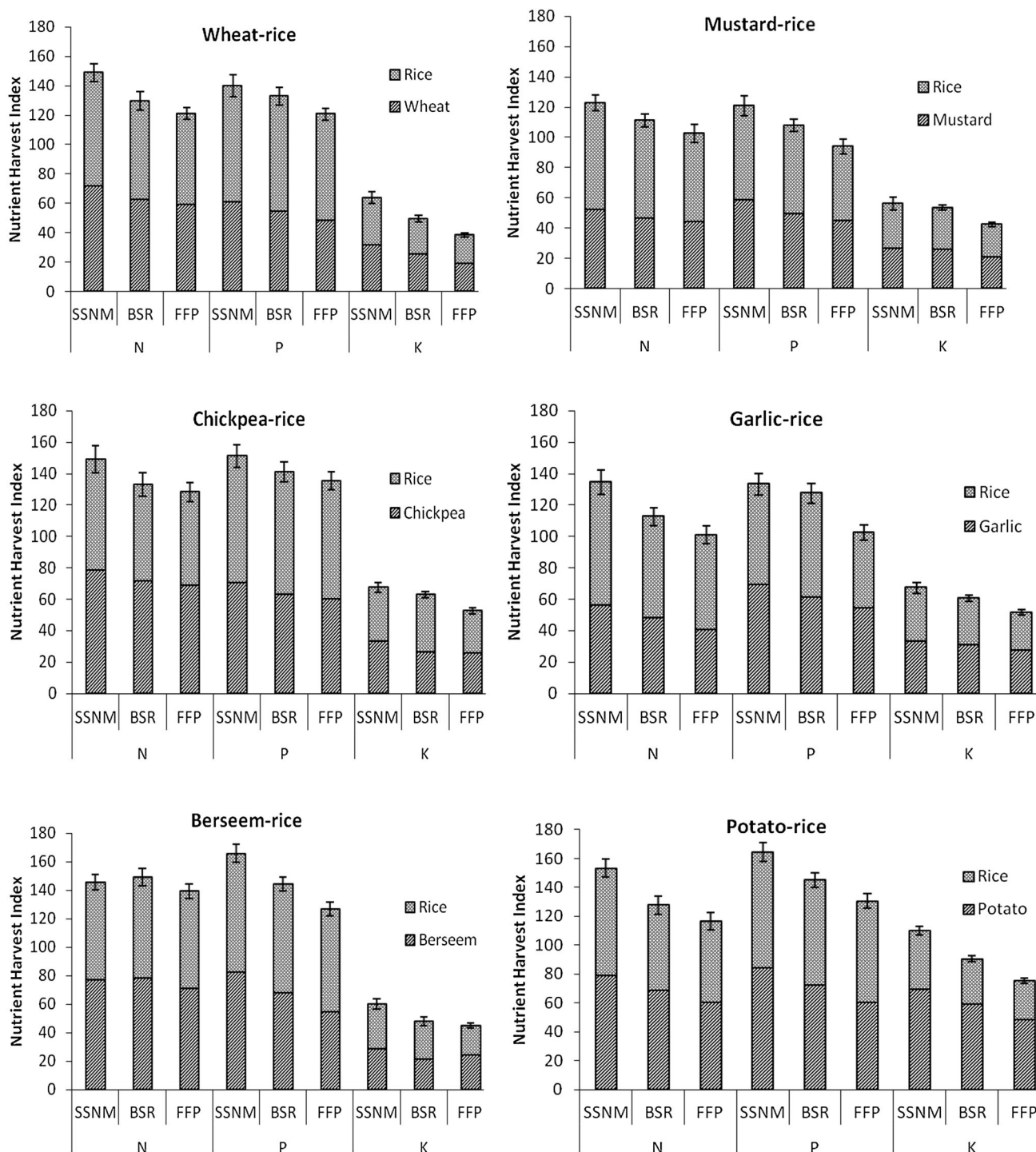


Fig. 1 Nutrient harvest index (NHI) of N, P and K as influenced by different nutrient management options. @ Bar indicates standard error of mean ($n = 9$)

(11.41 t ha⁻¹) cropping system. Across the cropping systems, SREY under SSNM (20.14 t ha⁻¹) was significantly higher ($p < 0.05$) compared with other nutrient management options, whereas the same was lowest (14.01 t ha⁻¹) under FFP. Among the studied cropping systems, highest

increase due to SSNM option over FFP was recorded in G-R system (13.68 t ha⁻¹) followed by P-R system (8.86 t ha⁻¹). The highest system equivalent productivity under G-R system may be ascribed to the maximum yield increase due to SSNM plot for garlic (70.1 %) over FFP and higher

unit price of garlic economic yield (₹ 34998 t⁻¹). Relatively higher yield gain over FFP under both the crop of the P–R system also resulted in increased system equivalent productivity. The beneficial effect of potato based system on succeeding crops and system productivity is already documented in earlier reports [14].

Effect on Nutrient Harvest Index

Nutrient harvest index (NHI) for N, P and K were highest under SSNM in all the cropping system followed by BSR and FFP (Fig. 1). The magnitude of increased NHI for N, P and K over FFP was in the range of 6.1–18.1, 5.9–27.9 and 3.8–21.3, respectively under different crops. In general, sequences having legumes or potato as a component crop had highest NHI_P for all the crops of the system. Higher NHI for N, P and K values under SSNM and IBSR may be ascribed due to inclusion of K under fertilizer application schedule and its role towards assimilation of nutrients in the economic parts [22]. 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 [1]. 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 potato and legume based system as compared to other cropping system (Table 3). Averaged across the nutrient management options, the available N content was maximum under P–R system (294.8 kg ha⁻¹) followed by C–R (283.2 kg ha⁻¹), B–R (282.2 kg ha⁻¹), G–R (280 kg ha⁻¹), W–R (154.6 kg ha⁻¹) and M–R system (253.8 kg ha⁻¹). Higher residual soil N availability after potato cultivation due to relatively more balanced N, P, K use and better soil condition was already reported by earlier researcher [9]. Further, 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 [6, 20, 21]. In addition, relatively greater amount of rice residues recycled owing to higher yield of rice after legume (chickpea) also had added advantage in enriching the N pools [23]. Averaged over the cropping system, IBSR had the highest soil N content (310 kg ha⁻¹) followed by SSNM option (292 kg ha⁻¹) and the lowest N

content was recorded with FFP (230 kg ha⁻¹). The lower N content under FFP, BSR and STLR indicates potential N loss from soil caused by imbalance or insufficient nutrient applications [6, 17, 21]. 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 IBSR (66 %) and SSNM (56 %) options. Increased soil N availability may be corroborated with earlier reports of Singh et al. (2010) [21], wherein better root foraging caused by balanced nutrition helps to trap NO₃-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 [30].

Olsen-P Content

After three crop cycles, Olsen-P content of the soil (0–15 cm depth) increased over the initial content, consequent to different fertilizer management options under all the cropping systems and magnitude of increase was more under W–R system (27.44 %) followed by M–R system (27.35 %) and P–R system (18.9 %) (Table 3), whereas sequences having legumes as a component crop of the system did not show any significant change over initial P status. Lower P content in the soil under legume based cropping system may be due to higher P need of legumes and better P utilization efficiency as indicated in NHI_P (Fig. 1) due to its deeper root system [19–21]. The higher P content of soil in R–W system corroborated with the earlier studies by Dwivedi et al. (2003) [6], wherein continuous P application at 26 kg ha⁻¹ to both the crops resulted in build up of P content in the soils.

Among nutrient management options, IBSR 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 treatment may be ascribed to the higher P utilization efficiency 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 are inadequate and needs a fresh look in the view of changing management practices, cultivars' yield potential and indigenous soil nutrient supply capacity of soil.

Available K Content

Soil K content varied among the cropping systems and it ranged between 169 to 236 kg ha⁻¹ (Table 3). In general, available K content increased over initial K status under different crop sequences with exception of G–R wherein it declined by 2 % over its initial status. Negative K content under this system may be ascribed as relatively lower K application rate to the garlic crop, almost nil-K recycling

Table 3 Soil 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

Treatments	Wheat–rice		Mustard–rice		Chickpea–rice		Garlic–rice		Berseem–rice		Potato–rice		Average over cropping systems		
	Initial	After 03 cycle over initial	Initial	After 03 cycle over initial	Initial	After 03 cycle over initial	Initial	After 03 cycle over initial	Initial	After 03 cycle over initial	Initial	After 03 cycle over initial	Initial	After 03 cycle over initial	
Available N (kg ha ⁻¹)															
FFP	187	207c	10.70	201c	7.49	241c	28.88	230c	22.99	248c	32.62	254c	35.83	230.17c	23.08
BSR	187	238bc	27.27	240bc	28.34	269b	43.85	262b	40.11	266bc	42.25	286bc	52.94	260.17bc	39.13
IBSR	187	296a	58.29	288a	54.01	312a	66.84	312a	66.84	323a	72.73	330a	76.47	310.17a	65.86
STLR	187	256b	36.90	264b	41.18	296ab	58.29	294ab	57.22	284b	51.87	294ab	57.22	281.33b	50.45
SSNM	187	276ab	47.59	276ab	47.59	298ab	59.36	302ab	61.50	290ab	55.08	310ab	65.78	292.00ab	56.15
Mean		254.6s	36.15	253.8s	35.72	283.2r	51.44	280r	49.73	282.2r	50.91	294.8r	57.65	–	–
Olsen P (kg ha ⁻¹)															
FFP	23.4	28.5bc	21.79	28.2bc	20.51	25.9a	10.68	24.8ab	5.98	25.2b	7.69	30.4a	29.91	27.17bc	16.10
BSR	23.4	30.2ab	29.06	29.8b	27.35	23.2ab	-0.85	22.8b	-2.56	24.3bc	3.85	26.1c	11.54	26.07b	11.40
IBSR	23.4	33.9a	44.87	32.9a	40.60	24.8ab	5.98	26.3a	12.39	27.3a	16.67	28.4ab	21.37	28.93a	23.65
STLR	23.4	26.31c	12.44	27.4bc	17.09	21.4b	-8.55	20.4c	-12.82	23.2c	-0.85	26.3bc	12.39	24.17c	3.28
SSNM	23.4	30.2ab	29.06	30.7ab	31.20	23.9ab	2.14	24.3ab	3.85	24bc	2.56	27.9b	19.23	26.83ab	14.67
Mean		29.822r	27.44	29.80r	27.35	23.84s	1.88	23.72s	1.37	24.8rs	5.98	27.82r	18.89	–	–
Available K (kg ha ⁻¹)															
FFP	172	149c	-13.37	156b	-9.30	141b	-18.02	132c	-23.26	149c	-13.37	288a	67.44	169.17c	-1.65
BSR	172	186bc	8.14	184ab	6.98	186ab	8.14	170b	-1.16	196b	13.95	214bc	24.42	189.33b	10.08
IBSR	172	287a	66.86	203a	18.02	212a	23.26	184a	6.98	230a	33.72	236bc	37.21	225.33a	31.01
STLR	172	207b	20.35	189ab	9.88	160b	-6.98	163ab	-5.23	202ab	17.44	202c	17.44	187.17b	8.82
SSNM	172	293a	70.35	212a	23.26	216a	25.58	195a	13.37	234a	36.05	242b	40.70	232.00a	34.88
Mean		224.4r	30.47	188.8 s	9.77	183 s	6.40	168.8st	-1.86	202.2rs	17.56	236.4	37.44	–	–

Within a column values of the same group (except mean) with the same letter are not significantly different at $P < 0.05$

through residues stubbles and greater K uptake by the crops.

Averaged over the cropping systems, highest soil K content was recorded under SSNM (232 kg ha^{-1}) followed by IBSR, STLR, BSR and least under FFP (169.2 kg ha^{-1}). After 03 crop cycle, whereas SSNM and IBSR enhanced available soil K pool by 34.8 and 31 % over initial soil K status, a depletion soil K was noted under FFP (-1.65%). The highest K depletion under FFP treatment was noted under G–R system (-23%). Here it may be argued that the higher K rates under SSNM and 25 % additional K use under IBSR led to greater crop yields and an enhanced residue (root stubble) recycling, which in turn resulted in higher available K status of the soil under these treatments. On the other hand, depletion of K under FFP may be ascribed to imbalanced crop nutrition and lower residue recycling [18, 22]. Soil K depletion (5–7 %) over initial content under C–R and G–R system with STLR treatment further cautioned that soil test-based K recommendation on soil fertility rating basis needs to be relooked and changed in the view of crop demand, indigenous nutrient supply and other management factors.

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 $931\text{--}1063 \text{ kg N ha}^{-1}$ in W–R, $805\text{--}847 \text{ kg N ha}^{-1}$ in M–R, $572\text{--}654 \text{ kg N ha}^{-1}$ in C–R, $793\text{--}930 \text{ kg N ha}^{-1}$ in G–R, $581\text{--}715 \text{ kg N ha}^{-1}$ in B–R and $1015\text{--}1306 \text{ kg N ha}^{-1}$ in P–R system (Table 4). 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, except in C–R and B–R system where the N balance were negative and had wider output: input ratios. The negative N balance under C–R and B–R systems may be explained in two ways: (i) the N addition through fertilizer to pigeonpea and groundnut was much lower than the other crops, though the N removal in former case was invariably greater (data not reported) and (ii) the contribution of BNF in chickpea and berseem was not measured while computing apparent N balance. Literature indicates that legumes may derive 54–70 % of their N requirement through BNF [2]. 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. Averaged over cropping systems, 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 P–R followed by G–R system (Table 4). Since component crops of these crop sequences removed less P than the additions through fertilizers and other sources, the P balances were positive. These results corroborate with the findings of Singh et al. [22] wherein higher P use in Upper Gangetic Plain to crop like potato and garlic lead to more P availability to succeeding crops and many times farmers grow residual crops without P application. Our results are supported with long-term fertilizer experiments being conducted on diverse soils, under All Indian Coordinated Research Project, the application of P at recommended rate led to positive balance in intensive production system [26]. 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 negative in all the crop sequences and the magnitude was more under M–R and R–W system. Among the different nutrient management options highest negative apparent K balance was noticed with FFP followed by BSR and least in SSNM (Table 4). Relatively higher negative K balance under FFP and BSR underline the neglectance of K use in existing farmer fertilizer practices and or sub-optimal K recommendations by the state departments are not sustainable for modern high yielding cultivars in intensive cropping systems. Further, these results advised 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. Average across the treatments, in potato–rice system, fertilizer cost was maximum (₹ 18854) as well as total returns (₹ 346465) whereas lowest cost of cultivation and total return were noted under B–R system (Fig. 2). Comparing the net return from different nutrient management options, the SSNM was the premier option among the treatments, which on average contributed ₹ 236763, ₹ 207121, ₹ 224597, ₹ 396985, ₹ 180879 and ₹ 416803 as profit in W–R, M–R, C–R, G–R, B–R and P–R systems, respectively. The additional fertilizer input cost accrued for SSNM treatment was in the range of ₹ 5492.4–10119.7, ₹ 2940–5290.6, ₹ 674.14–2236.86 and ₹ 2773.94–4948.69 ha^{-1} as compared FFP, BSR, IBSR and STLR treatments in different cropping system. The added net return in SSNM

Table 4 Effect of nutrient management options on apparent nutrient balance sheet and output: input ratio under different cropping systems after 03 year of cropping

Treatments	Nitrogen						Phosphorus						Potassium					
	Nutrient addition (kg ha ⁻¹)		Nutrient removal (kg ha ⁻¹)	Apparent balance (kg ha ⁻¹)	Output: input ratio	Total	Nutrient addition (kg ha ⁻¹)		Nutrient removal (kg ha ⁻¹)	Apparent balance (kg ha ⁻¹)	Output: input ratio	Total	Nutrient addition (kg ha ⁻¹)		Nutrient removal (kg ha ⁻¹)	Apparent balance (kg ha ⁻¹)	Output: input ratio	Total
	Fertilizer	INS [@] and other sources					Fertilizer	INS and other sources					Fertilizer	INS and other sources				
Wheat–rice system																		
FFP	1038	25	1063	622	441	0.59	161	8	169	100.0	69.1	0.59	71	71	728.0	-657.0	10.25	71
BSR	900	31	931	729	202	0.78	177	15	192	123.0	68.9	0.64	85	358	804.0	-446.3	2.25	85
SSNM	900	40	940	876	64	0.93	177	17	194	140.0	53.9	0.72	88	628	938.0	-310.0	1.49	88
Mustard–rice system																		
FFP	789	16	805	702	103	0.87	156	7	163	94.0	68.9	0.58	35	35	765.0	-730.0	21.86	35
BSR	810	17	827	745	82	0.90	164	12	176	104.0	71.8	0.59	28	301	854.0	-553.3	2.84	28
SSNM	825	22	847	811	36	0.96	197	16	236	134.0	102.0	0.57	42	557	928.0	-370.5	1.66	42
Chickpea–rice system																		
FFP	602	52	654	680	-27	1.04	153	10	163	98.0	65.3	0.60	33	33	445.0	-412.0	13.48	33
BSR	510	62	572	754	-182	1.32	164	16	180	112.0	67.8	0.62	39	284	556.0	-271.5	1.95	39
SSNM	540	81	621	816	-195	1.31	197	20	217	143.0	73.5	0.66	42	517	615.0	-98.5	1.19	42
Garlic–rice system																		
FFP	774	19	793	412	381	0.52	153	13	166	89.0	77.3	0.54	40	40	579.0	-539.0	14.48	40
BSR	825	25	850	512	338	0.60	177	18	195	94.0	100.9	0.48	44	371	643.0	-271.7	1.73	44
SSNM	900	30	930	574	356	0.62	216	21	237	126.0	111.2	0.53	45	585	711.0	-126.0	1.22	45
Berseem–rice system																		
FFP	659	56	715	724	-9	1.01	143	10	153	101.0	51.8	0.66	36	36	529.0	-493.0	14.69	36
BSR	510	71	581	788	-207	1.36	164	12	176	117.0	58.8	0.67	42	206	612.0	-406.4	2.98	42
SSNM	570	82	652	834	-182	1.28	177	16	193	132.0	60.9	0.68	52	527	683.0	-156.5	1.30	52
Potato–rice system																		
FFP	1284	22	1306	822	484	0.63	274	12	286	123.0	162.8	0.43	38	147	572.0	-424.9	3.89	38
BSR	990	25	1015	896	119	0.88	203	15	218	141.0	77.1	0.65	44	480	624.0	-143.6	1.30	44
SSNM	1080	30	1110	931	179	0.84	228	19	247	174.0	72.9	0.70	51	730	710.0	20.1	0.97	51

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

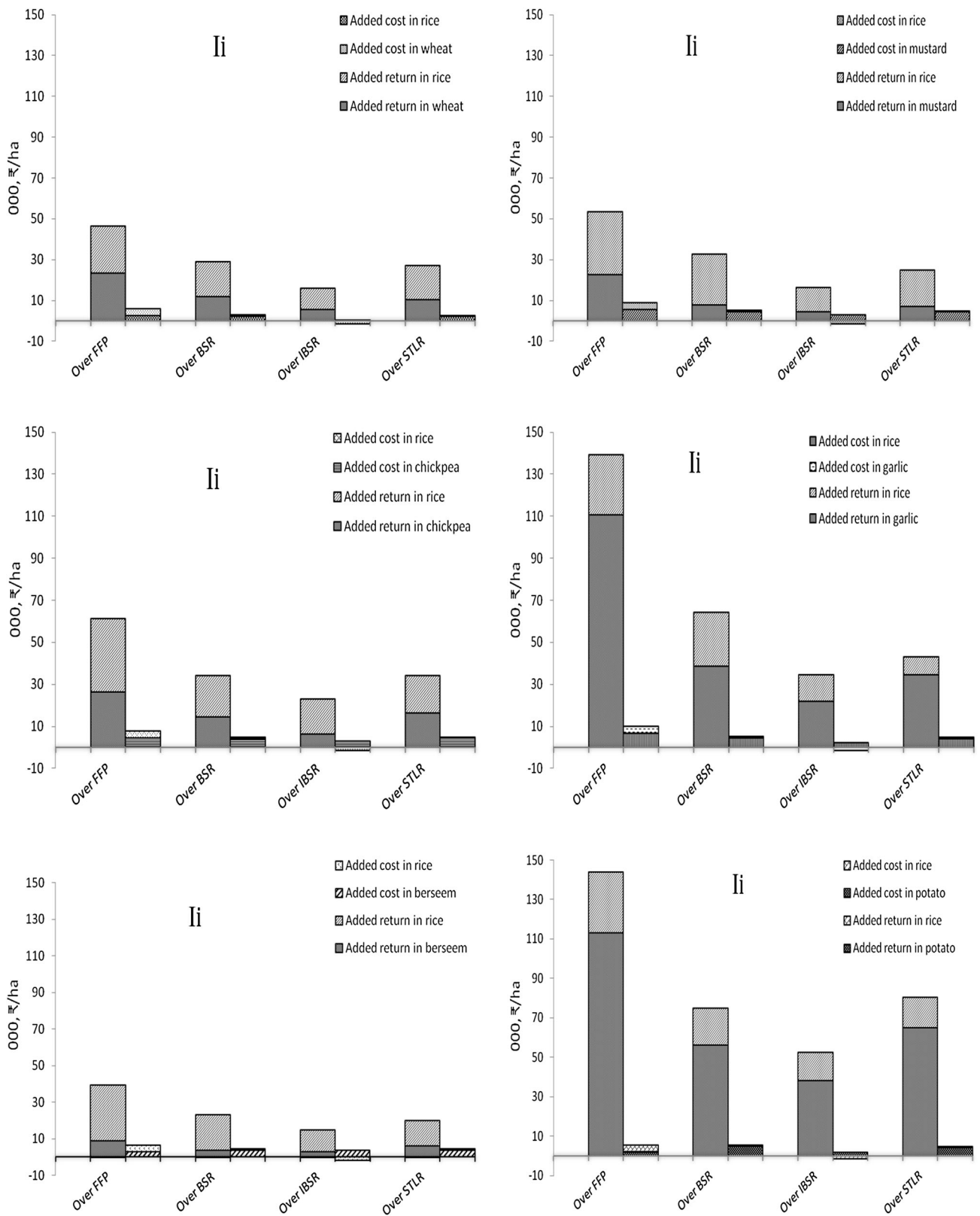


Fig. 2 Added cost and added net return in SSNM treatment over FFP, BSR, IBSR and STLR. \bar{I} indicates LSD at 0.05 for added cost and added return of the system, respectively

over other nutrient management options depended upon grain and straw yield and their prices in each cropping systems, and it varied from ₹ 39577–143899 (mean ₹ 80655) over FFP, ₹ 23236–75056 (mean ₹ 43013) over BSR, ₹ 15165–52470 (mean ₹ 26271) over IBSR and ₹ 20164–80263 (mean ₹ 38243) over STLR. The favourable economics of SSNM over FFP, BSR, IBSR and STLR underlines the significance of balanced nutrition in improving crop yield as well as farm profitability, and counter the effect of increasing fertilizer cost, which is a major challenge towards sustainability of intensive cropping systems [18].

Conclusions

Foregoing results reveals that the existing nutrient management options, i.e. BSR 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 as per yield target. Otherwise, the yield grains with STLR may not be different from adhoc 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 options for other locations-specific pre-dominant cropping systems considering farmers' resource availability and socio-economic conditions. In view of negative K balance observed under all nutrient management options including SSNM, there is need to integrate crop residue management with SSNM in order to curb excessive K mining from the soil.

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