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Influence of balanced fertilization on productivity and nutrient use efficiency of cereal based cropping systems

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ABSTRACT

Increasing the use efficiency of nitrogen in system mode was always a concern due to escalating input cost of fertilizer. The "researcher designed farmer managed trials" were conducted in farmers' field during 2009 -10 at 27 districts covering 17 states. A total of 192 trials in rice-rice, 233 in rice (*Oryza sativa* L.) -wheat (*Triticum aestivum* L.), 48 in rice-greengram and 77 in maize-wheat system were conducted with five common treatments, viz. control, recommended quantity of N alone, NP, NK and NPK in all the locations and cropping systems. Application of recommended quantity of NPK in all the systems recorded higher yield and increase was found to be more than 50% in maize (*Zea mays* L.) -wheat and rice-rice systems and > 30% in rice-greengram [*Vigna radiata* (L.) Wilczek] and rice-wheat systems over application of N alone. On an average additional yield of 2 794 kg rice equivalent yield (REY)/ha was realized, in cereal based systems with application of all the nutrients together instead of N alone. Among the various systems, maize-wheat was found to respond well to balanced application as it recorded 162% increase in yield over control. Partial factor productivity (PFP) of N, can be increased by >50% in rice-rice and maize-wheat system through application of recommended dose of NPK. Efficiency of applied nutrients measured in the form of agronomic efficiency was found to be >100% for all the systems under balanced application compared to N alone, or with P with K. Similarly combined application increased the P and K efficiency in all the systems with maize-wheat recording the highest efficiency of K. Relative response of treatment over control also displayed similar trend. Marginal returns due to application of NPK together was found to be 136.7, 24.5, 11.5 and 46.4% higher in rice-rice, rice-wheat, rice-greengram and maize-wheat systems respectively over application of N alone. Balanced application of N, P and K was found to increase the system productivity and nutrient use efficiency of cereal based systems.

Key words : Agronomic efficiency, Marginal returns, Partial factor productivity, Systems

Rice (*Oryza sativa* L.), wheat (*Triticum aestivum* L.) and maize (*Zea mays* L.) provide about two-thirds of all energy in human diets and four major cropping systems namely rice-rice, rice-wheat, rice-greengram and maize-wheat in which these cereals are grown occupying more than 16 million ha area greatly affects the livelihood and health of the urban and rural poor in India. As a result of intensified crop management involving improved germplasm, greater inputs of fertilizer and irrigation yield per unit time and land, the yield has increased markedly during the past 30 years in these systems. Cereal production in the country increased by five fold, while fertilizer consumption increased 322 times during the 1950–51 to 2007–08 period, implying a very low fertilizer use efficiency (Rajendra Prasad 2009). Large scale applications of fertilizer nitrogen (N) have also shown deleterious effects on groundwater quality, especially its nitrate content, which is harmful to health. Furthermore, gaseous losses of N as NH_3 and NO_2 resulting from N fertilization have adverse effects on the environment. The most commonly observed effect of intensive cereal based systems is a decline in the partial factor productivity of nitrogen fertilizer (Hobbs and Morris 1996). Cassman *et al*. (1994) indicated that the decline in partial factor productivity of nitrogen in rice monoculture systems is due to a decline in the nitrogen supplying capacity of intensively cultivated wetland soils. Rice-wheat systems could be facing a similar phenomenon. Fertilized rice and wheat obtain 50.8% of their nitrogen requirement from the soil; unfertilized rice obtains an even larger portion, mainly through the mineralization of organic matter (De Datta 1981). Declining soil N supply results in declining factor productivity of chemical nitrogen, since soil N is a natural substitute for chemical nitrogen. The magnitude of 30% yield decline over a 20 year period due to declining soil nitrogen supply is estimated by Cassman and

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Pingali (1993). In addition to nitrogen, phosphorus and potassium are the two other macro-nutrients required by the cereal based systems. Phosphorus and potassium deficiencies are becoming widespread in areas not previously considered to be deficient. These deficiencies are directly related to the increase in cropping intensity and the predominance of year-round irrigated production systems. It is estimated that in India, nearly one-half of the districts have been classified as low in available phosphorus (Desai and Gandhi 1989) which is due to the emphasis on nitrogen rather than a balanced application of all macro-nutrients required for sustaining soil fertility. The result of unbalanced application of fertilizers leads to decline in the efficiency of fertilizers.

An effective nutrient management must include timely balanced NPK applications, using appropriate methods. In addition to proper nutrient management, other aspects of soil and crop management including the use of high yielding, nutrient-efficient cultivars, correcting soil physical and chemical problems and water management, disease and pest management, and post-harvest care and safe storage are important to achieve high fertilizer use efficiency. Fertilizer was considered an important tool to augment food production in India since independence. Meeting future food demand while minimizing expansion of cultivated area primarily will depend on continued increase in yield and nutrient use efficiency of the four major cereal based systems. With this background, the present investigation was envisaged to identify the production potential in cereal based cropping systems, factor productivity and agronomic efficiency of applied nutrients along with marginal returns from balanced fertilization under on-farm locations.

MATERIALS AND METHODS

Experiments were conducted during 2009-10 at 27 districts covering 17 states spread across length and breadth of the country through on-farm research centres of All India Coordinated Project on Cropping Systems (now Integrated Farming Systems). The details of the locations with National Agricultural Research Project (NARP) zone for each system, soil type, varieties and recommended dose of nutrients used are presented in Table 1. Five common treatments consisting of control, N alone, NP, NK and NPK were imposed in all locations and cropping systems. No application of nutrients was resorted in control, while recommended dose of nitrogen, phosphorus and potassium as indicated in Table 1 was applied to respective treatments and crops. In general, 24 trials were conducted in each district by selecting four villages in each block and six blocks in a district. In each village one farmer was selected through randomization and all the treatments are imposed in the predominant cereal based cropping system of the area. However, the number of trials varied in some locations based on local requirements. In case of rice-rice system, 192 trials were conducted at six locations [72 trials in Thiruvalla (Kerala) and 24 each in 5 other locations] while in rice-wheat system, 233 trials were conducted at 13 locations. Rice-greengram system comprised 48 trials in 2 locations (24 each at Odisha and West Bengal) and maize-wheat system comprised 77 trials in 4 locations. The recommended dose of nitrogen application ranged 180-270, 160-300, 100 and 120-210 kg/ha with mean value of 237, 232, 100 and 182 kg/ha for rice-rice, rice-wheat, rice-greengram and maize-wheat systems, respectively across the locations. Similarly, the recommended dose of P ranged from 88-120, 90-120, 80 and 70-100 kg/ha with mean value of 101, 110, 80 and 82 kg P_2O_5/ha and K ranged from 40 to 120 kg K_2O/ha with mean values of 88, 83, 70 and 56 kg/ha for systems, respectively. Rice equivalent yield of other crops was calculated by multiplying the yield of respective crops with its price and divided by price of rice. Rice equivalent yields were totalled and expressed as rice equivalent system yield (RESY). Nutrient use efficiencies were measured in terms of Partial Factor Productivity (PFP) and Agronomic efficiency (AE). The PFP, a ratio of the grain yield to applied nutrient is a useful measure of nutrient use efficiency as it provides integrative index that quantifies total economic output relative to the utilization of all nutrient resources in the system including native soil nutrients and nutrients from applied fertilizers. It is possible to increase the PFP by increasing the amount, uptake and utilization of indigenous nutrients, and by increasing the efficiency with which applied nutrients are taken up by the crop and utilized to produce grain (Cassman *et al.* 1996). PFP ((kg grain/kg of native+applied nutrient) was calculated as PFPn = Yn/Fn, Ynp/Fn, Ynk/Fn and Ynpk/Fn for the respective treatments. PFP of phosphorus was calculated as PFPp=Ynp/Fp and Ynpk/Fp while PFP of K was calculated as PFPk=Ynk/Fk and Ynpk/Fk where PFPn, PFPp and PFPk are the PFP of nitrogen, phosphorus and potassium respectively, Yn, Ynp, Ynk and Ynpk are the yield of respective treatments (N alone, N with P, N with K and N with P and K) and Fn, Fp and Fk are the amount of applied N, P_2O_5 and K_2O respectively. All these values are in kg/ha. PFP can be determined for a single or a combination of nutrients or for a fertilizer *per se*. The Agronomic Efficiency (AE:kg grain/kg nutrient applied), an incremental efficiency from applied nutrients of N, P, K over control, was calculated as AEn=(Yn-Yo)/Fn, (Ynp-Yo)/Fn, (Ynk-Yo)/Fn and (Ynpk-Yo)/Fn for respective treatments. AE of P was calculated as AEp=(Ynp-Yo)/Fp, (Ynpk-Yo)/Fp while AE of K was calculated as AEk= (Ynk-Yo)/Fk and (Ynpk-Yo)/Fk where AEn, AEp and AEk were the AE of applied nutrients in terms of nitrogen, phosphorus and potassium, Yo Yn, Ynp, Ynk and Ynpk are the yield of respective treatments (control, N alone, N with P, N with K and N with P and K) and Fn, Fp and Fk are the amount of applied N, P_2O_5 and K_2O respectively. All these values are in kg/ha. Native nutrient supplying capacity of the soil was estimated by deducting AE from PFP for the respective nutrients (Yadav 2003). AE is the same as "crop

Table 1 Details of NARP zone, location, varieties and recommended dose of nutrients of on-farm experiments on cereal based cropping systems

NARP zone	Location (State)	Soil Type	First crop				Second crop			
			Variety	Nutrient dose (kg/ha)			Variety	Nutrient dose (kg/ha)		
				N	P	K		N	P	K
Rice-Rice										
Southern Telangana	Nellore (AP)	Sandy clay	NLR-34449	120	60	40	NLR-34242	120	60	40
Central Telangana	Warrangal (AP)	Sandy clay	BPT-5204	120	60	40	MTU-1010	120	60	40
Special situation	Thiruvalla (Kerala)	Alluvial	Uma	90	45	45	Uma	90	45	45
North Konkan	Roha (Maharashtra)	Sandy clay	Shyadri	100	50	50	KJT-3	120	50	50
North western	Paiyur (TN)	Sandy loam	Paiyur-I	150	50	50	ADT-42	120	40	40
Southern	Chettinad (TN)	Clay loam	ADT-39	150	50	50	ADT-36	120	38	38
Rice-Wheat										
North West Alluvial Plain	Patna (Bihar)	Alluvial	R.Shweta	80	40	20	PBW-373	120	60	40
Bhal & Coastal	Arnej (Gujarat)	Clay	Gujari	100	50	50	GW-496	120	60	60
Eastern Alluvial Plain	Karnal (Haryana)	Clay-loam	PR-114	150	60	60	DBW-17	150	60	60
Central and NEP	Dumka (Jharkhand)	Sandy loam	Lalat	100	50	25	K-9107	100	50	25
Sub-Tropical	Jammu (J&K)	Clay loam	Jaya	120	60	30	DBW-17	100	50	25
High Rainfall EV2	Gondia (Maharashtra)	Sandy clay	PKV-Khamang	100	50	50	AKW-3722	100	50	50
Kymore Plateau & Satpura Hill	Seoni (MP)	Clay loam	MR-38-28	120	60	40	DL-803-3	120	60	40
Kymore Plateau & Satpura Hill	Katni (MP)	Clay loam	MR-3828	120	60	40	DL-8033	120	60	40
Mid-Central Table land	Dhankanal (Odisha)	Sandy loam	Lalat	80	40	40	Sonalika	80	50	40
Central Plain	Amritsar (Punjab)	Sandy loam	PAU-201	120	30	30	HD-2733	120	60	30
Eastern Plain	Varanasi (UP)	Sandy loam	NDR-359	120	60	60	HD-2733	120	60	40
Bundelkhand	Sant Kabirnagar (UP)	Sandy loam	NDR-359	120	60	60	HUW-234	120	60	40
Mid Western	Pantnagar (UK)	Sandy loam	Pusa 1121	100	60	40	PBW-550	150	60	40
Mid Western	Pantnagar (UK)	Sandy loam	PSD-3	150	60	40	PBW-550	150	60	40
Rice-Greengram										
Coastal saline	Kakdwip (WB)	Clay loam	Pankaj	80	40	40	Chait Moong	20	40	40
Eastern Coastal Plain	Kendrapara (Odisha)	Clay loam	Swarn	80	40	40	Local	20	40	20
Maize-Wheat										
Sub- mountain and low hill sub tropical	Palampur (HP)	Clay loam	KH-101A	90	45	30	HPW-155	80	40	40
Central North Platue	Dumka (Jharkhand)	Sandy loam	HQPM-1	100	50	25	K-9107	100	50	25
Sub- tropical	Jammu (J&K)	Sandy clay loam	Kanchan	60	40	20	DBW-17	60	30	20
Sub-humid Southern Plain &Aravalli Hills	Udaipur(Rajasthan)	Sandy Loam	Pratap-Makka-5	90	35	30	Raj-4037	120	40	30
Southern Plain	Udaipur(Rajasthan)	Sandy clay loam	Pratap-Makka-5	90	40	30	Raj-4037	120	40	30

AP: Andhra Pradesh, TN: Tamil Nadu, J&K: Jammu & Kashmir, MP: Madhya Pradesh, UP: Uttar Pradesh, UK: Uttarakhand, WB: West Bengal, HP: Himachal Pradesh response ratio" or productivity index used by FAO (1989) and can be determined for a single nutrient (N, P, or K) or for a combination of nutrients (NP, NK, PK, or NPK), or for a fertilizer material *per se*. Relative yield responses to different nutrient combinations were calculated by using the formula of [grain yield $_{(\text{treatment X})}$ - grain yield $_{(\text{control})}$]/ grain yield $_{(\text{control})}$ where, treatment X represents N, NP, NK and NPK application (Tittonell *et al.* 2008). Economic evaluation of the treatments was made through marginal analysis. The cost of cultivation of different cereal systems were calculated on the basis of different operations performed and materials used for raising the crops. The cost of cultivation of treatments was calculated by using the nutrient based subsidy rates of Government of India. Accordingly, ₹ 27.481, 29.407 and 24.628 /kg was used for N, P and K respectively. Marginal returns (MR) for the treatment over the control was calculated as MR= [(NRt-NRc)/(CCt-CCc)] x 100, where NRt and NRc are Net returns of treatment and control respectively while CCt and CCc are cost of cultivation of treatment and control respectively. Descriptive statistical analysis was performed for measured and estimated parameters to ascertain the range of variability and deviation.

RESULTS AND DISCUSSION

System yield

All the cereal based systems responded positively with the addition of recommended quantity of N, P and K. Among the various systems, rice-rice recorded higher rice equipment system yield (RESY) of 11 439 kg/ha with recommended quantity of NPK application followed by rice-wheat (8 959 kg/ha), rice-greengram (8 103 kg/ha) and maize-wheat (8 069 kg/ha) systems. Application of recommended quantity of nutrients to maize-wheat system recorded 161.8% increased yield over control followed by 95.3 and 94.8% in rice-wheat and rice-rice systems respectively. Rice-greengram system recorded only 72.4% increase in yield (Table 2). Similarly, application of recommended quantity of NPK registered increase in RESY to the tune of 55.6, 51.9, 35.7 and 33.5% in maize-wheat, rice-rice, rice-greengram and rice-wheat systems respectively compared to application of N alone to these systems. It was found that application of NP was more beneficial in rice-rice, rice-wheat and maize-wheat systems, while NK found to be better for rice-greengram system as it registered marginal (3.4%) increase over NP. On an average, an additional yield (REY) of 2 794 kg/ha was obtained by application of recommended quantity of NPK instead of application of N alone to the cereal based systems, which is in practice under larger area in India. The yield increase due to application NP or NK was found to be only 1 274 and 1 674 kg/ha respectively. Maize-wheat system is the better system as it increased the yield by 161.8% with recommended quantity of nutrients over control and 55.36% over application of N alone. The better yield observed in balanced application of NPK to all the systems can be attributed to involvement of P in better root development and subsequent absorption of N, while K is involved in N metabolism in cereals. Hegde and Babu (2004), Prasad *et al.* (2004), Ghosh *et al.* (2004) and Jat *et al.* (2011) have also reported balanced NPK fertilization is essential in crops to achieve the targeted yield.

Partial factor productivity (PFP)

Partial factor productivity (PFP) proved to be higher under balanced nutrient application in all the systems compared to application of N alone or NP and NK. PFPn can be increased to 55.6% and 54.6% in maize-wheat and rice-rice systems, while in rice-greengram and rice-wheat, it was found to be 35.7 and 33.9% respectively. The increase in efficiency of N was observed in all the systems by way of combining recommended quantity of P and K with nitrogen application. Similarly, the recovery of P and K was higher when the same is applied together with N in all the systems. Among the different systems, rice-rice system recorded higher PFPp (116 kg/ha) with NK followed by rice-greengram system (101.3 kg/kg of P with NK) (Table 3). However, PFPk was higher in maize-wheat system (147.3 kg/kg of K with NP) followed by rice-rice and rice-wheat system. Balanced application of nutrients have helped in better recovery of N, P and K from native soil as well as from the applied fertilize as it is evident from the partial factor productivity analysis of nutrients in major cereal based systems. Haerdter and Fairhurst (2003) have concluded that the recovery of N from fertilizers increases from 16% at traditional NP fertilization to 76% at balanced NPK supply. Also the recovery of P from fertilizers improved with balanced fertilization, namely from 1% at NP to 13% at NPK, and the recovery of K increased from 22% at NK to 61% at NPK fertilization.

Table 2 Rice equivalent yield (kg/ha) of cereal based cropping systems as influenced by nutrient application

Cropping system	Rice equivalent yield (kg/ha)				
	Control	N	NP	NK	NPK
Rice-rice	5 871± 608	7 529 ± 569	9 470 ± 550	9 234 ± 536	11 439 ± 711
Rice-wheat	4 585 ± 478	6 712 ± 664	8 080 ± 663	7 464 ± 678	8 959 ± 665
Rice-greengram	4 699 ± 416	5 970 ± 144	6 895 ± 204	7 136 ± 115	8 103 ± 124
Maize-wheat	3 082 ± 435	5 186 ± 892	7038 ± 958	6 040 ± 953	8 069 ± 1032

Table 3 Partial factor productivity (PFP) N, P and K (kg grain/ kg of applied + native nutrient) of cereal based cropping systems as influenced by nutrient application

Cropping system	PFP of N			PFP of P			PFP of K	
	N alone	with P	with K	with PK	With N	With NK	With N	With NP
Rice-rice	31.7 ± 1.2	40.3 ± 2.1 (27.1)	39.5 ± 2.7 (24.6)	49.0 ± 3.5 (54.6)	95.8 ± 9.5	116.0 ± 12.010 (21.1)	4.9 ± 4.9	129.9 ± 6.4 (23.8)
Rice-wheat	28.6 ± 2.2	34.5 ± 2.0 (20.6)	31.9 ± 2.3 (11.5)	38.3 ± 2.0 (33.9)	73.7 ± 6.3	81.7 ± 6.4 (10.9)	93.1 ± 9.3	113.5 ± 10.6 (21.9)
Rice-greengram	59.7 ± 1.4	69.0 ± 2.0 (15.6)	71.4 ± 1.2 (19.6)	81.0 ± 1.2 (35.7)	86.2 ± 2.6	101.3 ± 1.5 (17.5)	103.8 ± 13.2	117.9 ± 15.1 (13.6)
Maize-wheat	28.8 ± 4.2	39.1 ± 4.3 (35.8)	33.5 ± 4.3 (16.3)	44.8 ± 4.5 (55.6)	88.0 ± 14.1	100.7 ± 15.3 (14.4)	109.6 ± 15.7	147.3 ± 17.8 (34.4)

Figures in parenthesis are per cent increase over N alone

Table 4 Agronomic Efficiency (AE) of N, P and K (kg grain/ kg of applied nutrient) of cereal based cropping systems as influenced by nutrient application

Cropping system	AE of N			AE of P			AE of K	
	N alone	with P	with K	with PK	With N	With NK	With N	With NP
Rice-rice	7.2 ± 1.2	15.8 ± 2.8 (119.4)	14.9 ± 3.0 (106.9)	24.4 ± 3.9 (238.9)	36.3 ± 6.1	56.5 ± 8.5 (55.6)	38.2 ± 4.9	63.1 ± 6.8 (65.1)
Rice-wheat	8.7 ± 1.4	14.6 ± 1.6 (67.8)	12.0 ± 1.4 (37.9)	18.5 ± 1.6 (112.6)	31.4 ± 4.0	39.4 ± 4.1 (25.5)	35.5 ± 4.2	55.9 ± 6.6 (57.5)
Rice-greengram	12.7 ± 2.7	22.0 ± 2.1 (73.2)	24.4 ± 3.0 (92.1)	34.0 ± 2.9 (167.7)	27.5 ± 2.6	42.5 ± 3.7 (54.5)	36.2 ± 9.5	50.2 ± 11.4 (38.7)
Maize-wheat	11.3 ± 2.5	21.5 ± 3.0 (90.3)	16.0 ± 2.6 (41.6)	27.2 ± 3.1 (140.7)	49.0 ± 9.5	61.7 ± 10.6 (25.9)	53.8 ± 10.3	91.5 ± 13.8 (70.1)

Figures in parenthesis are per cent increase over N alone

Agronomic efficiency (AE)

Farmers, specially the marginal and dryland farmers, generally, tend to apply only N. However, the AEn of applied N can be largely increased by adequate P and K fertilization. Agronomic efficiency of N can be increased to 238.9% (Table 4) in rice-rice system by applying the recommended quantity of N with recommended quantity of P and K instead of N alone as being practiced in many regions having the cereal based systems. Rice-greengram recorded 167.7% increased AE of N with PK followed by maize-wheat systems (140.7%). Though, application of N with P or K had registered increase in AE of N in all the systems compared to N alone, the magnitude of increase was lesser than the balanced application of NPK. Similar to N, AE of P was found to be better in all the systems when P is applied with N and K rather than N alone which can be attributed to positive interaction effect of these nutrients in growth and development of plants. Among the systems, AE of P and K was found to be higher in rice-rice and rice-greengram systems. More recovery of K due to balanced application was found in maize-wheat system (70.1%). On an average, AE of N, P and K can be increased to the tune of 165, 40.4 and 57.9% respectively through balanced application of nutrient in major cereal cropping systems.

Relative response and native nutrient supply

Relative response of balanced application of nutrients over control also exhibited the similar trend as that of partial factor productivity and Agronomic efficiency. Relative response of application of NPK over control was found to be 1.04, 1.14, 0.74 and 1.79 in rice-rice, rice-wheat, rice-greengram and maize-wheat systems respectively, which is higher than the N, NP and NK treatments. Among the various system evaluated, maize-wheat had recorded higher relative response with NPK over control which is mainly due to the fact of higher and efficient utilization of nutrients by this system which is also evident from higher partial factor productivity of N and K. Inclusion of greengram in the system led to higher supply of native soil N to the rice-greengram system (47 kg REY/kg of native nutrient) (Table 5). Among the different systems, higher P and K supply from soil was observed in rice-rice and rice-greengram systems. In case of maize-wheat systems, one kg of native N, P, K have contributed for 17.5, 39 and 55.8 kg REY. Yadav (1998)

Table 5 Relative response of treatments over control and Native nutrient supplying capacity (kg REY/kg of native nutrient) of soils of cereal based cropping systems as influenced by nutrient application

Cropping system	Relative response				Native soil nutrient supply		
	N	NP	NK	NPK	N	P	K
Rice-rice	0.31 ± 0.06	0.68 ± 0.16	0.64 ± 0.16	1.04 ± 0.22	24.6 ± 1.4	59.5 ± 8.2	66.8 ± 6.5
Rice-wheat	0.53 ± 0.11	0.90 ± 0.16	0.71 ± 0.11	1.14 ± 0.19	19.9 ± 1.9	42.3 ± 5.1	57.6 ± 7.3
Rice-greengram	0.28 ± 0.08	0.48 ± 0.09	0.53 ± 0.11	0.74 ± 0.13	56.9 ± 14.0	58.7 ± 5.2	67.7 ± 3.7
Maize-wheat	0.71 ± 0.17	1.42 ± 0.37	1.01 ± 0.21	1.79 ± 0.44	17.5 ± 2.7	39.0 ± 6.5	55.8 ± 7.9

Table 6 Cost of cultivation (₹/ha) of cereal based system as influenced by NPK application

Cropping system	Cost of cultivation (₹/ha)					Net returns (₹/ha)				
	Control	N alone	with P	with K	with PK	Control	N alone	with P	with K	with PK
Rice-rice	30 000	36 504	39 484	38 671	41 651	31 125	42 361	60 539	58 737	79 427
Rice-wheat	33 121	39 501	42 735	41 532	44 767	10 961	25 043	34 961	30 170	41 243
Rice-greengram	22 500	25 248	27 601	26 972	29 325	18 977	27 327	33 139	35 862	42 015
Maize-wheat	28 900	33 902	36 313	35 281	37 692	3 021	19 874	36 053	27 200	45 168

also concluded that balanced application ensures higher responses of nutrients in rice-wheat system.

Marginal returns

Cost of cultivation was higher in balanced application of nutrient in all the systems and it ranged from ₹ 6 825/ha in rice-greengram to as high as ₹ 11 651/ha in rice-rice system (Table 6). However, the net returns were found to be much higher in all the systems under NPK application compared to control, N alone, NP and NK combinations. The increase was found to be 87.5, 64.6, 53.7 and 127.3% under NPK over N alone in rice-rice, rice-wheat, rice-greengram an maize-wheat systems, while the cost of cultivation increase due to additional application of P and K was found to be only 14, 13.3, 16.1 and 11.2 for the respective systems. Marginal returns (Table 7) were found to be higher with combined application of NPK than N alone, NP and NK. Among the systems, maize-wheat recorded higher (476%) marginal returns under balanced application followed by rice-rice (426%), rice-greengram (339%) and rice-wheat (254%) systems. Application of N alone or with P and with K recorded lower marginal returns in all the systems compared to balanced application of nutrients.

Table 7 Marginal Returns (%) due to application of N with P and K over control in cereal based cropping systems

Cropping system	N alone	with P	with K	with PK
Rice-rice	180	323	333	426
Rice-wheat	204	240	217	254
Rice-greengram	304	278	381	339
Maize-wheat	325	440	371	476

In many parts of the country, application of only N or P is resorted to the cereal based systems; hence, full potential of applied N or P is not realized. In order to increase the use efficiency and increase the returns from the investment made on nutrients, application of recommended quantity of NPK together is essential. Thus, it can be concluded that application of recommended quantity of nitrogen, phosphorus and potassium together is essential for realizing higher system equivalent yield, increased efficiency of applied and native nutrients and enhanced marginal returns in rice-rice, rice-wheat, rice-greengram and maize-wheat systems which plays vital role in meeting the food production target for the ever growing population.

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