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Improvement in productivity and economics of major food production systems of India through balanced dose of nutrients

Raghuveer Singh*, N. Ravisankar and Kamta Prasad

ICAR-Indian Institute of Farming System Research, Modipuram, Meerut 250 110, India

Increasing the nutrient use efficiency in major food production systems has always been a major concern because of escalating costs of production of crops, especially with regard to nutrient management. 'Researcher-designed farmer managed trials' were conducted during 2013–14 through farmer participatory research covering the major food production systems in India. A total of 144 trials in rice–rice, 156 in rice–wheat, 48 in rice–green gram and 60 in maize–wheat systems were conducted with 7 treatments. Across the various National Agricultural Research Project zones and cropping systems, farmers applied 29%, 25%, 71% and 100% lower level of N, P_2O_5, K_2O and micronutrients respectively, than the recommended dose. Application of recommended dose of NPK + deficient micronutrients in all the systems recorded higher yield over farmer package. Balanced application of recommended NPK + deficit micronutrients gave additional yield. The increase in agronomic efficiency (AE) of nitrogen (two times on an average), phosphorus (45%) and potassium (60%), partial factor productivity and relative response was also observed with the balanced application compared to N, NP and NK alone. Higher increase of AE of N and P was observed in rice–rice system while AE of K was observed in rice–wheat system. Increase in net returns was found to be 24.9%, 63.3%, 27.4% and 92.2% with the application of NPK + deficient micronutrients over farmer practice in rice–rice, rice–wheat, rice–green gram and maize–wheat systems respectively, whereas the increase in cost of cultivation due to addition of P, K and micronutrients was found to be only 4.8%, 7.3%, 13.0% and 17.9% for the respective systems.

Keywords: Agronomic efficiency, food systems, nutrient application, partial factor productivity, productivity and economics.

RICE, wheat and maize crops supply about two-thirds of the energy requirement in human diets. The four key cropping systems of India, namely rice–rice (5.89 m ha), rice–wheat (10.50 m ha), rice-green gram (0.59 m ha) and maize–wheat (1.86 m ha) occupy more than 18 million ha and greatly influence food production in the country.

*For correspondence. (e-mail: rsbicar@gmail.com)

India has achieved noteworthy increase in food production in the post-green revolution phase, from 90 MMT (million metric tonne) in 1969–70 to 251.6 MMT during 2015–16. Occurrence of multi-nutrient deficiency due to imbalanced use of nutrients and declining soil organic matter are the factors affecting the productivity of major food crops at the farmers' field level and these contribute to the wider yield gap between on-station (controlled condition) and on-farm conditions. With a consumption of 16.6 Tg N, 8.0 Tg P_2O_5 and 3.5 Tg K_2O in 2010, India occupies the second position following China in N and P consumption[1]. In K consumption, the country occupies the fourth place and in overall N + P_2O_5 + K_2O (NPK) consumption, it holds the second position in the world. India also occupies the second place in fertilizer N production (12.2 Tg in 2010) and third place in phosphate fertilizer production (4.4 Tg in 2010)[1]. However, nutrient use efficiency (NUE) in India has always been major concern. In the last 35 years, fertilizer response in irrigated areas of the country has declined almost three times from 13.4 kg grain/kg NPK in 1970 to 3.7 kg grain/kg NPK in 2005 (ref. 2). In 1970, only 54 kg NPK/ha was required for an yield of 2 t/ha, but around 218 kg NPK/ha is now being used to obtain the same yield[3]. The declining fertilizer response compared to the seventies is a matter of concern; it affects the economy of food production systems in the country. Fertilizer input has been the mainstay of food production system in India, contributing about 50% towards crop productivity over the period of the last three decades. Nitrogen application has made substantial contribution to the tripling of global food production over the last five decades. However, its use efficiency in agriculture is in general low and ranges between 20% and 50%. Imbalanced application of essential nutrients (secondary and micro) is one of the reasons for low nitrogen use efficiency. Even though India stands third in the world in terms of gross fertilizer consumption, the consumption levels in different agro-ecological regions are highly skewed. Only 102 out of total 500 districts studied contribute to 50% of national fertilizer consumption. The North zone, considered to be the food grain bowl of India, has the highest consumption of N but lowest consumption of potassium. Comparing Punjab in the northern part and Tamil Nadu in the southern part of the country, the N : P_2O_5 : K_2O consumption ratio was much wider in the former (42.6 : 11.9 : 1.0) compared to the latter state (2.6 : 1.0 : 1.0). This indicates that the highest fertilizer consuming state has the greatest imbalanced use of nutrients[4]. Continuous mono-cropping with high-yielding cereal crop varieties has led to the depletion of native micronutrients and now most of the soils are deficient in nutrients. Around 41%, 48%, 12%, 5%, 4%, 33% and 13% soils are affected with deficiency of S, Zn, Fe, Mn, Cu, B and Mo respectively[5]. Zinc deficiency in soils is further expected to amplify from 48% to 63% by the year 2025, as most of the marginal soils are being brought under cultivation. Besides this, hidden hunger of micronutrients is widely noticed leading to the failure of entire crops and reduced micronutrients content in different plant parts, which ultimately reflect in the form of low yield. Rice, wheat and maize cultivated in zinc-deficient soils contained more than two times lower micronutrients content than those cultivated on soils rich in trace elements. Sample study conducted under AICRP on Integrated Farming Systems (AICRP-IFS) across the various National Agricultural Research Project (NARP) zones and cropping systems of the country indicated 29%, 25%, 71% and 100% lower application of N, P_2O_5, K_2O and micronutrients under farmer practice than the recommended dose. Farmers generally avoid application of micronutrients and apply suboptimal doses of NPK. On-farm experiments in farmer participatory mode in the form of scientist-designed farmer-managed trials were carried out with seven treatments, viz. control, recommended dose of N alone, NP, NK, NPK, NPK+ addition of deficient micronutrients based on soil test and farmer practice at 18 locations to assess the yield, improvement in NUE and economics in the major food production systems of the country.

Experiments were conducted during 2013–14 at 18 districts covering 17 states spread across the country through on-farm research centres of AICRP-IFS. Details about location with NARP zone for each system, soil type, variety and recommended dose of nutrients used are presented in Supplementary Table 1. Seven treatments as mentioned above were carried out in all the locations and cropping systems. No application of nutrients was resorted in control, while recommended dose of nitrogen, phosphorus and potassium (Supplementary Table 1) was applied to the respective treatments and crops. In general, 24 trials were conducted in each district by selecting 3 villages in each block and 2 blocks in a district. In each village four farmers were selected through randomization and all the treatments were carried out in the predominant cereal-based food production cropping system of the area. In case of rice–rice system, 144 trials were conducted at 6 locations while in rice–wheat system, 156 trials were conducted at 7 locations. Rice–green gram system comprised 48 trials in 2 locations (24 each at Odisha and West Bengal) and maize–wheat system consisted of 60 trials in 3 locations (24 each in Himachal Pradesh and Rajasthan, and 12 in Jammu and Kashmir). The recommended dose of nitrogen application ranged from 120 to 300, 130 to 300, 100 and 120 to 210 kg/ha with mean value of 199, 220, 100 and 163 kg/ha for rice–rice, rice–wheat, rice–green gram and maize–wheat systems respectively, across the locations. Similarly, the recommended dose of P ranged from 60 to 120, 60 to 120, 80 and 70 to 85 kg/ha with a mean value of 138, 122, 110 and 93 kg P_2O_5/ha, while K ranged from 60 to 120, 35 to 100, 60 to 80 and 40 to 70 kg K_2O/ha with a mean value of 44, 34, 30 and 30 kg/ha respectively, for the systems. Rice equivalent yield of other crops was calculated by multiplying the yield of the respective crops with their price and then dividing by the price of rice. Rice equivalent yields were totalled and expressed as rice equivalent system yield (RESY). NOE was calculated in terms of partial factor productivity (PFP) and agronomic efficiency (AE). PFP, a ratio of grain yield to native + applied nutrient, is a useful measure of NUE. It is possible to increase PFP by increasing the amount, uptake and utilization of native nutrients, and also the competence with which the applied nutrients are consumed by the crops and utilized to convert solar energy in chemical energy to produce grains[6]. PFP of nitrogen was worked out as $PFP_n = Y_n/F_n$, Y_{np}/F_n, Y_{nk}/F_n and Y_{npk}/F_n for the respective treatments. PFP of phosphorus was calculated by $PFP_p = Y_{np}/F_p$ and Y_{npk}/F_p, while PFP of potassium was calculated as $PFP_k = Y_{nk}/F_k$ and Y_{npk}/F_k, where PFP_n, PFP_p and PFP_k are PFP of N, P_2O_5 and K_2O respectively; Y_n, Y_{np}, Y_{nk} and Y_{npk} are the yields of the respective treatments (N alone, N with P, N with K and N with P and K) and F_n, F_p and F_k are the amounts of applied N, P_2O_5 and K_2O respectively. All these values are in kg/ha. PFP can be calculated for a single, combined application of nutrients or for a fertilizer per se. AE (kg grain/kg nutrient applied), an incremental competence from applied nutrients of N, P, K over control, was calculated as: $AE_n = (Y_n - Y_o)/F_n$, $(Y_{np} - Y_o)/F_n$, $(Y_{nk} - Y_o)/F_n$ and $(Y_{npk} - Y_o)/F_n$ for the respective treatments. AE of P was calculated as $AE_p = (Y_{np} - Y_o)/F_p$, $(Y_{npk} - Y_o)/F_p$ while AE of K was calculated as $AE_k = (Y_{nk} - Y_o)/F_k$ and $(Y_{npk} - Y_o)/F_k$ where, AE_n, AE_p and AE_k are AE of applied nutrients in terms of nitrogen, phosphorus and potassium: Y_o, Y_n, Y_{np}, Y_{nk} and Y_{npk} are the yields of the respective treatments (control, N alone, N with P, N with K, N with P and K, NPK + micronutrients and farmer practice), and F_n, F_p and F_k are the amounts of applied N, P_2O_5 and K_2O respectively. Indigenous nutrient supplying ability of the soil was estimated by deducting AE from PFP for the respective nutrients[7]. AE is the same as 'crop response ratio' or productivity index used by FAO[8] and can be calculated for a single nutrient (N, P or K), for combined application of nutrients (NP, NK, PK or NPK) or for a fertilizer per se. Relative yield responses to different nutrient combinations were calculated using the following formula: (grain yield (treatment X) – grain yield (control))/grain yield (control), where treatment X represents N, NP, NK, NPK application, NPK + micronutrient and farmer practice[9]. Economic assessment of the treatments was done by marginal analysis. The cost of cultivation of different food production systems was calculated on the basis of different farm operations performed and inputs used for growing the crops and using the nutrient-based subsidy rates of the Government of India[10]. Accordingly, Rs 27.481/kg, Rs 29.407/kg and Rs 24.628/kg was used for N, P and K respectively. Marginal returns (MR) for the treatment over control were worked out as $MR = [(NR_t - NR_c)/(CC_t - CC_c)] \times 100$, where NR_t and NR_c are net returns of treatment and control respectively, while CC_t and CC_c are cost of cultivation of treatment and control respectively. Descriptive statistical analysis was used for measured and estimated parameters to establish the range of variability and deviation using standard error of mean.

All the cereal-based systems responded positively to the balanced application of recommended quantity of NPK + supplementation of deficient micronutrients. Among the various systems, rice–rice recorded higher RESY of 10,512 kg/ha with recommended quantity of NPK + supplementation of location-specific deficient micronutrients followed by rice–wheat (10,448 kg/ha), rice–green gram (8376 kg/ha) and maize–wheat (6584 kg/ha) systems. Application of recommended quantity of nutrients to maize–wheat system recorded 147.1% higher RESY over control, followed by 128.6% and 99.9% in rice–wheat and rice–rice systems respectively. Rice–green gram system recorded only 51.8% increase in RESY (Table 1). Similarly, balanced dose of application of NPK registered increase in RESY to the tune of 56.5%, 47.4%, 45.3% and 25.7% in maize–wheat, rice–wheat, rice–rice and rice–green gram systems respectively, compared to application of N alone to these systems. It was found that application of NPK gave 387, 1272, 827 and 2295 kg/ha higher yield over the farmer practice, which can be further increased up to 1192, 2059, 1073 and 2636 kg/ha in rice–rice, rice–wheat, rice–green gram and maize–wheat systems respectively with the addition of soil test-based micronutrients. On an average, an additional yield (RESY) of 2780 kg/ha can be obtained by application of recommended dose of NPK instead of application of N alone, which can be further increased up to 3451 kg/ha by inclusion of deficient micronutrients to the cereal-based systems. Also, maize–wheat system is comparatively better as it increased the yield by 147.1% with recommended quantity of NPK + supplementation of location-specific deficient micronutrients over control, and by 56.5% over application of N alone. It was also observed that 66.7%, 24.54%, 17.2% and 12.8% higher yield can be obtained by application of recommended dose of NPK and addition of deficient micronutrients over farmer practices in maize–wheat, rice–wheat, rice–rice and rice–green gram systems respectively. The better yield observed in balanced application of NPK to all the systems can be attributed to the involvement of P in better root development and subsequent absorption of N, while K is involved in N metabolism in cereals. Balanced NPK fertilization is essential in crops to achieve the targeted yield and enhance the productivity[11–14].

PFP was found to be higher under balanced nutrient application in all the systems compared to application of N alone or NP and NK, and it can be further increased by application of deficient micronutrients. On an average, 10–15% increase in PFP_n was observed with the application

Table 1. Rice equivalent system yield (RESY; kg/ha) of cereal-based cropping systems as influenced by nutrient application

Cropping system	Control	Rice equivalent yield (kg/ha)					
		N	NP	NK	NPK	NPK + micronutrients	Farmer practice
Rice–rice	5258 ± 270	6681 ± 540	7996 ± 813	8542 ± 599	9706 ± 1128	10512 ± 1009	9320 ± 1144
Rice–wheat	4570 ± 596	6554 ± 805	8557 ± 867	7768 ± 895	9661 ± 948	10448 ± 1057	8389 ± 1067
Rice–green gram	3595 ± 439	5262 ± 471	6652 ± 731	6348 ± 669	7833 ± 820	8376 ± 860	6679 ± 920
Maize–wheat	2664 ± 655	3989 ± 956	5313 ± 1364	4826 ± 1183	6243 ± 1545	6584 ± 1637	3948 ± 780

of deficit micronutrients in cereal-based systems. Highest increase in PFP_n was recorded in maize–wheat (64.1%) over N alone followed by rice–wheat (60.6%) and rice–rice (59.7%) systems. The increase in efficiency of N was observed in all the systems by way of combining recommended quantities of P and K with nitrogen application. Similarly, the recovery of P and K was higher when applied together with N in all the systems. Among the different systems, rice–rice recorded higher PFP_p (103.5 kg/kg of P with NK) followed by rice–wheat (101.4 kg/kg of P with NK (Supplementary Table 2). However, PFP_k was higher in rice–wheat system (146.4 kg/kg of K with NP) followed by rice–rice and maize–wheat systems. Balanced application of nutrients has helped in better recovery of N, P and K from native soil as well as from the applied fertilizers, as is evident from PFP analysis of nutrients in major cereal-based systems. The recovery of N from fertilizers increased from 16% at conventional NP fertilization to 76% at balanced NPK supply[15].

Small, marginal and dryland farmers have a tendency to apply only N. However, AE_n of applied N can be improved several folds by adequate P, K and micronutrients application. Improvement in AE_n was found to be 297% (Supplementary Table 3) in rice–rice system with balanced nutrients having NPK and micronutrients instead of N alone as being practised in many regions with the cereal-based systems. Rice–green gram system recorded improvement of 210% in AE_n with P, K and micronutrients followed by maize–wheat and rice–wheat systems (204% and 201% respectively). AE_p was found to be better in all the systems when P was applied with N, K and micronutrients rather than N alone, which can be attributed to positive interaction effect of these nutrients in the growth and development of plants; the same result was found in case of K as well. Increased recovery of K due to balanced application was found in rice–wheat system (86%) compared to other systems. On an average, AE_n, AE_p and AE_k can be increased to the tune of 90.3%, 90.6% and 89.6% over the farmer practices by balance application of NPK along with deficient micronutrients in the cereal crop-based systems.

Relative response (RR) of balanced application of nutrients along with micronutrients over control also exhibited similar trend as that of PFP and AE. Relative response of application of NPK + deficient micronutrients over control was found to be 1.00, 1.35, 0.51 and 1.48 in rice–rice, rice–wheat, rice–green gram and maize–wheat systems respectively, which is higher than N, NP, NK, NPK and farmer practice. Relative response almost doubled in all the systems compared to farmer practice. Among the various systems evaluated, maize–wheat recorded higher relative response with NPK + micronutrients over control, which is mainly due to higher and efficient utilization of nutrients by this system, as also evident from higher PFP of N and K. Inclusion of green gram led to higher supply of native soil N to the rice–green gram system (48 kg RESY/kg of native nutrient), which is two times more than other systems (Table 2). Among the different systems, higher P and K supply from soil was observed in rice–rice and rice–green gram systems (Supplementary Table 4). In case of rice–green gram system, 1 kg of native N, P and K contributed to 48.0, 60.0 and 68.7 kg RESY respectivey. Balanced application ensures higher responses of nutrients in cereal-based system[16].

Cost of cultivation was higher in balanced application of nutrients along with micronutrients in all the systems. It ranged from Rs 46,451/ha in maize–wheat to as high as Rs 82,024/ha in rice–rice system (Supplementary Table 5). However, the net returns were found to be much higher in all the systems under NPK + micronutrients application compared to control, N alone, NP, NK, NPK and farmer practice. The increase in net returns under NPK + micronutrients over farmer practice was found to be 24.9%, 63.3%, 27.4% and 92.2% in rice–rice, rice–wheat, rice–green gram and maize–wheat systems respectively (Supplementary Table 6), while increase in the cost of cultivation due to balanced application was found to be only 4.8%, 7.3%, 13.0% and 17.9% for the respective systems. Marginal returns (MR) were found to be higher with combined application of NPK than N alone, NP and NK (Table 3). Among the different systems, maize–wheat recorded highest (476%) MR under balanced application followed by rice–rice (426%), rice–green gram (339%) and rice–wheat (254%) systems.

Comparison of application of nutrients by farmers and recommended dose, revealed a wider gap in K and micronutrients in all the cereal-based systems. It was found that farmer practice completely excluded application of K_2O in rice–wheat and maize–wheat systems; farmers applied only suboptimal dose in case of N and P_2O_5

Table 2. Relative response of treatments over control of cereal-based cropping systems as influenced by nutrient application

Cropping system	Relative response					
	N alone	With P	With K	With PK	With NPK + m*	With farmer practice *
Rice–rice	0.26 ± 0.05	0.51 ± 0.13	0.62 ± 0.08	0.84 ± 0.20	1.00 ± 0.18	0.79 ± 0.24
Rice–wheat	0.44 ± 0.07	0.92 ± 0.12	0.72 ± 0.08	1.12 ± 0.13	1.35 ± 0.16	0.84 ± 0.10
Rice–green gram	0.17 ± 0.01	0.31 ± 0.03	0.32 ± 0.02	0.46 ± 0.04	0.51 ± 0.04	0.28 ± 0.07
Maize–wheat	0.51 ± 0.12	1.02 ± 0.33	0.81 ± 0.22	1.36 ± 0.33	1.48 ± 0.35	0.57 ± 0.17

Table 3. Marginal returns (MR) (%) due to application of N with P and K over control in cereal-based cropping systems

Cropping system	MR (%)					
	N alone	With P	With K	With PK	with NPK + m*	With farmer practice
Rice–rice	202	242	342	305	285	266
Rice–wheat	1032	560	821	653	600	493
Rice–green gram	279	113	189	144	139	177
Maize–wheat	641	593	709	643	605	683

(Supplementary Table 7). On an average 24.18%, 29.6%, 78.4% and 100% less application of N, P_2O_5, K_2O and micronutrients was observed in major cereal-based systems (Supplementary Table 8). Application of N alone or with P and with K recorded lower marginal returns in all the systems compared to balanced application of nutrients. In many parts of the country, application of only N or P is reported in cereal-based systems; hence, full potential of the applied N or P is not realized[17].

In order to increase the use efficiency and returns from the investment made on nutrients, balanced application of recommended quantity of NPK with micronutrients is essential. Thus, it can be concluded that application of recommended quantity of nitrogen, phosphorus and potassium together with supplementation of location-specific deficient micronutrient is essential for realizing higher production, increased efficiency of applied and native nutrients, and enhancing MR in major food production systems of the country.

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