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Research Paper

Site specific nutrient management for yield maximization in rice (*Oryza sativa*)–wheat (*Triticum aestivum*) cropping system in north-western Himalayas

S.S. RANA[1], S.K. SUBEHIA[2], RAMESH[3] AND S.C. NEGI[4]

Choudhary Sarvan Kumar Himachal Pradesh Krishi Vishvavidyalaya, Palampur, Himachal Pradesh 176 062

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ABSTRACT

A field experiment was conducted in a permanent layout for 7 consecutive years (rainy season 2007 to winter season (2010) at Palampur for yield maximization of rice (*Oryza sativa* L.)–wheat (*Triticum aestivum* L.) cropping system through site-specific nutrient management. Twelve combinations of primary, secondary and micronutrients [T_1, $N_{100}P_{25}K_{120}S_{40}B_5Zn_{20}$, (figure as subscript indicate dose in kg/ha of N, P_2O_5, K_2O, S, Borax and $ZnSO_4$, respectively) T_2, $N_{100}P_{50}K_{120}S_{40}B_5Zn_{20}$; T_3, $N_{100}P_0K_{120}S_{40}B_5Zn_{20}$; T_4, $N_{100}P_{25}K_{80}S_{40}B_5Zn_{20}$; T_5, $N_{100}P_{25}K_{40}S_{40}B_5Zn_{20}$; T_6, $N_{100}P_{25}K_0S_{40}B_5Zn_{20}$; T_7, $N_{100}P_{25}K_{120}S_{40}B_5Zn_0$; T_8, $N_{100}P_{25}K_{120}S_{40}B_0Zn_{20}$; T_9, $N_{100}P_{25}K_{120}S_0B_5Zn_{20}$; T_{10}, $N_{100}P_{25}K_{120}S_0B_0Zn_0$; T_{11}, RDF, (recommended dose of fertilizers, $N_{90}P_{40}K_{40}$ for rice and $N_{120}P_{60}K_{30}$ for wheat) and T_{12}, INM (integrated nutrient management, $N_{36}P_{16}K_{16}$ + 5 t FYM/ha for rice and $N_{48}P_{24}K_{12}$ + 5 t FYM/ha for wheat]-based upon the available nutrient status of the site were evaluated. N, P and K were applied to both the crops. S, B and Zn were applied to rice only. State recommended application of nutrients (T_{11}) maintained its superiority for rice grain yield initially, however, $N_{100}P_{25}K_{120}S_0B_0Zn_0$ (T_{10}) excelled over it at last. INM practice (T_{12}) was lowest yielder in the early years but at last next only after $N_{100}P_{25}K_{120}S_0B_0Zn_0$ and RDF. The complete deletion of K application from $N_{100}P_{25}K_{120}S_{40}B_5Zn_{20}$ under T_6, resulted in significantly the lowest rice yield. In increasing wheat yield, $N_{100}P_{50}K_{120}S_{40}B_5Zn_{20}$ maintained its superiority throughout and therefore, had the highest sustainable yield index. This was followed by $N_{100}P_{25}K_{120}S_0B_0Zn_0$, RDF and $N_{100}P_{25}K_{120}S_{40}B_5Zn_0$ both in terms of yield and sustainability. The system productivity (rice + wheat grain) ranged between 5.0 ($N_{100}P_{25}K_{120}S_0B_0Zn_0$) to 12.7 t/ha ($N_{100}P_{50}K_{120}S_{40}B_5Zn_{20}$) under different treatments. The system productivity and sustainability index was higher under $N_{100}P_{50}K_{120}S_{40}B_5Zn_{20}$, RDF and $N_{100}P_{25}K_{120}S_0B_0Zn_0$ over other treatments. Among the soil properties, *p*H decreased significantly over the initial test value of 5.3 in all the treatments except INM (T_{12}). A definite build up of organic carbon over its initial value of 0.7% was observed in $N_{100}P_{25}K_{80}S_{40}B_5Zn_{20}$, $N_{100}P_{25}K_{40}S_{40}B_5Zn_{20}$, $N_{100}P_{25}K_{120}S_0B_0Zn_0$, RDF and INM treatment. There was depletion of available P in all the treatments over its initial test value of 50 kg/ha. There was significant build up of available K in $N_{100}P_{25}K_{120}S_{40}B_5Zn_{20}$, $N_{100}P_0K_{120}S_{40}B_5Zn_{20}$, $N_{100}P_{25}K_{120}S_{40}B_5Zn_0$, $N_{100}P_{25}K_{120}S_{40}B_0Zn_{20}$ and INM treatment over the initial status of 86 kg/ha. Available K was significantly low where no K or low K was applied. $N_{100}P_{25}K_{120}S_0B_0Zn_0$ gave the highest benefit: cost ratio of 3.07 and was comparable to RDF in influencing total net returns. $N_{100}P_{50}K_{120}S_{40}B_5Zn_{20}$ resulted in the highest total apparent nutrient recovery, apparent N recovery and N physiological productivity. P physiological productivity was the highest under RDF and K physiological productivity was the highest under $N_{100}P_{25}K_0S_{40}B_5Zn_{20}$.

Key words: Economics, Nutrient uptake, Rice-wheat cropping system, SSNM, Sustainability, Yield,

Rice–wheat occupies 10.5 million ha productive lands in Indo-Gangetic plains and contributes about 25% of the national food production (Ladha *et al.*, 2000 and Prasad, 2005). In Himachal Pradesh, rice and wheat are grown on 76.7 and 381.2 thousand ha area with production of 118.3 and 381.2 thousand tonnes and productivity of 1.54 and 1.06 t/ha, respectively. Balanced application and efficient utilization of plant nutrients are essential for increasing the productivity in sustainable way. Ever since the introduction of high yielding varieties, the production and productivity have increased substantially. However, the soils are now not able to sustain the production at a reasonable level even with application of very high doses of NPK. The deficiency of secondary and micronutrients have turned out to be yield limiting factors. Kanwar *et al.* (2004) have documented that 62.5% surface soil in cauliflower growing area of Himachal Pradesh was low in

[1]**Corresponding author's Email:** ranass_dee@yahoo.com
[1]Senior Scientist, [2]Principal Scientist, [3]Ph.D. Student, [4]Principal Scientist, Choudhary Sarvan Kumar Himachal Pradesh Krishi Vishvavidyalaya, Palampur, Himachal Pradesh 176 062

available B. Deficiency of Zn has also been recognized as a widespread nutritional problem throughout the world (Reddy, 2004; Rashid and Ryan, 2004). The current and generalized fertilizer recommendations, which were developed decades ago were no longer valid and there is a need for site specific nutrient management which accommodates field-specific needs of crop for supplemental nutrient requirements. Site-specific nutrient management (SSNM) is a widely used term, generally with reference to addressing nutrient deficiencies which exist within fields and making adjustments in nutrient application to match these location or soil differences. In the soil test based SSNM approach (Johnston *et al*., 2009), the fertilizer rates are established based on the concept of crop removal adjusting the soil residual nutrients. In this approach, both the macro and secondary nutrients are applied at rates that are required to meet the crop yield removal and micronutrients were applied at blanket recommendations when the soil testing shows to be marginal or deficient. This allows complete yield expression of crop in the absence of any nutrient deficiency and once the yield potential of a site was determined, the next step is to refine nutrient application rates with further field trials. Chatterjee and Sanyal (2007) outlined an approach for site-specific K recommendations based on the soil test results, wherein the K rates were calculated by computing a factor with respect to available and non-exchangeable pools of K to maintain the balance between K mining and a productivity target. Majority of plant nutrient elements have positive interaction. Therefore, to increase the overall nutrient-use efficiency, alleviation of deficiency of various nutrient elements is more critical than application of high doses of NPK only. In view of these facts, a field experiment was conducted to explore the yield potential of the rice-wheat system.

MATERIALS AND METHODS

A field experiment was conducted in a permanent layout for 7 consecutive years (rainy season 2003–winter 2010) at the research farm (Padiarkhar) of the Farming System Research Centre, Palampur situated at (32°6' N latitude and 76°3' E longitude) to find out sustainable site specific nutrient management system in rice–wheat cropping system under mid hills conditions of Himachal Pradesh. The site (Palampur) lies in sub-temperate humid zone of Himachal Pradesh (NARP zone II), which is characterized by mild summer and severe winter as well as occasional snowfall during winter. The region receives an average rainfall of 2600 mm/annum, major portion of which (80%) is received during June–September (south-west monsoon). Winter rains are received during December–February (north-east monsoon). Taxonomically the soils of the region are classified as 'Typic Hapludalf' (Verma 1979). The soil of the experimental field was silty clay loam in texture, with organic matter content of 0.7% and *p*H 5.3. Available N, P, K, Ca, Mg and S contents were 207 (low), 50 (high), 86 (low), 1170, 104 and 156 kg/ha, respectively. The Zn, Cu, Fe, Mn and B contents were 1.997, 5.293, 193.74, 11.934 and 0.999 ppm, respectively. Twelve nutrient management treatments [T_1, $N_{100}P_{25}K_{120}S_{40}B_5Zn_{20}$, figure as subscript indicate dose in kg/ha of N, P_2O_5, K_2O, S, Borax and $ZnSO_4$ respectively; T_2, $N_{100}P_{50}K_{120}S_{40}B_5Zn_{20}$; T_3, $N_{100}P_0K_{120}S_{40}B_5Zn_{20}$; T_4, $N_{100}P_{25}K_{80}S_{40}B_5Zn_{20}$; T_5, $N_{100}P_{25}K_{40}S_{40}B_5Zn_{20}$, T_6, $N_{100}P_{25}K_0\ S_{40}B_5Zn_{20}$; T_7, $N_{100}P_{25}K_{120}S_{40}B_5Zn_0$; T_8, $N_{100}P_{25}K_{120}S_{40}B_0Zn_{20}$; T_9, $N_{100}P_{25}K_{120}S_0B_5Zn_{20}$; T_{10}, $N_{100}P_{25}K_{120}S_0B_0\ Zn_0$; T_{11}, RDF, Recommended dose of fertilizers ($N_{90}P_{40}K_{40}$ for rice and $N_{120}P_{60}K_{30}$ for wheat), T_{12}, 40% of recommended NPK + 5 t FYM/ha (on dry weight basis) to each crop] were evaluated in randomized block design with 4 replications. 25–30 days old seedlings of rice 'Hybrid PHB 71' from 2003 to 2006 and 'Arize 6129' from 2007 to 2009) were transplanted from last week of June to first fortnight of July and wheat (variety 'Surabhi' in 2003–04, 'HPW 42' in 2007–08 and 'HPW 155' in rest of the seasons) crop was sown on second week of November to first week of December. The nutrients were applied as per the treatment (Table 1). N, P and K were applied to both the crops (through urea, di-ammonium phosphate, single superphosphate, muriate of potash as per the treatment). S, B and Zn (from T_1, T_9) were applied only to rice. S and B were applied through elemental sulphur and borax, respectively. Zn was applied through $ZnSO\text{-}_4$ for the first three years and through ZnO (equivalent quantity of Zn as in $ZnSO_4$) during rest of the years. In rice, N was applied in two splits (first half at last puddling and second at panicle initiation stage). In wheat, it was in three equal splits (one-third each at sowing, crown root initiation and tillering). The rest of the nutrients (P, K, S, B and Zn) were applied at sowing. Each season during 2007–08 and 2008–09, FYM at 5 t/ha was also applied to all the treatments. The rest of the package of practices was followed as per the recommendations for individual crops (HPKV, 1998a&b).

Yields were harvested from net plot (rice 15 m^2 and wheat 11 m^2). Different soil chemical parameters, viz. *p*H (Jackson 1967), organic carbon (Piper 1966) and available N (Subbiah and Asija 1956), P (Olsen *et al.* 1954) and K (AOAC 1970) were estimated following standard procedures. To find out treatment differences, pooled analysis of grain and straw yield data from 2003–04 to 2009–10 was done and results were compared using critical difference at 5% level of significance (P=0.05). To minimize the year to year variation, 3 years moving averages were worked out. Sustainable yield index (SYI) was determined using standard procedure as below:

$$SYI = \frac{Y - SD}{Y_{max}}$$

Where, Y is the average yield of a treatment over years, SD its standard deviation and Y_{max} is the observed maximum yield in the experiment.

Economics of the treatments was computed based on prevalent market prices. The system profitability was obtained by dividing the net return (₹/ha) in a treatment by 365. Apparent nutrient productivity was calculated by dividing the total productivity (rice + wheat grain) with the total quantity of nutrients (NPKSBZn in the present study) applied (Yadav, 2003). Similarly apparent N productivity was obtained by dividing the total productivity (rice + wheat grain) with the total quantity of N applied. Physiological productivity was determined by dividing the total productivity (rice + wheat grain) with the total quantity of nutrients absorbed. Productivity cost (₹ invested/kg grain produced) was obtained by dividing the cost of cultivation of a treatment by the total productivity (rice + wheat grain) under that treatment.

RESULTS AND DISCUSSION

Yield and sustainability

The higher grain yields of rice were harvested during the middle years than initial and latter years (Fig.1). This was owing to application of FYM in the middle years and use of superior hybrid rice variety in the latter years. Across the years, rice grain yield ranged between 3.7 (T_6, $N_{100}P_{25}K_0S_{40}B_5Zn_{20}$ to rice and $N_{100}P_{25}K_0$ to wheat) and 9.5 t/ha (T_8, $N_{100}P_{25}K_{120}S_{40}B_0Zn_{20}$ to rice and $N_{100}P_{25}K_{120}$ to wheat) under different treatments (data not shown). State recommended application of nutrients (RDF, T_{11}, $N_{90}P_{40}K_{40}$ for rice & $N_{120}P_{60}K_{30}$ for wheat crop) maintained its superiority initially, however, T_{10} ($N_{100}P_{25}K_{120}$ to both rice and wheat) excelled over it at last. INM practice (T_{12}, $N_{36}P_{16}K_{16}$ + 5 t FYM/ha for rice and $N_{48}P_{24}K_{12}$ + 5 t FYM/ha for wheat crop) was the lowest yielder in the early years but at last next only after T_{10} ($N_{100}P_{25}K_{120}$ to both rice and wheat) and T_{11} (RDF). This may probably owing to con-

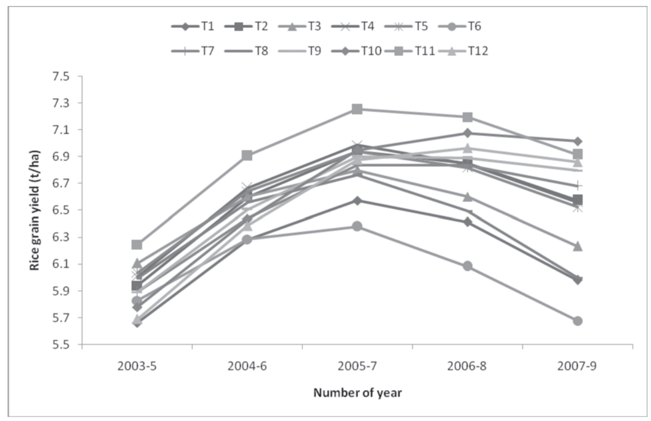

Fig. 1. Effect of SSNM on yield trend of rice from 2003–2010 under rice–wheat system

Table 1. Effect of site specific nutrient management on grain and straw yield (t/ha) of rice and wheat, system productivity (t/ha) and sustainability index under rice–wheat system (pooled data over 7 years)

Treatments	Yield (t/ha)										Sustainability index		
	2003				Pooled				System productivity		Rice	wheat	Rice + wheat
	Rice		Wheat		Rice		Wheat						
	Grain	Straw	Grain	Straw	Grain	Straw	Grain	Straw	2003	Pooled			
T_1, $N_{100}P_{25}K_{120}S_{40}B_5Zn_{20}$	4.96	8.03	3.57	4.99	6.03	8.61	3.56	6.26	8.54	9.59	0.78	0.63	0.77
T_2, $N_{100}P_{50}K_{120}S_{40}B_5Zn_{20}$	5.10	7.73	3.51	5.26	6.52	9.44	4.36	6.65	8.60	10.87	0.85	0.71	0.85
T_3, $N_{100}P_0K_{120}S_{40}B_5Zn_{20}$	5.26	7.56	2.80	4.49	6.32	9.44	3.60	5.41	8.06	9.92	0.82	0.62	0.80
T_4, $N_{100}P_{25}K_{80}S_{40}B_5Zn_{20}$	5.36	7.63	3.87	5.92	6.54	9.56	3.67	5.95	9.23	10.21	0.86	0.62	0.81
T_5, $N_{100}P_{25}K_{40}S_{40}B_5Zn_{20}$	5.61	7.50	2.85	3.98	6.51	8.80	3.74	5.84	8.46	10.25	0.85	0.63	0.81
T_6, $N_{100}P_{25}K_0S_{40}B_5Zn_{20}$	5.39	7.60	3.28	5.15	5.87	8.22	3.39	4.61	8.67	9.25	0.75	0.56	0.74
T_7, $N_{100}P_{25}K_{120}S_{40}B_5Zn_0$	5.70	7.46	3.48	5.28	6.54	9.49	3.91	6.73	9.18	10.45	0.86	0.65	0.82
T_8, $N_{100}P_{25}K_{120}S_{40}B_0Zn_{20}$	5.34	7.99	3.42	4.78	6.15	9.19	3.70	6.23	8.75	9.85	0.78	0.61	0.79
T_9, $N_{100}P_{25}K_{120}S_0B_5Zn_{20}$	4.98	7.01	4.01	5.67	6.63	9.96	3.62	6.00	8.99	10.25	0.87	0.60	0.80
T_{10}, $N_{100}P_{25}K_{120}S_0B_0Zn_0$	4.98	7.35	2.86	3.97	6.73	9.37	4.08	6.61	7.84	10.81	0.86	0.64	0.81
T_{11}, RDF	5.18	6.98	3.76	5.56	6.84	9.31	4.00	6.04	8.94	10.84	0.90	0.65	0.85
T_{12}, INM	4.31	7.18	2.64	3.73	6.61	9.72	3.58	6.50	6.96	10.19	0.85	0.58	0.78
SEm±	0.21	0.33	0.23	0.47	0.08	0.17	0.05	0.08	0.35	0.12	-	-	-
CD (P=0.05)	0.62	NS	0.66	1.34	0.23	0.49	0.15	0.21	1.00	0.34	-	-	-

N, P and K were applied to both crops and S, B and Zn were applied only to rice; RDF, recommended dose of fertilizers; $N_{90}P_{40}K_{40}$ for rice and $N_{120}P_{60}K_{30}$ for wheat crop); INM, integrated nutrient management ($N_{36}P_{16}K_{16}$ + 5 t FYM/ha for rice and $N_{48}P_{24}K_{12}$ + 5 t FYM/ha for wheat crop.

tinue addition of FYM, which might have improved the physicochemical properties of soil that resulted in increased productivity (Chaudhary and Thakur, 2007). Further, the organic matter supplies macro and micronutrients and several complexing agents, which maintain balanced supply of nutrients to crop. These results are also in conformity with the earlier findings (Gupta *et al.* 2006; Sharma *et al.*, 2005 and Urkurkar *et al.,* 2010). Application of $N_{100}P_{25}K_{120}S_0B_5Zn_{20}$ to rice and $N_{100}P_{25}K_{120}$ to wheat; T_9, $N_{100}P_{25}K_{120}S_{40}B_5Zn_0$ to rice and $N_{100}P_{25}K_{120}$ to wheat; and T_7, $N_{100}P_{50}K_{120}S_{40}B_5Zn_{20}$ to rice and $N_{100}P_{50}K_{120}$ to wheat T_2 were the other superior treatments in influencing rice yield in the latter years. Recommended dose of fertilizers T_{11}, $N_{90}P_{40}K_{40}$ for rice & $N_{120}P_{60}K_{30}$ for wheat crop) was at par with T_{10}, $N_{100}P_{25}K_{120}$ to both rice and wheat; and T_9, $N_{100}P_{25}K_{120}S_0B_5Zn_{20}$ to rice and $N_{100}P_{25}K_{120}$ to wheat, resulted in significantly higher pooled grain yield of rice over other treatments. Application of $N_{100}P_{25}K_{120}S_0B_5Zn_{20}$ to rice and $N_{100}P_{25}K_{120}$ to wheat T_9, being at par to $N_{36}P_{16}K_{16}$ + 5 t FYM/ha for rice and $N_{48}P_{24}K_{12}$ + 5 t FYM/ha for wheat crop) was significantly superior to other treatments in influencing rice straw yield. Potassium is indispensable in rice plant nutrition (Satyanarayana *et al.* 2011). The complete deletion of potassium application from $N_{100}P_{25}K_{120}S_{40}B_5Zn_{20}$ (i.e. T_6, $N_{100}P_{25}K_0S_{40}B_5Zn_{20}$ to rice $N_{100}P_{25}K_0$ to wheat) resulted in significantly lowest rice yield. Puddling and subsequent land submergence has a major role in increasing the availability of nutrients especially P (Reddy, 2004). It is pertinent to highlight that even in the absence of P application in $N_{100}P_0K_{120}S_{40}B_5Zn_{20}$ to rice (T_3) and $N_{100}P_0K_{120}$ to wheat (T_3), rice yield was comparable as under T_2, ($N_{100}P_{50}K_{120}S_{40}B_5Zn_{20}$ to rice and $N_{100}P_{50}K_{120}$ to wheat), where P was applied at 50 kg P_2O_5/ha along with other nutrients. This also showed that under conditions of puddling and subsequent land submergence, P application in soils high in P content can be curtailed. Recommended dose of fertilizers (T_{11}) had the highest sustainable yield index (rice) and was followed by T_9, $N_{100}P_{25}K_{120}S_0B_5Zn_{20}$ to rice and $N_{100}P_{25}K_{120}$ to wheat; T_{10}, $N_{100}P_{25}K_{120}$ to both rice and wheat; T_7, $N_{100}P_{25}K_{120}S_{40}B_5Zn_0$ to rice and $N_{100}P_{25}K_{120}$ to wheat); T_2, $N_{100}P_{50}K_{120}S_{40}B_5Zn_{20}$ to rice and $N_{100}P_{50}K_{120}$ to wheat and T_3, $N_{100}P_0K_{120}S_{40}B_5Zn_{20}$ to rice and $N_{100}P_0K_{120}$ to wheat, in that order.

Wheat yield was progressively higher over the years (Fig. 2). It ranged from 1.2 (T_6 - $N_{100}P_{25}K_0S_{40}B_5Zn_{20}$ to rice $N_{100}P_{25}K_0$ to wheat) to 5.1 t/ha (T_2- $N_{100}P_{50}K_{120}S_{40}B_5Zn_{20}$ to rice and $N_{100}P_{50}K_{120}$ to wheat) under different treatments. T_2 ($N_{100}P_{50}K_{120}S_{40}B_5Zn_{20}$ to rice and $N_{100}P_{50}K_{120}$ to wheat) where higher P was applied, maintained its superiority throughout and therefore, had the highest sustainable yield index (wheat). The importance of P nutrition in wheat in the rice–wheat system has been documented (Ladha *et al.* 2000 and Prasad 2005). This was followed by T_{10} ($N_{100}P_{25}K_{120}$ to both rice and wheat), T_{11} (RDF- $N_{90}P_{40}K_{40}$ for rice and $N_{120}P_{60}K_{30}$ for wheat crop) and T_7 ($N_{100}P_{25}K_{120}S_{40}B_5Zn_0$ to rice and $N_{100}P_{25}K_{120}$ to wheat) both in terms of yield and sustainability. T_{10} ($N_{100}P_{25}K_{120}$ to both rice and wheat) was superior to T_7 ($N_{100}P_{25}K_{120}S_{40}B_5Zn_0$ to rice and $N_{100}P_{25}K_{120}$ to wheat) in terms of wheat yield. T_6 ($N_{100}P_{25}K_0S_{40}B_5Zn_{20}$ to rice $N_{100}P_{25}K_0$ to wheat), where no K was applied had the lowest wheat grain and straw yield. The role of K in plant nutrition is indispensable and has been amply demonstrated (Sharma *et al.* 2003; Satyanarayana *et al.* 2011 and Reddy 2004).

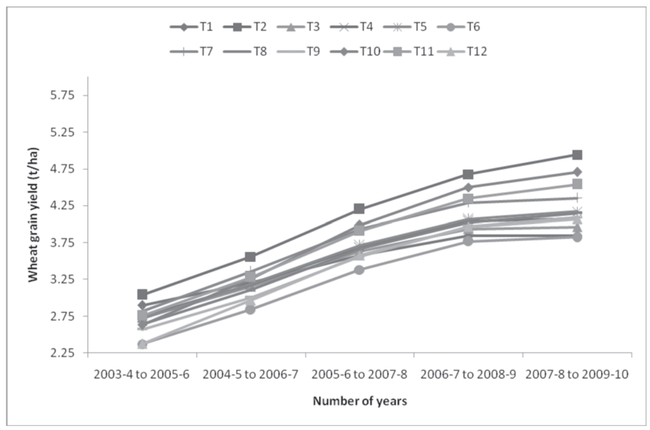

Fig. 2. Effect of SSNM on yield trend of wheat from 2003–04 to 2009–10 under rice–wheat system

Because of higher rice and wheat yield, the system productivity was significantly higher under T_2 ($N_{100}P_{50}K_{120}S_{40}B_5Zn_{20}$ to rice and $N_{100}P_{50}K_{120}$ to wheat), T_{11} ($N_{90}P_{40}K_{40}$ for rice & $N_{120}P_{60}K_{30}$ for wheat crop) and T_{10} ($N_{100}P_{25}K_{120}$ to both rice and wheat) over other treatments (Table 1, Fig. 3). These treatments also had higher sustainability index over other treatments. This may be

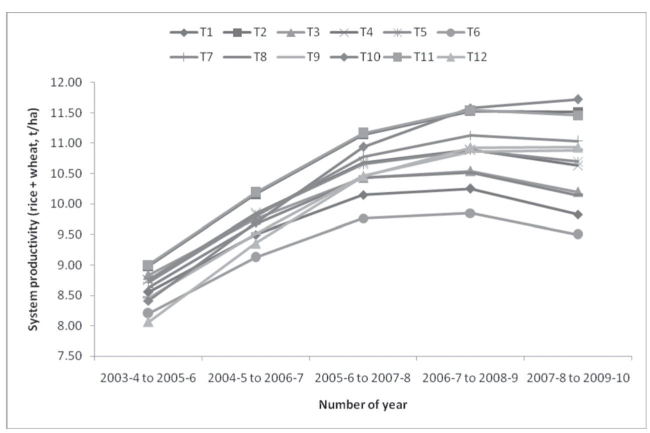

Fig. 3. Effect of SSNM on trend of system productivity (rice + wheat) from 2003–04 to 2009–10 under rice–wheat system

Table 2. Effect of SSNM on nutrient uptake (kg/ha) in rice and wheat under rice–wheat system (pooled data)

Treatment	Rice			Wheat			Total		
	Grain	Straw	Total	Grain	Straw	Total	Grain	Straw	Total
					Nitrogen				
T_1, $N_{100}P_{25}K_{120}S_{40}B_5Zn_{20}$	36.8	58.7	95.5	78.5	17.3	95.8	115.3	76.0	191.3
T_2, $N_{100}P_{50}K_{120}S_{40}B_5Zn_{20}$	49.0	63.0	112.0	100.6	21.8	122.5	149.6	84.8	234.4
T_3, $N_{100}P_0K_{120}S_{40}B_5Zn_{20}$	42.9	57.4	100.3	91.9	14.7	106.6	134.8	72.1	206.9
T_4, $N_{100}P_{25}K_{80}S_{40}B_5Zn_{20}$	46.1	71.9	118.0	89.2	20.6	109.8	135.3	92.6	227.9
T_5, $N_{100}P_{25}K_{40}S_{40}B_5Zn_{20}$	49.0	56.1	105.1	93.4	15.3	108.7	142.4	71.5	213.9
T_6, $N_{100}P_{25}K_0S_{40}B_5Zn_{20}$	45.0	57.3	102.4	73.9	13.4	87.3	118.9	70.7	189.7
T_7, $N_{100}P_{25}K_{120}S_{40}B_5Zn_0$	45.1	72.8	117.9	79.8	16.6	96.4	124.9	89.4	214.2
T_8, $N_{100}P_{25}K_{120}S_{40}B_0Zn_{20}$	42.8	65.3	108.1	80.1	15.0	95.1	122.9	80.3	203.3
T_9, $N_{100}P_{25}K_{120}S_0B_5Zn_{20}$	47.2	78.0	125.2	75.1	17.0	92.1	122.3	95.0	217.3
T_{10}, $N_{100}P_{25}K_{120}S_0B_0Zn_0$	49.8	62.1	112.0	95.8	17.3	113.2	145.7	79.5	225.1
T_{11}, RDF	47.7	69.0	116.7	90.9	14.9	105.8	138.6	83.9	222.5
T_{12}, INM	47.9	63.0	110.8	73.8	15.7	89.5	121.7	78.7	200.4
SEm±	1.2	2.3	2.5	1.6	0.9	2.0	2.1	2.3	3.6
CD (P=0.05)	3.3	6.4	7.1	4.5	2.7	5.6	6.0	7.9	10.2
					Phosphurus				
T_1, $N_{100}P_{25}K_{120}S_{40}B_5Zn_{20}$	14.1	7.0	21.1	10.2	2.5	12.6	24.3	9.5	33.8
T_2, $N_{100}P_{50}K_{120}S_{40}B_5Zn_{20}$	16.1	8.7	24.7	13.4	3.2	16.6	29.5	11.8	41.3
T_3, $N_{100}P_0K_{120}S_{40}B_5Zn_{20}$	14.4	8.3	22.6	10.5	2.1	12.6	24.9	10.3	35.3
T_4, $N_{100}P_{25}K_{80}S_{40}B_5Zn_{20}$	16.1	8.6	24.7	10.0	2.7	12.7	26.1	11.3	37.4
T_5, $N_{100}P_{25}K_{40}S_{40}B_5Zn_{20}$	16.5	7.2	23.7	10.8	2.8	13.5	27.2	10.0	37.2
T_6, $N_{100}P_{25}K_0S_{40}B_5Zn_{20}$	15.0	6.8	21.7	9.2	2.9	12.1	24.2	9.6	33.8
T_7, $N_{100}P_{25}K_{120}S_{40}B_5Zn_0$	16.7	8.2	24.9	10.6	3.1	13.7	27.2	11.3	38.6
T_8, $N_{100}P_{25}K_{120}S_{40}B_0Zn_{20}$	15.0	7.6	22.7	9.6	3.0	12.6	24.6	10.6	35.3
T_9, $N_{100}P_{25}K_{120}S_0B_5Zn_{20}$	16.8	7.9	24.7	10.2	2.5	12.8	27.0	10.5	37.5
T_{10}, $N_{100}P_{25}K_{120}S_0B_0Zn_0$	16.5	7.7	24.2	10.9	3.8	14.7	27.4	11.5	38.9
T_{11}, RDF	15.0	8.0	23.0	10.9	3.0	14.0	25.9	11.0	36.9
T_{12}, INM	16.4	8.2	24.6	9.9	4.6	14.5	26.3	12.8	39.2
SEm±	0.3	0.2	0.4	0.3	0.2	0.3	0.5	0.3	0.6
CD (P=0.05)	0.8	0.6	1.2	0.9	0.4	1.0	1.3	0.8	1.6
					Potassium				
T_1, $N_{100}P_{25}K_{120}S_{40}B_5Zn_{20}$	14.3	52.1	66.5	11.3	56.9	68.2	25.6	109.1	134.7
T_2, $N_{100}P_{50}K_{120}S_{40}B_5Zn_{20}$	14.7	62.2	77.0	14.5	61.2	75.6	29.2	123.4	152.6
T_3, $N_{100}P_0K_{120}S_{40}B_5Zn_{20}$	14.3	66.4	80.7	11.4	43.5	54.9	25.7	109.9	135.6
T_4, $N_{100}P_{25}K_{80}S_{40}B_5Zn_{20}$	14.4	65.4	79.7	11.6	50.9	62.5	26.0	116.2	142.2
T_5, $N_{100}P_{25}K_{40}S_{40}B_5Zn_{20}$	13.6	63.8	77.5	11.6	44.8	56.3	25.2	108.6	133.8
T_6, $N_{100}P_{25}K_0S_{40}B_5Zn_{20}$	12.3	54.0	66.2	10.2	34.3	44.5	22.5	88.3	110.8
T_7, $N_{100}P_{25}K_{120}S_{40}B_5Zn_0$	15.0	65.9	80.9	12.6	54.0	66.6	27.6	119.9	147.5
T_8, $N_{100}P_{25}K_{120}S_{40}B_0Zn_{20}$	13.4	61.5	74.9	11.5	49.8	61.2	24.9	111.2	136.2
T_9, $N_{100}P_{25}K_{120}S_0B_5Zn_{20}$	15.2	74.3	89.5	12.0	47.0	59.0	27.1	121.4	148.5
T_{10}, $N_{100}P_{25}K_{120}S_0B_0Zn_0$	14.1	66.6	80.7	12.8	53.9	66.7	26.9	120.5	147.4
T_{11}, RDF	17.1	61.0	78.2	13.0	48.0	61.0	30.1	109.0	139.2
T_{12}, INM	14.3	65.6	79.9	12.2	55.6	67.9	26.5	121.3	147.8
SEm±	0.4	1.7	1.8	0.2	0.7	0.8	0.5	2.1	0.2
CD (P=0.05)	1.0	4.8	5.0	0.6	2.0	2.3	1.4	5.8	6.3

RDF, Recommended dose of fertilizers ($N_{90}P_{40}K_{40}$ for rice & $N_{120}P_{60}K_{30}$ for wheat crop); INM, integrated nutrient management ($N_{36}P_{16}K_{16}$ + 5 t FYM/ha for rice and $N_{48}P_{24}K_{12}$ + 5 t FYM/ha for wheat crop).

attributed to balancing the nutrient pool. The balanced application of NPK and application of deficient S, B and Zn might have been tended to fetch the sustainable productivity. The lowest total productivity was under T_6, $N_{100}P_{25}K_0S_{40}B_5Zn_{20}$ to rice $N_{100}P_{25}K_0$ to wheat, which was lacking potassium supplementation through fertilizers. The total productivity (rice + wheat grain) ranged between 5.0 (T_{10}, $N_{100}P_{25}K_{120}$ to both rice and wheat)) to 12.7 t/ha (T_2, $N_{100}P_{50}K_{120}S_{40}B_5Zn_{20}$ to rice and $N_{100}P_{50}K_{120}$ to wheat) under different treatments. The total biological productivity under different treatments varied from 12.7 (T_6, $N_{100}P_{25}K_0S_{40}B_5Zn_{20}$ to rice $N_{100}P_{25}K_0$ to wheat) to 34.0 t/ha/annum (T_2, $N_{100}P_{50}K_{120}S_{40}B_5Zn_{20}$ to rice and $N_{100}P_{50}K_{120}$ to wheat).

Nutrient uptake

Generally nutrient uptake is a function of crop yield (grain + straw) and nutrient content. Therefore, it is expected that it should follow the trend of yield influenced by content. The total yearly uptake of N (r=0.880**, significant at 1% level of significance), P (r=0.837**) and K (r=0.779**) was significantly and positively associated with total rice + wheat grain yield. Total yearly uptake of N (r=0.582*, significant at 5% level of significance), P (r= 0.390) and K (r= 0.654*) was also positively associated with total yearly biomass production. T_2, ($N_{100}P_{50}K_{120}S_{40}B_5Zn_{20}$ to rice and $N_{100}P_{50}K_{120}$ to wheat) where higher P was applied, resulted in the highest total P uptake (Table 2). However, it was statistically at par with T_{10}, ($N_{100}P_{25}K_{120}$ to both rice and wheat) in influencing N and K uptake and T_9, ($N_{100}P_{25}K_{120}S_0B_5Zn_{20}$ to rice and $N_{100}P_{25}K_{120}$ to wheat) and T_{12}, ($N_{36}P_{16}K_{16}$ + 5 t FYM/ha for rice and $N_{48}P_{24}K_{12}$ + 5 t FYM/ha for wheat crop) in influencing K uptake. Of the total N uptake by rice and wheat, 37.7–46.6 and 81.2–86.2%, respectively, was accumulated by grain. The corresponding P uptake by grain was 63.7–69.6 and 68.3–83.3%, while K uptake was 17.0–21.9 and 16.6–22.9% respectively.

Soil fertility status

The data on physicochemical properties of soil after the completion of experimentation are given in Table 3. The soil *p*H varied from 4.73 in the T_3 ($N_{100}P_0K_{120}S_{40}B_5Zn_{20}$ to rice and $N_{100}P_0K_{120}$ to wheat) to 5.20 in the T_{12}, ($N_{36}P_{16}K_{16}$ + 5 t FYM/ha for rice and $N_{48}P_{24}K_{12}$ + 5 t FYM/ha for wheat crop). *p*H decreased significantly over the initial test value of 5.3 in all the treatments except in the INM treatment (T_{12}). In the INM practice (T_{12}) where integrated use of chemical and organic manures was done *p*H remained more or less similar to the initial test value. This may be due to moderating effect of direct (FYM) or indirect (higher root growth) addition of organic matter as it decreases the activity of exchangeable Al^{3+} ions in soil solution due to chelation effect of organic molecules (Sharma and Subehia 2003). Due to acid nature of fertilizers, all treatments had lower pH than INM practice inspite of addition of organic matter through root biomass. pH was more acidic in T_3, ($N_{100}P_0K_{120}S_{40}B_5Zn_{20}$ to rice and $N_{100}P_0K_{120}$ to wheat), T_2, ($N_{100}P_{50}K_{120}S_{40}B_5Zn_{20}$ to rice and $N_{100}P_{50}K_{120}$ to wheat) and T_8, ($N_{100}P_{25}K_{120}S_{40}B_0Zn_{20}$ to rice and $N_{100}P_{25}K_{120}$ to wheat) treatments.

A definite build up of organic carbon over its initial value of 0.7% was observed in T_4, ($N_{100}P_{25}K_{80}S_{40}B_5Zn_{20}$ to rice and $N_{100}P_{25}K_{80}$ to wheat); T_5, ($N_{100}P_{25}K_{80}S_{40}B_5Zn_{20}$ to rice and $N_{100}P_{25}K_{80}$ to wheat); T_{10}, ($N_{100}P_{25}K_{120}$ to both rice and wheat); T_{11}, (RDF); and T_{12}, (INM). Improvement in soil organic carbon status may be due to the stimulating effect of organics on growth and activity of microorganisms (Babhulkar *et al.* 2000) due to addition of organic matter mainly through roots. However, in other treatments OC did not vary significantly over its initial value.

After the 7 cropping cycles, there was improvement in available N over its initial value of 207 kg/ha. From the low available status, available N reached to medium status irrespective of the treatment. However, it was not significantly different due to treatments. Generally crop uptake for P exceeds that of its application rate in most of the treatments, thus there was depletion of available P in all the treatments over its initial test value of 50 kg/ha. The highest depletion was in the treatment where no P was applied i.e. T_3, ($N_{100}P_0K_{120}S_{40}B_5Zn_{20}$ to rice and $N_{100}P_0K_{120}$ to wheat). T_6, ($N_{100}P_{25}K_0S_{40}B_5Zn_{20}$ to rice and $N_{100}P_{25}K_0$ to wheat) and T_9, ($N_{100}P_{25}K_{120}S_0B_5Zn_{20}$ to rice and $N_{100}P_{25}K_{120}$ to wheat) treatments were statistically at par with respect to P status. There was significant build up of available K in T_1, ($N_{100}P_{25}K_{120}S_{40}B_5Zn_{20}$ to rice and $N_{100}P_{25}K_{120}$ to wheat); T_3, ($N_{100}P_0K_{120}S_{40}B_5Zn_{20}$ to rice and $N_{100}P_0K_{120}$ to wheat); T_7, ($N_{100}P_{25}K_{120}S_{40}B_5Zn_0$ to rice and $N_{100}P_{25}K_{120}$ to wheat); T_8, ($N_{100}P_{25}K_{120}S_{40}B_0Zn_{20}$ to rice and $N_{100}P_{25}K_{120}$ to wheat) and T_{12}, (INM) treatments over the initial status of 86 kg/ha. Available K was significantly low where no K or low K was applied i.e. T_6, ($N_{100}P_{25}K_0S_{40}B_5Zn_{20}$ to rice and $N_{100}P_{25}K_0$ to wheat); T_5, ($N_{100}P_{25}K_{40}S_{40}B_5Zn_{20}$ to rice and $N_{100}P_{25}K_{40}$ to wheat) and T_4, ($N_{100}P_{25}K_{80}S_{40}B_5Zn_{20}$ to rice and $N_{100}P_{25}K_{80}$ to wheat). In the remaining treatments available K content was fairly unchanged over its initial status.

Nutrient-use efficiency

INM practice (T_{12}) resulted in the highest apparent nutrient recovery followed by recommended dose of fertilizers (T_{11}) (Table 3). Apparent nitrogen recovery was also the highest under INM practice followed by T_2, ($N_{100}P_{50}K_{120}S_{40}B_5Zn_{20}$ to rice and $N_{100}P_{50}K_{120}$ to wheat); T_{10},

($N_{100}P_{25}K_{120}$ to both rice and wheat) and T_7, ($N_{100}P_{25}K_{120}S_{40}B_5Zn_0$ to rice and $N_{100}P_{25}K_{120}$ to wheat). Physiological productivity for N was the highest for INM practice (T_{12}), followed by T_1, ($N_{100}P_{50}K_{120}S_{40}B_5Zn_{20}$ to rice and $N_{100}P_{50}K_{120}$ to wheat). P-physiological productivity was the highest for RDF T_{11}, followed by T_1, ($N_{100}P_{25}K_{120}S_{40}B_5Zn_{20}$ to rice and $N_{100}P_{25}K_{120}$ to wheat); T_3, and T_9, ($N_{100}P_{25}K_{120}S_0B_5Zn_{20}$ to rice and $N_{100}P_{25}K_{120}$ to wheat). K-physiological productivity was also highest for T_6, ($N_{100}P_{25}K_0S_{40}B_5Zn_{20}$ to rice $N_{100}P_{25}K_0$ to wheat) followed by T_{11}, (RDF); T_5, ($N_{100}P_{25}K_0S_{40}B_5Zn_{20}$ to rice $N_{100}P_{25}K_0$ to wheat) and T_{10}, ($N_{100}P_{25}K_{120}$ to both rice and wheat).

Economics

Owing to higher yields, T_2 ($N_{100}P_{50}K_{120}S_{40}B_5Zn_{20}$ to rice and $N_{100}P_{50}K_{120}$ to wheat) and T_{10} ($N_{100}P_{25}K_{120}$ to both rice and wheat) were comparable to T_{11} (RDF, $N_{90}P_{40}K_{40}$ for rice & $N_{120}P_{60}K_{30}$ for wheat crop) in influencing total gross returns. However, T_2, ($N_{100}P_{50}K_{120}S_{40}B_5Zn_{20}$ to rice and $N_{100}P_{50}K_{120}$ to wheat) had higher cost of cultivation, therefore, only T_{10}, ($N_{100}P_{25}K_{120}$ to both rice and wheat) was

Table 3. Change in soil fertility status after the harvest of wheat (2010) from its initial soil status (2003) and nutrient use-efficiency of crops as influenced by site specific nutrient management

Treatment	*p*H	OC (%)	Available nutrient (kg/ha)			Apparent nutrient recovery (kg grain/kg nutrient applied)	Apparent N recovery (kg grain/ kg N applied)	Physiological productivity unit		
			N	P	K			N	P	K
T_1, $N_{100}P_{25}K_{120}S_{40}B_5Zn_{20}$	4.83	0.77	386.0	33.6	108.9	27.0	47.9	50.1	283.7	71.2
T_2, $N_{100}P_{50}K_{120}S_{40}B_5Zn_{20}$	4.75	0.71	364.8	40.3	89.7	29.7	54.4	46.4	263.3	71.3
T_3, $N_{100}P_0K_{120}S_{40}B_5Zn_{20}$	4.73	0.73	358.8	24.1	129.4	28.8	49.6	47.9	281.0	73.1
T_4, $N_{100}P_{25}K_{80}S_{40}B_5Zn_{20}$	4.85	0.80	367.9	33.1	74.2	31.7	51.1	44.8	273.0	71.8
T_5, $N_{100}P_{25}K_{40}S_{40}B_5Zn_{20}$	4.90	0.80	346.8	31.9	65.2	35.4	51.2	47.9	275.5	76.6
T_6, $N_{100}P_{25}K_0S_{40}B_5Zn_{20}$	5.00	0.70	361.8	26.3	62.1	36.1	46.3	48.8	273.8	83.5
T_7, $N_{100}P_{25}K_{120}S_{40}B_5Zn_0$	4.90	0.80	373.8	38.1	100.6	29.7	52.2	48.8	270.6	70.8
T_8, $N_{100}P_{25}K_{120}S_{40}B_0Zn_{20}$	4.75	0.77	364.9	31.9	104.2	27.7	49.2	48.4	279.0	72.3
T_9, $N_{100}P_{25}K_{120}S_0B_5Zn_{20}$	4.95	0.71	361.8	30.2	98.4	32.5	51.3	47.2	273.3	69.0
T_{10}, $N_{100}P_{25}K_{120}S_0B_0Zn_0$	4.80	0.84	361.8	31.4	89.6	34.8	54.0	48.0	277.8	73.3
T_{11}, RDF	4.90	0.81	337.7	39.2	80.3	42.7	51.6	48.7	293.8	77.9
T_{12}, INM	5.20	0.83	349.8	41.5	115.6	54.4	93.5	50.8	259.9	68.9
SEm±	0.05	0.03	10.6	2.1	2.5	0.4				
CD (P=0.05)	0.14	0.08	NS	6.0	7.0	1.5	-	-	-	-

Table 4. Economics of rice wheat cropping system as influenced by SSNM in rice–wheat system (pooled data over 7 years)

Treatment	Cost of cultivation (× 10^3 ₹/ha/year)	Net returns (× 10^3 ₹/ha/year)	Benefit: cost ratio	Productivity cost (₹/invested/kg grain)	System profitability (₹/ha/day)
T_1, $N_{100}P_{25}K_{120}S_{40}B_5Zn_{20}$	52.9	84.0	1.59	5.51	230.1
T_2, $N_{100}P_{50}K_{120}S_{40}B_5Zn_{20}$	54.0	99.9	1.85	4.97	273.7
T_3, $N_{100}P_0K_{120}S_{40}B_5Zn_{20}$	51.5	87.7	1.70	5.19	240.2
T_4, $N_{100}P_{25}K_{80}S_{40}B_5Zn_{20}$	52.1	91.9	1.76	5.10	251.8
T_5, $N_{100}P_{25}K_{40}S_{40}B_5Zn_{20}$	51.2	91.7	1.79	5.00	251.1
T_6, $N_{100}P_{25}K_0S_{40}B_5Zn_{20}$	50.4	77.1	1.53	5.44	211.4
T_7, $N_{100}P_{25}K_{120}S_{40}B_5Zn_0$	48.4	100.6	2.08	4.64	275.7
T_8, $N_{100}P_{25}K_{120}S_{40}B_0Zn_{20}$	51.1	89.6	1.76	5.18	245.5
T_9, $N_{100}P_{25}K_{120}S_0B_5Zn_{20}$	43.6	101.6	2.33	4.25	278.3
T_{10}, $N_{100}P_{25}K_{120}S_0B_0Zn_0$	37.5	115.0	3.07	3.47	314.9
T_{11}, RDF	38.0	113.0	2.97	3.50	309.2
T_{12}, INM	41.0	105.0	2.56	4.02	286.5
SEm±	–	–	–	–	4.5
CD (P=0.05)	–	–	–	–	13.2

comparable to T_{11}, (RDF, $N_{90}P_{40}K_{40}$ for rice & $N_{120}P_{60}K_{30}$ for wheat crop) in influencing total net returns (Table 4). T_{10}, ($N_{100}P_{25}K_{120}$ to both rice and wheat) resulted in the highest benefit: cost ratio of 3.07 followed by T_{11}, (RDF), T_{12}, (INM practice), T_9, ($N_{100}P_{25}K_{120}S_0B_5Zn_{20}$ to rice and $N_{100}P_{25}K_{120}$ to wheat) and T_7, ($N_{100}P_{25}K_{120}S_{40}B_5Zn_0$ to rice and $N_{100}P_{25}K_{120}$ to wheat). Productivity cost (₹/kg grain produced) was the lowest and system profitability was higher under T_{10} ($N_{100}P_{25}K_{120}$ to both rice and wheat) followed by T_{11}, (RDF); T_{12}, (INM practice); T_9, ($N_{100}P_{25}K_{120}S_0B_5Zn_{20}$ to rice and $N_{100}P_{25}K_{120}$ to wheat); and T_7, ($N_{100}P_{25}K_{120}S_{40}B_5Zn_0$ to rice and $N_{100}P_{25}K_{120}$ to wheat).

The present investigation conclusively inferred that site specific nutrient management works well in boosting the productivity of both rice and wheat in the rice–wheat cropping system. The higher application of P was indispensable in wheat but under conditions of puddling and subsequent land submergence in the high status soil its application can be curtailed for subsequent rice production. K was found to be the most indispensable plant nutrient. However, under the conditions when FYM is applied, application of sulphur and micronutrients B and Zn can be skipped.

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