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Original Research Article

Climate Smart Nutrient Management (CSNM) for Enhanced Use Efficiency and Productivity in Rice and Wheat under Rice-Wheat Cropping System

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A B S T R A C T

Due to excessive use of fertilizers in imbalanced ratios causing the low nutrient use efficiency and associated environmental problems which has raised the serious concerns about the existing nutrient management practices. Increasing N_2O concentrations in the atmosphere have been linked to anthropogenic activities. Site specific nutrient management is a potent climate smart nutrient management (CSNM) technology which is able to establish synergy with crop–soil nutrient dynamics and is also able to reduce the possible threat to the environment in form of N_2O emission. Practices that improve crop N uptake can reduce N losses to the environment, thereby increasing fertilizer N use efficiency (NUE). The objective of the study was to evaluate different nutrient management approaches for enhanced nutrient use efficiencies by crop driven nutrient management by preventing the possible N losses. Treatments comprised of six location/site specific nutrient management approaches along with 4 nutrient omission treatments. The investigation results indicated that the treatment Nutrient Expert recommended fertilizer under SSNM (NE-SSNM) is able to mitigate crop driven N demand at the critical stages of crops and also superior in terms of grain yield and profitability. More grain yield with less fertilizer were obtained by using SSNM (Nutrient Expert recommended fertilizer) techniques in comparison to the blanket N application and other nutrient approaches, which is economically viable and environment friendly.

Keywords

Climate Smart Nutrient management, Nutrient Decision Support Systems (NDSS), Nutrient Use Efficiency (NUE), Site Specific Nutrient Management (SSNM)

Introduction

Growing concerns about impaired soil health, declining productivity growth and decreasing factor productivity or nutrient-use efficiency (NUE) are compelling the farmers to use higher levels of fertilizers during last two decades, which are now posing a serious threat to food security, agricultural sustainability, soil and environmental health in the developing world. Farmers tend to use more nitrogen (N) fertilizer than needed mainly because of subsidized price (CREMNET, 1998) and its immediate visible impact on plant growth and leaf color. Imbalanced use and application of N at wrong time is common. Increasing N_2O concentrations in the atmosphere have been linked to anthropogenic activities. Nitrous oxide is a potent greenhouse gas with a global warming potential 300 times greater than that of CO_2 (IPPC, 2007). For this reason, much attention is being given to N_2O emissions to mitigate climate change. Soil N_2O emissions from agricultural practices, including fertilizer applications, account for the largest (nearly 80%) source of total N2O (USEPA, 2016).

N recovery by rice is low, ranging from 20 to 40% because of N losses via ammonia volatilization, denitrification, and runoff and leaching (De Datta and Buresh, 1989; Win, 2003). Use of N fertilizer at higher dose as well as at wrong time makes plants succumb to lodging, attractive to insect pests and diseases and causing serious threat to environment. It has been suggested that, in principle, timing of N application can be an effective practice to reduce N_2O emissions (Robertson and Vitousek, 2009; Smith *et al.*, 2007). Further, other researchers evaluating N_2O emissions using a predictive model have indicated that increasing the number of N applications during the growing season would result in reduced N_2O emissions (Li *et al.*, 2012). Nevertheless, the potential benefit of split-N application to reduce N_2O emissions is uncertain because the data are limited.

The quantity of rice and wheat grain produced per unit of applied fertilizer N (partial factor productivity) has continuously decreased to very low values (Dobermann *et al.*, 2002) and N use efficiency following blanket fertilizer N application has been reported as low as 30% in rice–wheat cropping system (Krupnik *et al.*,2004). The main reason for low N use efficiency is an inefficient splitting of N doses coupled with N applications in excess of crop requirements. When managed inefficiently, a large portion of the applied N is lost and create associated environmental problems. It is high time to develop site specific nutrient management (SSNM) technologies which are able to make synergy with crop–soil nutrient dynamics. SSNM aims to apply nutrients at optimal rates and times to achieve high profit for farmers, with high efficiency of nutrient use by crops across spatial and temporal scales; thereby preventing leakage of excess nutrient to the environment. The SSNM is need-based feeding of crops with nutrients in right rate and right time while, recognizing the inherent spatial variability which enhances crop productivity, profitability, NUE and avoids nutrient wastage.

A recently developed nutrient decision support systems (NDSS), Nutrient Expert® for rice wheat enables farmers to rapidly implement SSNM for their individual fields. Pampolino *et al.*, (2012) suggested that Nutrient Expert (NE) was developed to provide crop advisors with a simpler and faster way to use SSNM. The real time N management approach can help increase N use efficiency by matching time of fertilizer application with plant need. Leaf colour chart (LCC) is a reliable tool for real time N management (Singh *et al.*, 2002). LCC in late 1990s developed to assist farmers to apply N fertilizer at right amount as and when needed by the plant (Shukla *et al.*, 2004). The color panels of the LCC are designed to indicate whether rice plants are hungry or over-fed by nitrogen fertilizer. By matching the color of the rice leaf to the color on the LCC, farmers can decide proper time and amount of N fertilizer for application. LCC validation experiments in Vietnam and other countries have shown that farmers can save a substantial amount of nitrogen without any reduction in grain yield, which subsequently led to its wider adoption (Alam *et al.*, 2006; Alam *et al.*, 2005; Balasubramanian *et al.,* 2000; Singh *et al.,* 2002).

Climate smart agriculture tackles the food insecurity and climate change problems together, rather than in isolation. This paper deals the soil based and plant based nutrient management approaches with the objectives to enhance NUE, crop productivity and profitability in rice and wheat crop under rice-wheat cropping system. Our hypothesis is that with a split application of N at the right crop stage and the right dose increase the nutrient use efficiencies hence, less leakage of N to the environment.

Materials and Methods

A field experiment was conducted on a silty loam soil (Mollisol) at A-2 block (Rice Agronomy block) of Norman E. Borlaug Crop Research Centre of G.B. Pant University of Agriculture and Technology, Pantnagar during *kharif* and *rabi* seasons of 2014-15 and 2015-16 to study the different nutrient management approaches on nutrient use efficiencies and productivity of rice and wheat under rice-wheat cropping system. Treatments comprised of 6 nutrient management approaches *viz* recommended dose of fertilizers (RDF), Nutrient Expert recommended fertilizer (NE-RF), Nutrient Expert recommended fertilizer under SSNM (NE-SSNM), recommended dose of fertilizer with nano-fertilizer (RDFNf),farmer's fertilizer practices (FFP) and soil test crop response (STCR) along with 4 nutrient omission treatments *viz.* PK, NK, NP and –NPK (Absolute control). The experiment was laid out in randomized block design with three replications. Rice variety NDR-359 and wheat variety UP-2572 were used for the experiment. Statistical analysis was carried out with STPR software developed by Pantnagar university.

An innovative, information and communications technology (ICT)-based decision support systems (DSS) tool Nutrient Expert® (NE) for maize, rice and wheat has been developed by International Plant Nutrition Institute (IPNI) and International Maize and Wheat Improvement Centre (CIMMYT) (Pampolino *et al.,* 2012). To know the current farmers fertilizer practices in the adjoining area of the experimental site, a planned survey has been made in the adjoining 5 villages namely Jawaharnagar, Bindukhatta, Shantipuri No.1, Shantipuri No.2, Shantipuri No.3 and Shaktifarm villages of District Udham Singh Nagar, Uttarakhand.

In LCC based nitrogen management treatment, the LCC values were recorded as per standard procedure at weekly interval starting from 14 DAT to flowering in rice and from 21 DAS in wheat.

Whenever the LCC values were found to be below the fixed critical level of three, recommended quantity of nitrogen was applied @ 30 kg $ha^{-1}$and the basal dose of nitrogen was applied @ 58 kg ha^{-1}. In wheat after applying basal N dose (54 kg N ha^{-1}) through urea remaining 58 kg N was equally spited in two as 28 kg N, whenever color of leaf fall below critical LCC reading four (≤4).

The efficiency of applied nutrient and nutrient taken up by the crop can be assessed using different indices which can be calculated by using the following formula (Cassman *et al.,* 1998).

Partial factor productivity from applied nitrogen (PFP- kg grain kg^{-1} N applied)

$$PFP = \frac{\text{Grain yield in N applied (kg/ha)}}{\text{Amount of N applied (kg/ha)}}$$

Agronomic efficiency of applied nitrogen (AEn- kg grain yield increase kg^{-1} N applied)

$$AEn = \frac{\text{Grain yield in N applied plot (kg/ha)} - \text{Grain yield in control plot (kg/ha)}}{\text{Amount of N applied (kg/ha)}}$$

Recovery efficiency (%) of applied nitrogen (REn- kg N taken up kg^{-1} N applied)

$$REn = \frac{\text{Total N uptake in N applied plot (kg/ha)} - \text{Total N uptake in control plot (kg/ha)}}{\text{Amount of N applied (kg/ha)}} X100$$

Results and Discussion

Yield and Nutrient Use Efficiencies in Rice

The highest grain yield (6042 kg ha^{-1}) and straw yield was recorded under STCR in 2014 followed by NE-SSNM, whereas, in 2015 significantly highest grain yield (7004 kg ha^{-1}) and straw yield was recorded in NE-SSNM. During 2015 the NE-SSNM (Nutrient Expert recommended fertilizer under SSNM) produced 1064 kg ha^{-1} more grain yield over FFP. In comparison to FFP, the SSNM technology i.e. NE-SSNM produced 3.73 and 16.88% more grain yield in 2014 and 2015, respectively. Pooled data of two years showed that comparatively highest grain yield was recorded under SSNM treatment i.e. NE-SSNM followed by STCR (Table 1).

During 2014, site specific nutrient management led to a large gain in N use efficiency (Table 1). The partial factor productivity (PFP) revealed that under Nutrient Expert recommended fertilizer under SSNM (NE-SSNM) registered 50.71 kg grain obtained over per kg N applied, 44.81 kg grain obtained over per kg N applied in FFP, means PFP increased by 13.67% under NE-SSNM in comparison to FFP. Agronomic N use efficiency (AEn over PK) under NE-SSNM showed that there was 28.16 kg grain increase over per kg N applied, whereas, in FFP it was 24.33 means there was benefit of 3.83 kg grain yield over per kg N applied in comparison to FFP, whereas, in RDF, the AEn was 27.30 means there was yield benefit of 0.86 kg grain yield increase per kg N applied under SSNM in comparison to blanket recommendation (RDF). Compared to FFP, average AEn (Agronomic efficiency of N) under NE-SSNM increased by 15.74%. REn expresses the kg N taken up over per kg N applied, which is greatly higher under NE-SSNM.

In 2014, minimum agronomic efficiency and recovery efficiency of N among all treatments (excluding nutrient omission plots) was recorded in FFP (AEn - 24.33 kg grain increase over per kg N applied; REn 50%). Dobermann (1999) who also reported that agronomic (AEN) and recovery efficiency (REN) of applied N increased by about 50% under SSNM, also leading to a significant increase in the partial factor productivity (PFP). In the NE-SSNM, N rates applied were lower than the FFP, but higher recovery efficiency and partial factor productivity of N was observed.

During 2015, agronomic N use efficiency (AEn over PK) under NE-SSNM showed 24.97 kg grain increase over per kg N applied, whereas, in FFP it was 14.47, means there was yield benefit of 10.5 kg over per kg N applied under SSNM in comparison to FFP, whereas, AEn under blanket fertilizer recommendation (RDF) was 18.61 means, there was yield benefit of 6.36 kg over per kg N applied under SSNM in comparison to RDF (Table 1). AEn (agronomic efficiency of N) under NE-SSNM increased by 72.56% in comparison to FFP. There was 28.80% increase in PFP in NE-SSNM over FFP and 12.59% increase over blanket recommendations (RDF).

Table.1 Effect of nutrient management approaches on PFP, AE, RE, grain and straw yield of rice

Treatments	PFP (kg grain kg^{-1} N)		AEn (kg grain increase kg^{-1} N applied)		REn% (kg N taken up kg^{-1} N applied)		Grain yield (kg ha^{-1})			Straw yield (kg ha^{-1})		
	2014	2015	2014	2015	2014	2015	2014	2015	Pooled	2014	2015	Pooled
T1 : RDF $N_{120}P_{60}K_{40}$ + Znf	49.48	55.45	27.30	18.61	58	39	5938	6654	5938	6654	5938	6654
T2 : NE-RF $N_{118}P_{27}K_{52}$	48.75	59.49	26.19	22.03	53	52	5753	7020	5753	7020	5753	7020
T3 : NE-SSNM (LCC) $N_{118}P_{27}K_{52}$	50.71	62.43	28.16	24.97	65	65	5984	7366	5984	7366	5984	7366
T4 : T2 – N ($N_0P_{27}K_{52}$) PK	0.00	0.00	0.00	0.00	0	0	2662	4420	2662	4420	2662	4420
T5 : T2 - P ($N_{118}P_0K_{52}$) NK	42.77	50.54	20.21	13.08	38	25	5047	5964	5047	5964	5047	5964
T6 : T2– K ($N_{118}P_{27}K_0$) NP	46.69	51.21	24.13	13.75	50	28	5510	6043	5510	6043	5510	6043
T7 : Absolute Control (-NPK)	0.00	0.00	0.00	0.00	0	0	2766	3793	2766	3793	2766	3793
T8 : RDF $N_{120}P_{60}K_{40}$ + Nano-fertilizer (RDFNf)	49.39	56.75	27.20	19.91	57	44	5926	6810	5926	6810	5926	6810
T9 : FFP– Farmers' Fertilizer Practices $N_{130}P_{40}K_{20}$	44.81	48.47	24.33	14.47	50	31	5825	6302	5825	6302	5825	6302
T10 : STCR ($N_{133}P_{96}K_{54}$)	45.43	52.66	25.41	19.43	55	44	6042	7004	6042	7004	6042	7004
S.Em.±							161.9	200.4	161.9	200.4	161.9	200.4
C.D. at 5 %							481.1	595.3	481.1	595.3	481.1	595.3
C.V. %							5.45	5.7	5.5	5.7	5.4	5.7

Table.2 Effect of nutrient management approaches on PFP, AE, RE, grain and Straw yield of wheat

Treatments	PFP (kg grain kg^{-1} N)		AE (kg grain increase kg^{-1} nutrient applied)		REn% (kg N taken up kg^{-1} N applied)		Grain yield (kg ha^{-1})			Straw yield (kg ha^{-1})		
	2014-15	2015-16	2014-15	2015-16	2014-15	2015-16	2014-15	2015-16	Pooled	2014-15	2015-16	Pooled
T1 : RDF $N_{150}P_{60}K_{40}$	27.70	27.77	18.20	18.90	42	43	4155	4166	4161	4748	5251	5000
T2 : NE-RF $N_{110}P_{50}K_{39}$	38.29	38.82	25.34	26.72	60	64	4212	4270	4241	5034	5316	5175
T3 : NE-SSNM (LCC) $N_{110}P_{50}K_{39}$	39.59	38.85	26.64	26.75	73	71	4355	4274	4315	5182	5336	5259
T4 : T2 – N ($N_0P_{50}K_{39}$) PK	0.00	0.00	0.00	0.00	0	0	1425	1331	1378	2312	2323	2317
T5 : T2 - P ($N_{110}P_0K_{39}$) NK	34.02	29.77	21.06	17.67	48	40	3742	3275	3509	4808	4615	4712
T6 : T2– K ($N_{110}P_{50}K_0$) NP	34.57	32.43	21.61	20.33	49	44	3802	3567	3685	4811	4674	4743
T7 : Absolute Control(-NPK)	0.00	0.00	0.00	0.00	0	0	1246	1251	1249	2184	2181	2182
T8 : RDF $N_{150}P_{60}K_{40}$ + Nano-fertilizer (RDFNf)	29.19	28.04	19.69	19.17	53	45	4379	4206	4293	5296	5294	5295
T9 : FFP– Farmers' Fertilizer Practices $N_{84}P_{40}K_{20}$	36.00	35.97	19.03	20.13	43	48	3024	3022	3023	3859	4981	4420
T10 : STCR ($N_{115}P_{72}K_{43}$)	36.92	33.56	24.52	21.99	61	49	4245	3860	4053	5105	5208	5156
S.Em.±							96.7	141	87.7	67.5	109.5	55.2
C.D. at 5 %							287.3	418	260.5	200.5	325.3	164.1
C.V. %							4.8	7.3	4.5	2.7	4.2	2.2

The minimum agronomic efficiency and recovery efficiency of N among all nutrient management approaches (except nutrient omission plots) was recorded in FFP (AEn 14.47 kg grain increase over per kg N applied; REn 31%). N rates used in Nutrient Expert recommended fertilizer under SSNM (NE-SSNM), were lower than FFP, but higher recovery efficiency and partial factor productivity of N was observed in NE-SSNM.

In Nutrient Expert-based nutrient management, plant nutrients are applied based on the SSNM principle of 'feeding crops with nutrient as and when they are needed' (IRRI, 2013). The concomitant increase in the index leaf nitrogen with increasing LCC levels revealed that leaf N concentration was directly related to leaf greenness (Nachimuthu *et al.,* 2007). The highest grain yield of rice under LCC based nitrogen management could be attributed to adequate N availability as was observed from significant and positive association between grain yield and nitrogen uptake. The site specific nutrient management led to a large gain in N use efficiency.

Yield and Nutrient Use Efficiencies in Wheat

The maximum grain yield was recorded in RDF with nano-fertilizer (RDFNf) as 4379 kg $ha^{-1}$and also maximum straw yield during 2014-15, followed by NE-SSNM and STCR. During 2015-16, significantly higher grain and straw yield was recorded in Nutrient Expert recommended fertilizer under SSNM (grain yield 4274 kg ha^{-1}) (Table 2). The same yield pattern also exhibited in the pooled data over two years revealing that the highest grain yield obtained under NE-SSNM. The percent increase in grain yield in NE-SSNM treatment was 44 and 41.4 over FFP in the year 2014-15 and 2015-16, respectively. Higher grain and biomass yield with NE-based nutrient management strategies over farmers' practice of nutrient management clearly indicated the benefit of judicious nutrient management in wheat. In Nutrient Expert-based nutrient management, plant nutrients are applied based on the SSNM principle of 'feeding crops with nutrient as and when they are needed' (IRRI, 2013).

Different nutrient management approaches had pronounced influence on nutrient use efficiencies. During 2014-15 the factor productivity in SSNM plot was 39.59 kg grain kg^{-1} N applied, whereas, in FFP and RDF it was 36.0 and 27.7 kg grain kg^{-1} N applied, respectively. Thus, the PFP (partial factor productivity) in NE-SSNM increased by 9.97 and 42.92% in comparison to FFP and RDF, respectively. Agronomic N use efficiency (AEn over PK) under NE-SSNM plot was 26.64 (kg grain increase per kg N applied), whereas, in FFP it was 19.03, means there was yield benefit of 7.61 kg over per kg N applied, whereas, AEn under RDF was 18.20 thus, there was yield benefit of 8.44 kg over per kg N applied. N rates applied in NE-SSNM were lower than RDF, but higher recovery efficiency and partial factor productivity of N was recorded. During 2015-16 revealed that there was increase in NUE under site specific nutrient management. The PFP under NE-SSNM plot was 38.85 kg grain kg^{-1} N applied, whereas, in FFP and RDF it was 35.97 and 27.77, respectively (Table 2), means under SSNM it was increased by 8.0 and 39.89% over FFP and RDF, respectively. Agronomic N use efficiency (AEn over PK) under NE-SSNM plot was 26.75 (kg grain increase per kg N applied), whereas, in FFP it was 20.13 means there was yield benefit of 6.62 kg over per kg N applied, whereas, it was 18.90 under blanket recommended fertilizer (RDF) means there was yield benefit of 7.85 kg over per kg N applied. In comparison to FFP, AEn in NE-SSNM increased by 32.89%.

Due to improved synchronization of N demand of the crop with dose and time of fertilizer nitrogen application by using LCC, significantly higher agronomic and recovery efficiency were observed as compared to blanket recommendation treatment. Better efficiency of nutrients applied according to Nutrient Expert recommendations than in farmers' practice indicates that location specific nutrient application rate and better timing of nutrient application (i.e. more number of splits and matching physiological demand of the crops) reduced N losses and enhanced efficiency of nutrient utilization. Systematic approach of NE to capture site information thus improves nutrient use efficiency by providing location specific recommendation considering the crop's nutrient requirement and inherent soil nutrient supplying capaciity (Pampolino *et al.,* 2012a).

Production of more grain yield with less fertilizer N can be obtained in SSNM based fertilizer application which minimizes the possible risks to the environment pollution. Nutrient Expert recommended fertilizer under SSNM (NE-SSNM) is superior over other nutrient management approaches in terms of grain yield and efficient use of nutrient.

Nutrient Expert based fertilizer use through SSNM technology is able to mitigate crop driven N demand at the critical stages of crops and possible leakage of N. Split N application at the right time with right dose facilitated by nutrient decision support system and tools may be a reliable and feasible way to achieve both environmental protection and enhanced grain productivity goals.

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