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Enhancing nutrient use efficiencies for rainfed rice through fertilizer splitting

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Abstract
Nutrient use efficiency concept is used to increase the overall performance of rainfed rice by providing economically optimum nutrition to the crops and at same time minimizing nutrient losses from the crop yield. A field experiment was undertaken during wet seasons of 2017 and 2018 to evaluate the response of soil applied Potassium and Nitrogen splitting in rice (Sahbhagi Dhan) under rainfed lowland conditions. The experimental was laid out on a sandy loam soil of Bihar Agricultural College farm, Sabour to derive inputs for rationalizing the use of Potassium (K) and Nitrogen (N) fertilizers by splitting and real time management respectively for making them more suitable for rainfed conditions. Nutrient and water management are important for diversifying and intensifying the rainfed rice based cropping systems. The experiment involved three K splitting schemes *viz*., K_0 (No K application), K_{40} (K applied as basal @ 40 kg K_2O per ha) and K_{20+20} (K application as basal, and at panicle initiation stage each @ 20 kg K_2O per ha) in main plots, and five N splitting schemes in sub plots *viz*.,N_0 (No N application), N_{50+50} (N application as basal and at active tillering, each @ 50 kg per ha) N_{SPAD} (N application as basal each application @ 33.33 kg ha^{-1} and top dressing as guided by SPAD meter with critical SPAD value of 38, N_{GS} (N application as basal @ 33.3 kg per ha and top dressing as guided by Green Seeker optical sensor) and $N_{33+33+33}$ (N application as basal, at active tillering and at panicle initiation, each @ 33.3 kg per ha.). The results revealed that the overall AE_N, PFP_N, RE_N and partial nutrient balance (PNB) of across all levels of K & N splitting for rainfed rice was comparatively lower than that of control plot which reflects that the nutrient splitting strategy of the effect of application of potassium and nitrogenous fertilizers was more than the direct effects in rainfed rice. Overall, the results indicated that the K & N splitting the use of real time fertilizers splitting in rainfed rice optimizing nitrogen use efficiency, as well as increased rainfed rice production and uptake thereby led to increased nutrient use efficiency of applied nutrients and crops.

Keywords: Rainfed rice, nutrient use efficiency of N and K

Introduction
Rice (*Oryza sativa* L.) is one of the most important food crops grown worldwide. Worldwide, drought affects approximately 23 million hectares of rainfed rice (Serraj *et al*. 2011). In India, 47 million hectares are under rice production, of which 45% is irrigated, 33% is rainfed lowland, 15% is rainfed upland and 7% is flood-prone. The rainfed rice area is about 24.4 million hectare in India out of which the rainfed lowland area (17 million hectares) is mostly in eastern India (Singh and Dwivedi, 1997) [10]. Drought is the most important factor limiting rice productivity in the rainfed rice agro-ecosystem. Climate change is predicted to increase the frequency and severity of drought, which will likely result in increasingly serious constraints to rice production worldwide.

Rice is also one of the nutrient exhaustive crop which remove large quantities of nutrients from soil. In India, the annual requirement of nitrogen, phosphorus, and potassium (NPK) has been reported to 28Mt while only 18Mt of these nutrients are actually being supplied by different sources thus creating a negative balance of about 10Mt of primary nutrient (Bhatt *et al*. 2016; Puniya *et al*. 2019) [2, 8].

Nutrient use efficiency (NUE) is a critically important concept in the evaluation of crop production systems (Fixen *et al*. 2015) [5] and is greatly influenced by genetic and physiological components of plants as well as their influence on its ability to absorb and utilize nutrients under different environmental and ecological conditions (Baligar and Fageria 2015) [1]. The NUE depends on the nutrient uptake, transport, assimilation, storage, remobilization, and synthesis of storage compounds during plant growth and development (Weih, Westerbergh, and Lundquist 2018) [12]. The objective of nutrient use is to increase the overall performance of cropping systems by providing economically optimum nourishment to the crop while minimizing nutrient losses for the field and supporting agricultural sustainability through contributions to soil fertility or other soil quality components (Fixen *et al*. 2015) [5].

The present investigation was undertaken with an objective to work out enhancing nutrient use efficiencies indices of N, P and K under Rainfed rice conditions.

Materials and Methods

Experimental site description

A field experiment was conducted during wet seasons of 2017 and 2018 at Bihar Agricultural University, Sabour, Bhagalpur. Sabour is situated in the Middle Gangetic Plain region of Agro-climatic Zone III (A) located at 25˚15′40″ N latitude, 87˚2′42″ E longitude and an altitude of 37 meter above mean sea level. The crop received a total rainfall of 862.1 mm and 1101.6 mm during *kharif* 2017 and 2018, respectively. The weekly weather condition of the experimental site during the crop growth period of the year 2017 and 2018. The daily maximum and minimum temperature during the crop growth period varied from 29.2-36.4ºC and 11.8 - 26.3ºC, respectively during the crop growth period of the year 2017 whereas, in the year 2018 the maximum and minimum temperatures ranged from 29.2- 37.4ºC and 12.6-26.8ºC, respectively. The crop received a total rainfall of 862.1 mm and 1101.6 mm during the year 2017 and 2018, respectively. The relative humidity at 07:00 AM and 02:00 PM during 2017 &2018 ranged from 81.9% to 94%, 44.7% to 81.9%, 80.2% to 91.7% and 45.1% to 81.2% in the same order.

The soil is Typic Haplustept (US Soil Taxonomy, Soil Survey Staff 2003) and clay loam in texture (50% sand, 28% silt, and 22% clay) with general initial properties ranged from: pH 7.25-8.21, electrical conductivity 0.13-0.19 dsm^{-1}, organic carbon 0.32-.58%, available N 150-213 kg ha^{-1}, available P_2O_5 11-35 kg ha^{-1} and available K_2O 138-173 kg ha^{-1}.

Experimental design and management

The experiment was laid out in split plot design with three replications and consisted of the following fifteen treatments as enlisted in table 1. The net plot size of each treatment is $8.1m^2$. While, the recommended dose of fertilizers the main plot treatment were K_0 (No K application), K_{40} (K applied as basal @ 40 kg K_2O per ha) and K_{20+20} (K splitting as basal, and at panicle initiation stage @ 20 kg K_2O per ha) and in sub plots treatment N_0 (No N application),N_{50+50} (N application as basal and at active tillering, each @ 50 kg per ha) N_{SPAD}(N application as basal @33.3 kg per ha and top dressing as guided by SPAD meter, critical SPAD reading considered as 38), N_{GS} (N application as basal @ 33.3 kg per ha and top dressing as guided by Green Seeker optical sensor) and $N_{33+33+33}$(N application as basal, at active tillering and at panicle initiation, each @ 33.3 kg per ha.) and zinc were applied as per area-specific recommended rates @ 25 kg ha^{-1}, and full dose of phosphorous @ 60 kg ha^{-1} single super phosphate (SSP) along with zinc as zinc sulfate hepta-hydrate were applied as basal at the time transplanting. The nursery of rice variety sahbhagi Dhan was sown in an adjacent plot which was tilled and puddled followed by on 25-06-2017 and same date in 2018 broadcasting of the pre-germinated seeds @ 30 g m^2 and N: P_2O_5: K_2O@75-50-50 kg ha^{-1}wereapplied. Twenty-one days old seedlings were transplanted at a spacing of 20 cm × 15 cm with 2 seedlings per hill on 16thJuly and 17th July during 2017 & 2018 respectively.

Sampling and storage

Grain yield and straw yield of rice crop was recorded from a harvested area of 18 m^2. Plant samples (grain straw and leaves) were collected after harvesting from each of the plots. Immediately after collection the plant samples were first washed with running tap water followed by washing of 0.01N HCl and finally with deionized water. After that, samples were dried in a hot air oven at 65 ºC for 48–72 hr until the constant weight was achieved. After drying, plant samples were ground to a fine powder by using stainless steel grinder and stored in polyethylene bag for further analysis. The collected soil samples were air dried, ground, and passed through 2 mm sieve and stored in polyethylene packets for further analysis.

Analytical procedure

The stored plant sample were analyzed for total N content by Kjeldahl method using Kel-Plus analyzer (Pelican Equipments, Chennai, India), while total P and K content were determined in aqueous extracts prepared after wet digestion with a tri-acid mixture of HNO_3, $HClO_4$, and H_2SO_4 (10:4:1 ratio) using UV-Visible spectrophotometer (Systronics 167; Systronics India Ltd., Ahmedabad, India) and Flame photometer (Systronics 128; Systronics India Ltd., Ahmedabad, India), respectively (Jackson 1973) [6]. The N, P, and K uptake was calculated from the nutrient concentration in straw, grain, and yield data. Analysis of soil was done for pH (Jackson 1973) [6], organic carbon (Walkley and Black 1934), available N (Subbiah and Asija 1956) [11], available P (Olsen *et al*. 1954), and available K (Hanway and Heidel 1952).

Nutrient use efficiency

Various use efficiency of nutrients N, P, and K were calculated as per the formulae given below:

Agronomic efficiency (AE) kg grain yield increase per kg nutrient applied (kg/kg)	= $(GY_F - GY_{UF})/F$	(Dobermann 2007; Fixen *et al*. 2015) [3, 5]
Apparent recovery efficiency (ARE) % Quantity of nutrient uptake per unit of nutrient applied	= $(N_{UF}-NU_{UF})/F$-100	
Partial factor productivity (PFP) kg grain yield per kg nutrient applied (kg/kg)	= GY/F	
Partial nutrient balance (PNB) Nutrient output per unit of nutrient input (kg/kg)	= U_H/F	
Internal utilization efficiency (IE) kg grain yield per kg nutrient uptake (kg/kg)	= GY/NU	
Agro-physiological efficiency (APE) Economic production obtained per unit of nutrient uptake (kg/kg)	= $(G_{YF}-GY_{UF})$/(NUF - NUUF)	
Physiological efficiency (PE) Biological yield obtained per unit of nutrient uptake (kg/kg)	= $(BY_F-BY_{UF})/(N_{UF}-NU_{UF}$	(Baligar and Fageria 2015) [1]

GY_F, Grain yield of fertilized plot; GY_{UF}, grain yield of unfertilized plot; F, amount of nutrient applied; N_{UF}, nutrient uptake of grain and straw in fertilized plot; NU_{UF}, nutrient uptake of grain and straw in unfertilized plot; GY, grain yield; NU, total nutrient uptake; U_H, nutrient content of harvested portion of crop; BY_F, biological yield of fertilized plot; BY_{UF}, biological yield of unfertilized plot.

Statistical analysis

The data were analysed statistically by applying "Analysis of Variance" (ANOVA) technique for split plot design (Cochran and Cox, 1985). Microsoft Office Excel 2010 was used to calculate different NUE parameters. The significance of different sources of variation was tested by Error mean square of Fisher Snedecor's 'F' test at probability level 0.05. Standard error of mean (SEm±) and least significant difference (LSD) at 5% level of significance were worked out for each character and provided in the summary tables of the results to compare the difference between the treatment means.

Results and Discussion

Nitrogen use efficiency

According to Fageria *et al*. (2008) [4], a nutrient-efficient plant is defined as one of that produces higher economic yield with the determined quantity of applied or absorbed nutrient compared to other or a standard plant under similar growing conditions. This statement that say highlights human use of the plant, the yield and the economic perspective, which are central in the field of agronomy. In terms of calculating nitrogen-use efficiency, one common definition used in agronomy is that by Moll *et al*. (1982) [7], according to which nitrogen-use efficiency is grain weights, divided by the nitrogen supply. If total nitrogen in the plant at maturity is including, nitrogen-use efficiency can be further divided into at least two different components, uptake efficiency (Nt/Ns) and utilization efficiency (Gw/Nt). Multiplying these two components yields the overall nitrogen-use efficiency (Gw/Ns). Somewhat bridging agronomy and ecology aspects, Siddiqi and Glass (1981) [9] suggest calculating the "efficiency of utilization" as the inverse of the internal nutrient concentration times the biomass or yield.

Agronomic N use efficiency (AE_N kg kg^{-1})

The data pertaining to the agronomic N use efficiency in rice under various treatments for the two years is presented in table 1. The agronomic N use efficiency was found statistically similar across all levels of K splitting in the year 2017. Whereas, in 2018 the agronomic N use efficiency in K_0 and K_{20+20}were found at par with each other. However, K_{40} was found significantly lower than K_{20+20} and K_0. Across various N splitting schemes, in 2017, agronomic N use efficiency was statistically similar across all levels of N splitting schemes. But in 2018, agronomic N use efficiency in N_{50+50}, N_{SPAD} and N_{GS} were statistically at par with each other, as and in $N_{33+33+33}$ was significantly lower than in N_{50+50}, N_{SPAD} and N_{GS}.

Partial factor productivity of applied N (PFP_N kg kg^{-1})

The partial factor productivity in rice under various treatments for the two years is presented in table 1. It was noticed that the partial factor productivity in the year 2017 and 2018 were found statistically similar across all levels of K splitting schemes. Across various N splitting schemes in 2017, partial factor productivity was found to be statistically similar. However in 2018, the partial factor productivity of N_{50+50}, N_{SPAD} and $N_{33+33+33}$ were found statistically similar. The partial factor productivity under the treatmentN_{50+50} and N_{SPAD} were at par with each other. But partial factor productivity in N_{GS} was significantly greater than that in N_{50+50}, N_{SPAD} and $N_{33+33+33}$.

Nitrogen recovery efficiency (RE_N (%))

The data pertaining to the nitrogen recovery efficiency in rice under various treatments for the two years is presented in table 1. In 2017, the nitrogen recovery efficiency was found significantly higher with split application of potassium in comparison to K_0 and when full dose of potassium was applied as basal (K_{40}). In the second year of study the nitrogen recovery efficiency was significantly higher in K_{20+20}in comparison to K_0 and K_{40}. But full dose of potassium as basal K_{40} and K_0 were statistically similar. Across various N splitting schemes, in 2017, the nitrogen recovery efficiency, N_{SPAD} and N_{GS} were found to be statistically similar, further nitrogen recovery efficiency of N_{50+50} and $N_{33+33+33}$were at par with each other. However nitrogen recovery efficiency under the treatments N_{SPAD} and N_{GS} based N application was found significantly greater than that in $N_{50+50}$and $N_{33+33+33}$. In 2018, the nitrogen recovery efficiency, across various N splitting methods was found to be statistically similar.

Table 1: AE_N, (kg kg^{-1}), PFP_N, (kg kg^{-1}) and RE_N (%) across all levels of K & N splitting for rainfed rice at BAC, Sabour during 2017 and 2018

Treatment	N applied (kg ha^{-1})		AE_N (kg kg^{-1})		PFP_N (kg kg^{-1})		RE_N (%)	
	2017	2018	2017	2018	2017	2018	2017	2018
K splitting schemes								
K_0	0	0	12	17	31	39	49	44
K_{40}	40	40	13	12	33	41	29	43
K_{20+20}	40	40	14	19	34	42	40	66
S.Em (±)	-	-	1.84	1.27	1.53	1.93	1.67	4.48
CD (P=0.05)	-	-	NS	4.98	NS	NS	6.57	7.85
N splitting schemes								
N_{50+50}	100	100	12.58	16.30	32.26	40.68	33.58	50.01
N_{SPAD}	114	107	15.10	16.67	32.51	39.81	44.89	53.38
N_{GS}	92	91	11.90	17.69	33.65	44.62	46.96	54.17
$N_{33+33+33}$	99.99	99.99	13.20	13.50	32.88	37.88	32.42	47.16
S.Em (±)	-	-	1.02	0.92	1.38	0.96	3.68	3.65
CD (P=0.05)	-	-	NS	2.73	NS	2.87	10.94	NS
CD K × N (P=0.05)	-	-	5.25	4.72	7.12	4.96	18.85	18.80

Conclusion

Nitrogen use efficiency is one of the most important yield constraints in crop production in almost all the agro ecological regions of the world. Nutrient management that involves conjoint use of different nutrient sources appears to be a promising strategy for sustaining high yields, and maintain soil fertility states as well as improvement in fertilizer use efficiency as whole including NUE. In the present study, it was found that the overall NUE of N and K was better across different Potassium and Nitrogen splitting regimes under rainfed lowland rice conditions.

Agronomic N use efficiency in N_{50+50}, N_{SPAD} and N_{GS} were statistically at par with each other, as and in $N_{33+33+33}$ was significantly lower than in N_{50+50}, N_{SPAD} and $N_{GS.}$

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