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Short Communication

Effect of Fertilizer Doses on Nutrient Uptake and Use Efficiencies under Different Rice Cultivation Methods

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A field experiment was conducted at ICAR-Indian Institute of Water Management Research Farm, Mendhasal, Odisha, during the *Rabi* (winter) season of 2024 to study the effect of different cultivation methods with varying NPK doses on grain yield, nutrient uptake, and their use efficiencies in rice crop. The experiment was laid out in a split-plot design with three replications, comprised of two crop establishment methods of rice, *viz.,* system of rice intensification (SRI) and conventional transplanting system (CTS) in the main plot and the sub-plot treatments were T_1- No application of recommended dose of fertilizer (RDF), T_2- 25% RDF, T_3- 50% RDF, T_4- 75% RDF, T_5- 100% RDF and T_6- 125% RDF. The recommended dose of fertilizers was 80 kg N, 40 kg P_2O_5, and 40 kg K_2O ha^{-1}. It was found that the highest grain yield for both SRI (5.89 t ha^{-1}) and CTS (4.56 t ha^{-1}) was observed in T_5-100% RDF. Overall, SRI produced a 30% higher grain yield than CTS. The uptake of NPK increased significantly in both grains and straws of crops grown under SRI. N, P, and K uptake in grains increased by 33.1%, 39.2%, and 37% more under SRI than CTS. The agronomic efficiency (AE) of SRI was 27% higher than that of the CTS crop. Under SRI, nearly 43 kg of grain was produced with the application of 1 kg of fertilizer. In contrast, with CTS, only 31 kg of grain was produced with the application of 1 kg of fertilizer, a 28% decrease in the partial factor productivity of applied fertilizer compared to SRI.

(***Key words:*** *Agronomic efficiency, Nutrient uptake, Rice crop, System of rice intensification*)

Rice (*Oryza sativa* L.) is a staple food crop in India, with a current rice area of 46.38 million hectares, producing 130.29 million tonnes of rice, and an average yield of 2.81 t ha^{-1} in the 2021-22 year (DES, 2023). Rice cultivation faces several challenges, *viz*. erratic rainfall due to climate change (Tabari, 2020), shrinking cultivable areas due to urbanization (Pandey and Seto, 2015), water scarcity due to increasing municipal and industrial demand (He *et al.,* 2021), labor shortages due to migration, and several other factors. To feed the growing population, it has been estimated to produce more than 70% of food to meet an expected 34% increase in the world population by 2050 (Tilman *et al.,* 2011; Tesfaye *et al.,* 2021).

Low nutrient utilization efficiency (NUE) for nitrogen (35-40%) and phosphorus (20-25%) in flooded rice is currently a significant concern (Pathak *et al.,* 2019; Thakur *et al.,* 2024). Apart from developing cultivars for using nutrients more efficiently, management techniques can also improve fertilizer usage efficiency, lower cultivation costs, and reduce pollution levels.

The System of Rice Intensification (SRI), a rice cultivation method, was developed in Madagascar (Laulanie, 1993). The main principles of SRI have been described by Stoop *et al.* (2002).The impact of integrated nutrient management on rice under the SRI method has been compared with the conventional cultivation system (CTS). Several researchers found that the SRI method significantly enhanced growth and physiological traits, increasing grain yield by 35-60% compared to CTS (Kumar *et al.,* 2016; Tomar *et al.,* 2018; Senthilvalavan and Ravichandran, 2019; Thakur *et al.,* 2020).

However, meager research has been conducted

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comparing SRI vs. conventional transplanting methods under different doses of NPK fertilizers. In this context, the present study aimed to understand how different crop establishment methods in rice with varying nutrient doses affect grain yield, nutrient uptake and use efficiencies.

The field experiment was conducted during the *Rabi* (winter) season of 2024 at Deras Research Farm of ICAR-Indian Institute of Water Management (IIWM), Bhubaneswar, Odisha. The soils at the experimental site are identified as *Aeric Haplaquepts*, with a sandy clay-loam texture comprising 63% sand, 16% silt, and 21% clay and a pH of 5.6. The soil analysis for different nutrients was done as described by Yoshida *et al.* (1976).

The experiment was conducted in a split-plot design with three replications to assess the performance of rice (var. Bina Dhan 11) under two crop establishment methods, *viz*., SRI and conventional transplanting system (CTS) in the mainplot, while the sub-plot treatments were T_1 - No application of the recommended dose of fertilizer (RDF), T_2 - 25% RDF, T_3 - 50% RDF, T_4 - 75% RDF, T_5 - 100% RDF, T_6 - 125% RDF. The recommended dose of fertilizers was 80 kg N, 40 kg P_2O_5, and 40 kg K_2O ha^{-1}. In all the plots, 5 t ha^{-1} of FYM was added during land preparation.The whole amount of phosphorus was applied during the final land preparation, and N and K were applied in three splits: 25% at ten days after transplanting (DAT), 50% at the tillering stage, and 25% at the panicle initiation (PI) stage of crop growth.

For the SRI plots, 12-day-old single seedlings were transplanted at a spacing of 20 × 20 cm, however, in the CTS plots, three seedlings per hill from 25-day-old plants were transplanted at a spacing of 20 × 10 cm. The first irrigation in the SRI plots was applied five days after transplanting (DAT) to wet the field without standing water, followed by 3-days after the disappearance of ponded water during the vegetative stage, then after a thin film of water was maintained in the SRI plots (Thakur *et al.,* 2011). In the CTS plots, 5-7 cm of standing water was maintained throughout the crop growth period. All plots were drained 15 days before harvest.Weeding in SRI plots was performed with a mechanical cono-weeder at 10, 20, and 30 days after transplanting (DAT), whereas in the conventional-method plots, manual weeding was carried out three times at the same intervals.

The chemical analysis of grains (including whole seeds and bran) and straws was conducted for nitrogen (AOAC, 1995), phosphorus (Jackson, 1973), and potassium (Page *et al.,* 1982). The uptake of nitrogen (N), phosphorus (P) and potassium (K) was determined by multiplying the content (%) of each nutrient by the grain yield or straw dry weight (in kg ha^{-1}), and the results were expressed in kg per hectare (kg ha^{-1}). The agronomic efficiency (AE) and partial factor productivity (PFP) were calculated as suggested by Liu *et al.* (2011) and modified by Ray *et al.* (2018). All data were statistically analyzed using the analysis of variance (ANOVA) technique as applicable to split-plot design (Gomez and Gomez, 1984).

Establishment methods and different fertilizer doses significantly influenced rice grain yield, as presented in Fig. 1. Grain yield increased with higher NPK fertilizer application, with the highest yield recorded in T_5 (100% RDF). The highest grain yield for both SRI (5.89 t ha^{-1}) and CTS (4.56 t ha^{-1}) was observed in T_5, followed by T_6 - 125% RDF. As obvious, the lowest yield was observed in T_1 - 0% RDF, where SRI yielded 1.94 t ha^{-1} and CTS yielded 1.27 t ha^{-1}. On average, SRI produced a higher yield (4.07 t ha^{-1}) than CTS (3.02 t ha^{-1}), 30% higher.

The higher grain yield in SRI compared to CTS is primarily attributed to greater nutrient uptake and increased root growth, optimal spacing for facilitating proper physiological responses in the plants, and the elimination of competition between plants. All these result in better grain development and yield attributes in the SRI method than in the CTS method. Thakur *et al.* (2013) revealed that SRI management practices, which promote profuse root development and improve physiological performance, led to a 49% higher grain yield and more efficient utilization of applied N. Ali and Izhar (2017) showed that all the SRI principles led to significant improvements in various growth parameters, as well as yield attributes and resulted in higher grain and straw yields by 33.3 and 28.3%, respectively, compared to the conventional methods. Several other researchers have shown that the SRI method produces significantly higher grain yields than the conventional

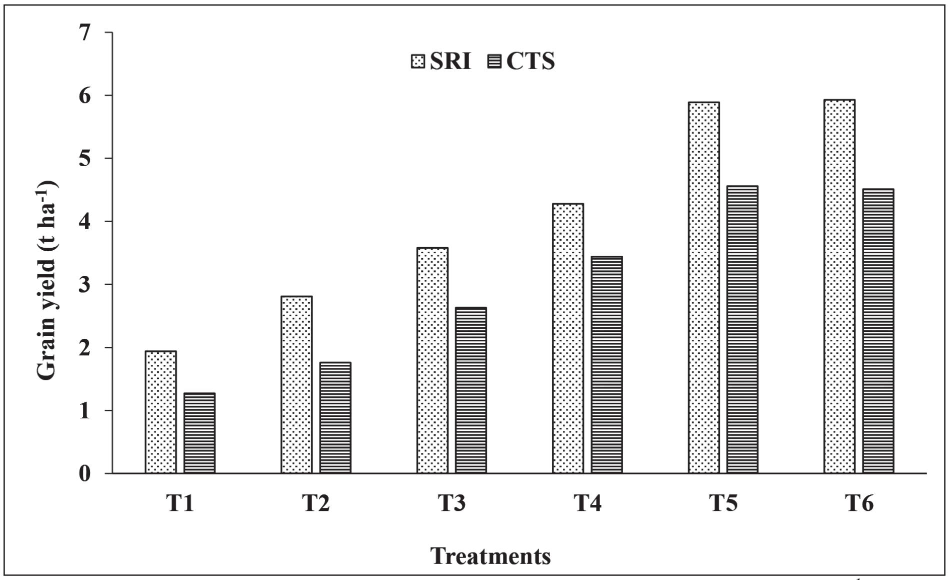

Fig 1. *Effects of establishment methods and fertilizer doses on grain yield (t ha^{-1}) of rice (LSD0.05: crop establishment methods=0.22; fertilizer doses=0.29)*

Table 1. *Effects of crop establishment methods and fertilizer doses on NPK uptake in the grains of rice crop*

Treatments	NPK uptake in grains					
	N uptake (kg ha^{-1})		P uptake (kg ha^{-1})		K uptake (kg ha^{-1})	
	SRI	CTS	SRI	CTS	SRI	CTS
T_1- No RDF	22.38	11.33	6.70	3.39	3.23	1.52
T_2- 25% RDF	34.28	21.72	8.71	5.34	4.50	2.67
T_3- 50% RDF	46.98	35.51	11.83	8.68	5.92	4.47
T_4- 75% RDF	60.78	48.85	16.26	12.38	8.13	6.19
T_5- 100% RDF	85.41	66.27	24.74	17.82	12.37	9.60
T_6- 125% RDF	82.91	66.30	23.12	18.04	12.97	9.92
Mean	55.45	41.66	15.23	10.94	7.85	5.73
LSD0.05						
Crop establishment methods(C)	3.35		0.91		0.51	
Fertilizer doses(F)	4.08		1.09		0.58	
C × F	ns		ns		ns	

SRI-system of rice intensification; CTS-conventional transplanting system; RDF-recommended dose of fertilizers, 80-40-40 kg N-P_2O_5-K_2O ha^{-1}; ns-non significant

method, due to increased yield attributes (Kumar *et al.,* 2021; Thakur et al., 2011; Mondol *et al.,* 2017). Baboo *et al.* (2023) reported that in terms of fertility management, the application of 100% RDF yielded the highest values for grain yield, straw yield, biological yield, harvest index, and the overall economics. These yields were significantly enhanced with the SRI method compared to the traditional transplanting method.

NPK uptake in grains was measured after harvest for both SRI and CTS across different NPK levels of RDF treatments and is presented in Table 1. NPK uptake increased significantly with higher doses of these fertilizers in both SRI and CTS. The highest nitrogen and phosphorus uptake was recorded in T_5 (100% RDF), with 85.41 and 24.74 kg ha^{-1} under SRI system and 66.27 and 17.82 kg ha^{-1} under CTS system, respectively. However, potassium uptake was highest in T_6 (125% RDF) but was statistically similar to T_5. On average, N, P and K uptake in grains increased by 33.1, 39.2 and 37% under SRI than CTS. SRI consistently demonstrated superior nitrogen, phosphorus and potassium uptake compared to CTS across all NPK treatments, reflecting greater nutrient utilization efficiency.

The higher NPK uptake in SRI compared to CTS can be attributed to enhanced nutrient absorption efficiency due to improved root and shoot development (Thakur *et al.,* 2011). Effective crop and water management in SRI creates favorable soil conditions that facilitate greater nutrient uptake. These factors collectively contribute to the superior nutrient absorption as observed in SRI-grown plants.Chesti *et al.* (2015) showed a significantly higher grain yield of 5.36 t ha^{-1} and total NPK uptake by rice (96.3, 20.4, and 109.5 kg ha^{-1}, respectively) for the combined application of 100% NPK and 10 t FYM ha^{-1}, compared to a grain yield of 4.96 t ha^{-1} and total NPK uptake (86.5, 18.1, and 96.8 kg ha^{-1}) with 100% NPK alone. Barison and Uphoff (2011) indicated that SRI practices can yield twice the amount of rice compared to conventional methods (6.26 vs. 2.63 t ha^{-1}). SRI plants demonstrate deeper root systems and greater nutrient uptake efficiency, particularly for phosphorus, suggesting that this innovative management practices can significantly enhance rice plant growth and productivity. Table 2 presents data on the uptake of N, P, and K in straws measured for both SRI and CTS across different NPK levels.

A similar trend in NPK uptake in straws was also found as in the case of grains. The results show a significant difference between the establishment methods and the different NPK levels of RDF. SRI consistently showed higher uptake of NPK compared to CTS across all NPK treatments, highlighting SRI's superior nutrient absorption and utilization efficiency. On average, N, P and K uptake in straws increased by 15.3, 21.0 and 8.1% under SRI than CTS. The highest nitrogen uptake was observed in T_5 (100% RDF),with 38.25 kg ha^{-1} for SRI and 32.88 kg ha^{-1} for CTS, followed closely by T_6 (125% RDF). However, the highest P and K uptake was observed in T_6 (125% RDF) under both SRI and CTS. The interaction between crop establishment methods and NPK treatments was non-significant for N, P, and K uptake.

SRI practices promote healthier plant growth through better root development, which improves the

Table 2. *Effects of crop establishment methods and fertilizer doses on NPK uptake in the straw of rice*

Treatments	NPK uptake in straw					
	N uptake (kg ha^{-1})		P uptake (kg ha^{-1})		K uptake (kg ha^{-1})	
	SRI	CTS	SRI	CTS	SRI	CTS
T_1- No RDF	20.89	19.72	4.38	3.94	63.97	63.00
T_2- 25% RDF	25.78	22.43	5.10	4.49	70.27	69.27
T_3- 50% RDF	30.46	24.84	6.09	5.18	78.76	75.59
T_4- 75% RDF	34.67	29.76	8.67	7.00	89.27	85.77
T_5- 100% RDF	38.25	32.88	12.04	9.31	101.74	94.29
T_6- 125% RDF	37.81	33.32	12.84	10.69	126.26	102.48
Mean	31.31	27.16	8.19	6.77	88.38	81.73
LSD0.05						
Crop establishment methods (C)	1.41		0.52		4.56	
Fertilizer doses (F)	2.33		0.61		6.76	
C × F	ns		ns		ns	

SRI-system of rice intensification; CTS-conventional transplanting system; RDF-recommended dose of fertilizers, 80-40-40 kg $N-P_2O_5-K_2O$ ha^{-1}; ns-non significant plant's capacity to absorb nutrients, including NPK. The increased spacing and reduced number of plants per hill in SRI decrease competition for soil nutrients, enhancing nutrient availability. Furthermore, effective water management and nutrient application in SRI create optimal soil conditions that further aid nutrient uptake, leading to higher NPK levels in the grains and straws. Kumar *et al.* (2016) also found that the highest nitrogen (123 kg ha^{-1}), phosphorus (37.1 kg ha^{-1}), and potassium (152 kg ha^{-1}) uptake were recorded in the treatment with 75% N from fertilizers and 25% N from green manuring. Thakur *et al.* (2020) reported that SRI-grown crops exhibited significantly higher nitrogen uptake in straws, roots, and grains than CTS, with grains in SRI plots contained 12% more nitrogen and 23% more phosphorus. Potassium concentrations were also higher in SRI. K uptake in rice straw and grain under SRI increased by 21% and 35%, respectively over CMP. Overall, SRI achieved an average increase of 9, 29, and 9% in nitrogen, phosphorus, and potassium uptake, respectively, compared to CMP across various nutrient management treatments.

The highest agronomic efficiency (AE) was observed in T_5, where 100% RDF was applied in both the SRI and CTS methods (Table 3), and subsequently declined. Overall, AE with SRI was 27% higher than in the CTS crop.

Partial factor productivity (PFP) of applied fertilizers was estimated to be 39% higher with SRI methods compared to CTS (Table 3). Under SRI, nearly 43 kg of grain was produced with the application of 1 kg fertilizer. In contrast, with CTS, only 31 kg of grain was produced with the application of 1 kg fertilizer. PFP was found to be significantly greater when 25% of RDF (T_1) was applied under both SRI and CTS; thereafter, it began to decline. It was lowest in T_6, where 125% of RDF was applied. Thakur *et al.* (2013) also reported an enhancement of 34 - 40% in agronomic nitrogen use efficiency with SRI compared to the CTS method in rice. They found that PFP from applied nitrogen was 49% more with the SRI method than with the CTS.

This study demonstrated that under SRI management, grain yields and NPK uptake increased significantly compared to those raised in conventional transplanted rice systems. Under the SRI method, the agronomic efficiency of applied nutrients was also significantly improved compared to flooded rice, resulting in higher factor productivity of these nutrients.

Table 3. *Effects of crop establishment methods and fertilizer doses on agronomic efficiency (AE) and partial factor productivity (PFP) in rice*

Treatments	AE (kg grain kg^{-1} fertilizer)		PPF (kg grain kg^{-1} fertilizer)	
	SRI	CTS	SRI	CTS
T_1- No RDF	-	-	-	-
T_2- 25% RDF	21.8	12.3	70.3	43.9
T_3- 50% RDF	20.5	17.0	44.8	32.8
T_4- 75% RDF	19.5	18.1	35.7	28.6
T_5- 100% RDF	24.7	20.6	36.8	28.5
T_6- 125% RDF	19.9	16.2	29.7	22.6
Mean	21.3	16.8	43.5	31.3
LSD0.05				
Crop establishment methods (C)	0.3		1.2	
Fertilizer doses (F)	1.3		2.8	
C × F	1.9		3.9	

SRI-system of rice intensification; CTS-conventional transplanting system; RDF-recommended dose of fertilizers, 80-40-40 kg N-P_2O_5-K_2O ha^{-1}

CONFLICTS OF INTEREST

The authors declare no conflict of interest.

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