

RESEARCH PAPER

# Yield, Economic Viability, and Potassium Sustainability of Rice–Wheat System as Influenced by Crop Establishment and Nutrient Management under Conservation Agriculture

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## ABSTRACT

The rice–wheat cropping system (RWCS) in the Indo-Gangetic plains faces sustainability challenges due to the biased application of nitrogenous and phosphatic fertilizers and the neglect of potassium (K), leading to soil K mining and long-term productivity risks. To address these concerns, a split-plot experiment was initiated in 2012 with four crop establishment techniques and three nutrient management practices under conservation agriculture. Results demonstrated that plots receiving crop residue in both seasons (CE4) significantly outperformed other treatments, achieving higher grain yield ( $9.1 \text{ Mg ha}^{-1}$ ), improved apparent K balance ( $+30 \text{ kg ha}^{-1}$ ), and superior sustainability index values. CE4 also recorded the lowest cost of cultivation ( $\text{₹ } 63,467 \text{ ha}^{-1}$ ), while delivering higher gross returns ( $\text{₹ } 189,513 \text{ ha}^{-1}$ ), net returns ( $\text{₹ } 126,046 \text{ ha}^{-1}$ ), and a better benefit: cost ratio (2.0). Sustainability index values improved progressively from CE1 (0.15–0.36) to CE4 (0.62–0.84), with residue incorporation (RWCM) and recommended dose of fertilizers (RDF) consistently outperforming farmers' fertilizer practice (FFP) by balancing yield, K management, and economic returns. Across treatments, rice exhibited lower cultivation costs, whereas wheat contributed greater economic returns. These findings highlight the critical role of balanced nutrient management and residue recycling in enhancing yield, profitability, and potassium sustainability of the rice–wheat system, offering a pathway to mitigate soil K depletion and secure long-term agricultural sustainability in the Indo-Gangetic plains.

## HIGHLIGHTS

- Conservation agriculture has better nutrient cycling, especially apparent K balance, higher grain yield and better farm income.
- Conservation agriculture is highly sustainable in IGP regions.

**Keywords:** Conservation agriculture, apparent K balance, crop residue, net returns, Benefit: Cost ratio

Rice and wheat have been the most preferred staple food crops globally, and the rice-wheat cropping system (RWCS) is the major cropping system in India (Banjara *et al.* 2022). The RWCS is prevalent in the Indo-Gangetic plains (IGP) and feeds more than half of the nation's population, while utilizing only 27% of the agricultural land (Kumar *et al.* 2018). This situation demands a substantial use of fertilizers. For instance, in 1971-1972, India produced 105.2 million tonnes (Mt) of food grains, and the fertilizer

consumption was 1.80 Mt N, 0.56 Mt  $\text{P}_2\text{O}_5$ , and 0.30 Mt  $\text{K}_2\text{O}$ . After five decades, in 2021-2022, food grain production grew threefold, while fertilizer usage rose 11.3 times for N, 14.2 times for  $\text{P}_2\text{O}_5$ , and only

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5.71 times for  $K_2O$  (Fertilizer Association of India, 2023). This skewed behaviour towards nitrogen (N) and phosphorus (P) application based on the assumption of adequate soil K reserve and higher K fertilizer cost has resulted K mining in Indian soils (Das *et al.* 2022). In India, the consumption ratio of N, P, and K fertilizers is reported to be 6.7:2.4:1 (Reddy, 2019), showing a significant bias towards N compared to the recommended ideal ratio of 4:2:1 by the Fertilizer Association of India (FAI, 2019). The fact itself emphasizes the disparity in K fertilization. The nitrogen and phosphatic fertilizer needs are fulfilled domestically, potassic fertilizers are entirely imported (Das *et al.* 2022). The complete dependence on imported potassic fertilizers underscores the necessity for their optimal and wise usage to maintain sustainability and profitability, and this can be achieved through optimal and efficient use of fertilizers especially potassic fertilizers through a series of various crop establishment techniques and nutrient management practices.

It is evident from previous research that the majority of plant K (80-85%) is stored in cereal straw (Singh *et al.* 2003; Whitbread *et al.* 2000). In conventional agriculture, with the removal of above ground biomass, the majority of the soil K reserve is also lost, resulting in negative K balance (Das *et al.* 2019). As an alternative to conventional agricultural practices, conservation agriculture (CA) is a multi-faceted production system which emphasizes crop residue retention as one of its core pillars (Jat *et al.* 2019). Globally, CA is practiced over 205 million hectares, accounting for 14.7% of the global crop area, and in India, it covers more than 3.5 Mha during 2018-19 (Kassam *et al.* 2022). The reduced tillage practices, along with crop residue retention coupled with optimum nutrient management practices, can reverse the deteriorating soil quality and enhance nutrient cycling. Thus, making the cropping system sustainable, producible, profitable, and in turn helps in addressing soil sustainability goals (Vermeulen *et al.* 2019). Sustainable agriculture is essential for fulfilling global food demands, safeguarding the environment, strengthening the economy, and promoting beneficial social transformations. As sustainability knowledge expands, sustainable agriculture models frequently utilize sustainability indicators (Yigitcanlar *et al.* 2015), which can be quantified and measured for a

system associated with sustainability (Pannell and Schilizzi, 1999). However, in the present scenario, the sustainable effects of CA on native soil K cycling and its associated economic parameters have not been well studied. Our present study is an attempt to address these challenges and enable smallholder farmers to reap the economic and environmental advantages of CA in a sustainable manner.

## MATERIALS AND METHODS

### Experimental site

A field study was conducted in the year 2023 at an experimental site established in 2012 at the agricultural research farm of the Institute of Agricultural Sciences, BHU, Varanasi, India (25°15'N, 82°59'E, elevation 231 m above sea level). The study site receives annual precipitation of 1110 mm, and the soil is sandy loam and belongs to the family of Typic Ustochrept.

### Treatment details

The experimental site is laid out in a split-plot design for rice (Sarajoo 52) and wheat (HD 2967) cropping system and, consisting of four major plots (crop establishment techniques) and three subplots (nutrient management practices) in a triplicate fashion. The four major treatments: (i) Conventional till rice (puddled transplanted) – Conventional till wheat (CE1) (ii) Conventional till direct seeded rice (DSR) – Conventional till wheat (CE2) (iii) Conventional till DSR – Zero till wheat (rice residue retention) (CE3) and (iv) Zero till DSR – Zero till wheat (residue retention in rice and wheat) (CE4). The three nutrient management practices: (i) Farmers' fertilizer practice (FFP) N:P<sub>2</sub>O<sub>5</sub>:K<sub>2</sub>O:Zn 164-50-32-4 kg ha<sup>-1</sup>, (ii) Recommended dose of fertilizers (RDF) N:P<sub>2</sub>O<sub>5</sub>:K<sub>2</sub>O:Zn 150-60-60-5 kg ha<sup>-1</sup>, and (iii) IRRI-Rice-wheat crop manager (RWCM) recommendation.

### Apparent K balance

Apparent K-balances were computed using the following formula:

$$\text{Apparent K-balance (kg ha}^{-1}\text{)} = FK + IK + \text{CRK} - CK \quad \dots(1)$$

where, *FK* is K addition through fertilizer (kg ha<sup>-1</sup>)

IK is K addition through irrigation water (kg ha<sup>-1</sup>)

CRK is K addition through crop residue (kg ha<sup>-1</sup>)

CK is K removal through above-ground biomass (kg ha<sup>-1</sup>)

### Economic analysis

The production cost was determined by taking into account the current market price of both input variables and output (unit cost). Numerous economic parameters were calculated using the following equations:

$$\text{Net return} = \text{Gross return} - \text{Cost of cultivation} \quad \dots(2)$$

$$\text{Gross return} = \text{Market price} \times \text{Grain yield} \quad \dots(3)$$

$$\text{Cost of cultivation} = \text{Total variable cost} + \text{Total fixed cost} \quad \dots(4)$$

Benefit: Cost (B:C) ratio =

$$\frac{\text{Net return (Rs. ha}^{-1}\text{)}}{\text{Cost of cultivation (Rs. ha}^{-1}\text{)}} \quad \dots(5)$$

Sustainability Index (SI) is a quantitative measure of a system related to sustainability. In the present study composite indices have been extensively used for SI, that integrates productivity (grain yield), nutrient balance (apparent K balance), and profitability (gross returns, net returns, cost of cultivation and B:C ratio), and is calculated as per the following equation (Iyengar and Sudarshan, 1982; Jatav and Naik, 2023):

$$Z_i = \frac{X_i - X_{\min}}{X_{\max} - X_{\min}} \quad \dots(6)$$

where,  $Z_i$  is the standardized value of the  $i^{\text{th}}$  indicator

$X_i$  is the actual value of the  $i^{\text{th}}$  indicator

$X_{\max}$  and  $X_{\min}$  are the maximum and minimum values of the  $i^{\text{th}}$  indicator in rice-wheat system

### Statistical analysis

The data generated were processed for analysis of variance as applicable to split-plot design to test differences among the treatment means as described by Gomez and Gomez (1984). Correlation coefficients were computed using SPSS 27.

## RESULTS AND DISCUSSION

### Effect on yield and apparent K balance

The experimental data revealed that different crop establishment techniques have a significant effect on crop yield (Table 1). The highest yield was observed in the CE4 plot in both rice (4.35 Mg ha<sup>-1</sup>) and wheat (4.75 Mg ha<sup>-1</sup>) crops, and the lowest yield was observed in the CE1 plot (4.0 and 4.29 Mg ha<sup>-1</sup> for rice and wheat, respectively). Within the sub-plot, nosignificant differences in yield were observed due to variation in nutrient application. The highest yield in CE4 treatments is a combined result of better availability of essential plant nutrients, optimum moisture content, and enhanced soil health (Jat *et al.* 2019). Crop residue retention in both cropping seasons in CE4 treatments has not only increased soil carbon content but has also enhanced nutrient cycling (Islam *et al.* 2023). This resulted in better grain yield production.

The annual apparent K balances for the 2022-2023 cropping cycle were determined by taking into account K inputs from irrigation water, fertilizers, and crop residue retention, along with the removal via grain and straw (Table 1). The treatments exhibited K balances of varying degrees, and were divided into two categories, viz. treatments with (i) negative balances (34-70 kg ha<sup>-1</sup>), e.g., CE1:FFP, RDF, RWCM; CE2: FFP, RDF, RWCM; CE3: FFP, and (ii) treatments with positive balances (3-42 kg ha<sup>-1</sup>), e.g., CE3: RDF, RWCM; CE2: FFP, RDF, RWCM. From apparent K balances data, it is evident that treatments receiving crop residue have positive K balances, and their extent was even greater in CE4 due to enhanced K addition in soil through decomposition of crop residue (Bader *et al.* 2021).

### Economics of the rice-wheat system

The feasibility of any agronomical practices of crop production relies on the farm income. The data from the present study (Table 2) revealed that various crop establishment techniques and nutrient management practices have severely affected gross returns, net returns, cost of cultivation, and Benefit: Cost ratio. From Table 2, it is evident that on average, the cost of cultivation was highest in CE1 (11.30% and 1.48% for rice and wheat, respectively) in comparison to CE4, followed by CE2. Higher cost of cultivation in CE1 is a result of several conventional tillage

**Table 1:** Economics and sustainability index of rice-wheat cropping system as affected by various establishment techniques and nutrient management practices

Treatments	Grain Yield (Mg ha <sup>-1</sup> , avg)	Apparent K Balance (kg ha <sup>-1</sup> )	Gross Returns (₹ ha <sup>-1</sup> )		Net Returns (₹ ha <sup>-1</sup> )		Benefit: Cost ratio	Sustainability Index (0-1)
			Rice	Wheat	Rice	Wheat		
CE1: FFP	4.10	-70	78742	98456	43954	66034	1.64	0.15
CE1: RDF	4.19	-41	80059	99714	44673	67133	1.65	0.29
CE1: RWCM	4.16	-38	82026	100971	47812	67929	1.72	0.36
CE2: FFP	4.22	-64	80294	99945	49065	67522	1.83	0.24
CE2: RDF	4.26	-55	81611	101202	49784	68621	1.84	0.34
CE2: RWCM	4.30	-57	83578	102460	52923	69417	1.92	0.43
CE3: FFP	4.35	-34	81512	101478	50283	69531	1.90	0.39
CE3: RDF	4.38	+3	82829	102735	51002	70630	1.90	0.53
CE3: RWCM	4.42	+2	84796	103992	54141	71427	1.99	0.62
CE4: FFP	4.55	+7	83623	103099	52370	71153	1.95	0.62
CE4: RDF	4.51	+42	84940	104356	53089	72252	1.96	0.73
CE4: RWCM	4.60	+41	86907	105614	56227	73048	2.04	0.84

**Table 2:** Correlation between soil and economic indices (rice-wheat system)

	Grain Yield	Apparent K	Gross Returns	Net Returns	B:C ratio
Apparent K	.892**				
Gross Returns	.897**	.866**			
Net Returns	.916**	.805**	.972**		
B:C ratio	.891**	.714**	.901**	.977**	
Sustainability Index	.945**	.952**	.974**	.934**	.855**

\*\*Correlation is significant at the 0.01 level (2-tailed).

practices, and a high rate of fertilizer application, without any nutrient compensation through crop residue (Jat *et al.* 2020). In contrast to this, several economic parameters like gross returns (6.08% for rice and 4.66% for wheat), net returns (18.50% and 7.64% for rice and wheat, respectively), and Benefit: Cost ratio (31.90% for rice and 9.23% for wheat) were found to be highest in CE4 as compared to CE1. This all happened because of the low cost of cultivation in CE4 coupled with high yield, which together resulted in higher economic returns and better Benefit: Cost ratio (Dutta *et al.* 2023). In total, irrespective of crop establishment techniques and nutrient management practices, the cost of cultivation and net returns were higher for wheat in comparison to rice.

### Sustainability index of rice-wheat cropping system

The negative K balances in CE1 and CE2 treatments show mining of soil reserves. This mirrors India's

current situation: farmers often apply N and P fertilizers but neglect K application, leading to hidden hunger and soil nutrient depletion. Treatments with positive K balance (CE3 RDF/RWCM, CE4 RDF/RWCM) not only sustain yields but also improve soil fertility, ensuring long-term productivity. India imports nearly all its potash requirements, and consumption is skewed (N:P:K ratio often > 6:2:1 instead of the recommended 4:2:1). This imbalance threatens sustainability. Hence, balanced fertilization (RDF) and residue recycling (RWCM) are crucial. They improve SI by maintaining soil K, reducing dependence on imports, and enhancing profitability.

### Relationship between crop yield, plant & soil K content, and economic parameters

Data in Table 2 have revealed that grain yield and apparent K balance is strongly and positively correlated with gross returns ( $r = 0.866^{**}$  to  $r = 0.897^{**}$ ), net returns ( $r = 0.805^{**}$  to  $r = 0.916^{**}$ ),

Benefit: Cost ratio ( $r = 0.714^{**}$  to  $r = 0.891^{**}$ ), and Benefit: Cost ratio ( $r = 0.714^{**}$  to  $r = 0.891^{**}$ ). In addition to this, economic factors were also highly correlated with each other ( $r = 0.901^{**}$  to  $r = 0.977^{**}$ ), and the Sustainability Index exhibited the strongest relationship with soil and economic indices ( $r = 0.855^{**}$  to  $r = 0.974^{**}$ ).

## CONCLUSION

The feasibility of conventional tillage practices has raised several concerns due to the ever-growing food demands on limited agricultural land. The CA has been an emerging tool that not only pioneering on efficient use of natural resources, but at the same time it is also reducing environmental degradation, and increasing farm income. From our present study, it is quite evident that CA practiced plot (CE4) has outperformed other treatments in terms of grain yield and apparent K balance. Its effect is also visible in terms of higher grain yield, low cost of cultivation, and high gross returns, net returns and better Benefit: Cost ratio. Different nutrient management practices have little to no effect on grain yield, but they significantly affect apparent K balance. Of all the treatment plots, the CE4 plot had a positive apparent K balance. CE4 RDF and CE4 RWCM emerge as the most sustainable options, combining high yield, positive K balance, and strong economics. For India, where potassium deficiency is rising and soil reserves are being depleted, adopting such balanced nutrient management is essential to secure food production and reduce external dependency. The present study is limited to only K budgeting in CA, and for future research, it needs careful consideration of other essential plant nutrients in order to have better farm income from limited resources without having a deleterious effect on the environment.

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