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Physiological and Biochemical Basis of Variation in Yield of Rice (*Oryza sativa* L.) under CA-based Crop Establishment Methods and Nutrient Management in R-W Cropping System

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ABSTRACT

Background: Crop establishment methods and nutrient management practices treatments were continuously practiced in the same plots since 2011-12 as a part of long-term experiment. A field study was conducted during 2019-2020 and 2020-2021 *i.e.* during 9th and 10th year of study to investigate the effects of CE methods and nutrient management on growth, physiological, biochemical, yield attributes and yield of rice crop.

Methods: Field experiments were carried out at the Agricultural Research Farm, Banaras Hindu University, Varanasi, laid out in split plot design replicated thrice with four crop establishment (CE) methods *viz*., CT (puddled transplanted) rice-CT wheat (CE_1),CTDSR rice-CT wheat (CE_2), CTDSR- ZT wheat (rice residue retention) (CE_3), ZT rice-ZT wheat (residue retention in rice and wheat) (CE_4) in main plots and three nutrient management (NM) practices *viz*., FP (164 kg N, 50 kg P_2O_5, 32 kg K_2O and 4 kg Zn ha^{-1}) (N_1), RFD (150 kg N, 60 kg P_2O_5, 60 kg K_2O and 5 kg Zn ha^{-1}) (N_2) and SSNM- RWCM recommendation (N_3). The rice variety used was 'Sarju-52' in the present study.

Result: The recorded data revealed that ZT rice–ZT wheat (CE_4) recorded significantly higher plant height, tillers $hill^{-1}$, leaf area, RWC, total chlorophyll content and protein content as compared to other CE methods. Among NM practices, SSNM-RWCM (N_3) recorded significantly higher plant height, tillers $hill^{-1}$, leaf area and protein content, whereas, RWC and total chlorophyll content did not differ significantly over farmer's practice and recommended fertilizer dose. Improved growth and physio-chemical attributes in ZT rice-ZT wheat (CE_4) and SSNM-RWCM (N_3) resulted in significantly higher panicles $hill^{-1}$, fertility percentage and number of filled grains $panicle^{-1}$ over other CE methods and NM practices. Panicle length, spikelets $panicle^{-1}$ and test weight showed non-significant differences. Grain yield, straw yield and biological yield were significantly higher in ZT rice-ZT wheat (CE_4) among CE methods and SSNM-RWCM (N_3) among NM practices. The harvest index showed non-significant differences for CE methods and NM practices both.

Key words: Chlorophyll content, Conservation agriculture, Conventional tillage, Direct seeded rice, Harvest index, RWC, Zero tillage.

INTRODUCTION

Rice is one of the most important cereal crops and rice-wheat production systems are fundamental to employment, income and livelihoods for hundreds of millions of rural and urban poor in South Asia (Jat *et al*., 2014). Multiple challenges associated with plough-based conventional production practices in rice-wheat rotation there such as declining factor productivity, shrinking farm profits due to increasing energy and labour costs, an emerging irrigation water crisis and recent challenges of climate change leading to a major threat to food security of South Asia. Hence the major challenge is to increase productivity to meet the growing food demand without adverse environmental impact. Long-term experiments are valuable for understanding the relationships between changing soil and crop management practices and productivity. The traditional practice of manually transplanting of rice seedlings in random geometry after intensive dry and wet tillage and conventionally tilled broadcast seeding of wheat contributes significantly to these challenges, making this system unsustainable. This practice is water, capital and energy-intensive and deteriorates soil health (Sharma *et al*., 2003). Puddling leads to the formation of a hard pan at shallow depths deteriorates the soil's physical properties and delays the planting of a succeeding wheat crop. Timely planting of wheat is crucial as yield reductions of 1-1.5% per day occur for each day after the optimum sowing date, November 15 in the IGP (Hobbs and Morris, 1996). In addition, a hard pan at shallow depths created by repeated puddling inhibits root elongation of the post-rice crop, which

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can ultimately reduce crop yield (Boparai *et al*., 1992). Direct seeding is an attractive alternative to transplanting rice to reduce labour input, drudgery in farming and the cost of cultivation. Rice is direct-seeded either by dry seeding primarily in rainfed areas and/or by wet seeding in irrigated areas. In India and Nepal, experiments evaluated dry-seeded rice with no soil puddling as an alternative to puddled transplanted rice followed by zero-till or conventional-tilled wheat (Hobbs *et al*., 2002). Published studies demonstrate an 8% reduction in wheat yield when sown after puddled transplanted rice compared with wheat sown after direct sown rice in non-puddled conditions (Kumar *et al*., 2008). In the conventional systems involving intensive tillage, there is a gradual decline in soil organic matter through accelerated oxidation and burning of crop residues causing pollution, greenhouse gases emission and loss of valuable plant nutrients. Conservation agriculture practices are recognized as a powerful tool to address the issues related to land and environmental degradation. CA has great relevance to restore the degraded ecologies where farm income and fatigue in yield have become major concerns. Conservation technologies involve minimum soil disturbance, providing soil cover through crop residues or other cover crops and crop rotations for achieving higher productivity. Resource-conserving technologies such as zero-tillage and un-puddled transplanting has been shown to be beneficial in terms of improving soil health, water use, crop productivity and farmers' income (Gupta and Sayre, 2007; Gupta and Seth, 2007; Singh *et al*., 2009). Due to the rising cost of labour and excessive water use in puddling for transplanting rice in the irrigated ecosystems, direct seeding of rice is gaining popularity in south-east Asia (Balasubramanian and Hill, 2002). Direct-seeded rice needs only 34% of the total labour requirement and saves 29% of the total cost of the transplanted crop. ZT is widely adopted in wheat by farmers in the North-western IGP of India, particularly in areas where rice is harvested late. ZT minimizes the loss on account of delayed sowing as it advances the wheat sowing by 10-15 days and also saves the time and cost involved in field preparation (Sharma *et al*., 2002; Chandana *et al*., 2010). However, to get the full benefits of ZT, both rice and wheat need to be grown with a 'double zero-tillage system (Jat *et al*., 2006; Bhushan *et al*., 2007). Important factors that are forcing a shift from the traditional puddled-transplanting system to unpuddled direct seeding of rice are shortages of labour and water and escalating fuel prices. Successful implementation of a conservation agriculture system depends to a large extent on a good understanding of the dynamics of nutrients in the soil and nutrient management which requires serious attention. Involuntarily on the part of the farming community in the adoption of zero tillage sowing of rice wheat in a large area is mainly due to associated with the management of nutrients. Nutrients are driven by an interaction of several factors; tillage, doses, timing and type of fertilizer management practice. The present study was planned to study the growth, physiological and biochemical parameters of rice crop in 2019-20 (9th year and 2020-21 (10th year) of a long-term study started in 2011 to find the suitability and discuss the variation of the yield of four CE methods and three NM practices in the rice-wheat cropping system.

MATERIALS AND METHODS

Treatments and experimental design

Field experiments were laid out in split plot design replicated thrice with four crop establishment methods *viz*., CE_1: Conventional till rice (puddled transplanted) - Conventional till wheat (line sowing) [CT rice-CT wheat], CE_2: Conventional till direct seeded rice - conventional till wheat (line sowing) [CTDSR rice-CT wheat], CE_3: Conventional till direct seeded rice - Zero-till wheat[CTDSR-ZT wheat], CE_4: Zero-till direct seeded rice -Zero-till wheat [ZT rice-ZT wheat] in main plots and three nutrient management practices *viz*., N_1: Farmers practice, N_2: Recommended fertilizer dose and N_3: SSNM-RWCM in subplots during both the years. In zero-till rice plots, the crop was established without any preparatory tillage. In CTDSR treatment the ploughing was done twice with a tractor-drawn cultivator followed by planking. In the CT method, the experimental area was tilled dry and wet followed by puddling with a cage wheel, levelled and thereafter layout was done. Glyphosate (1 kg ha^{-1}) was sprayed in all zero-till treatments before seeding during both years. Recommended herbicides pendimethalin at 1.0 kg *a.i.* ha^{-1} as pre-emergence and post-emergence herbicides bispyribac 25 g *a.i.* ha^{-1} at 20 DAS/DAT in rice were applied with 500 litter ha^{-1} of water with the help of a knapsack sprayer, fitted with a flat-fan nozzle.

Crop management

Seed Rate and crop geometry

In CTDSR and ZT rice treatments sowing was done by using a tractor-drawn zero-till seed-cum-fertilizer planter with a row spacing of 20 cm apart and seeding depth was maintained at 2-3 cm using the depth control wheel of the planter. The rice variety 'Sarju-52' was used at the rate of 30 kg ha^{-1}. The seeding was done on 23rd June 2019 and 27th June 2020 in CTDSR and ZT Rice treatments. On the same day, seeds were sown in the nursery for conventional till rice (puddled transplanted) and 30 days old seedlings were manually transplanted in line (farmer's practice) in both years.

Water management

During both years of rice experimentation, satisfactory/ sufficient monsoon showers were received. Total rainfall and distribution were more uniform in both years during the crop period. However, during both years one irrigation was provided as pre-sowing irrigation and after sowing and transplanting no irrigation was provided.

Nutrient management

Three nutrient management practices *viz*., Farmers practice (164 kg N, 50 kg P_2O_5, 32 kg K_2O and 4 kg Zn ha^{-1}), Recommended fertilizer dose (150 kg N, 60 kg P_2O_5, 60 kg K_2O and 5 kg Zn ha^{-1}) and SSNM- RWCM recommendation for rice 2019 transplanted, DSR and zero till basal application 39 kg N, 26.5 kg P_2O_5, 19.5 kg K_2O, 5.25 kg Zn ha^{-1}, at active tillering (AT) 45.5 kg N ha^{-1} and at panicle initiation (PI) 45.5 kg N ha^{-1} and 19.5 kg K_2O ha^{-1}. In 2020 transplanted rice basal application 32.5 kg N, 33.5 kg P_2O_5, 18 kg K_2O and 5.25 kg Zn ha^{-1}, at (AT) 38.5 kg N ha^{-1} and at (PI) 38.5 kg N and 18.0 kg K_2O ha^{-1} and in DSR and zero till rice basal application 34.5 kg N, 36.0 kg P_2O_5, 19.5 kg K_2O and 5.25 kg Zn ha^{-1} and at active tillering 40 kg N ha^{-1} and at panicle initiation,40 kg N and 19.5 kg K_2O ha^{-1} have been applied in sub-plots during both the years.

Growth, physiological, biochemical and yield observations

Growth, physiological and biochemical observations presented in this paper was recorded at 80 DAT/ DAS and yield attributes and yield were taken at the harvest stage of rice crop. The plant height was recorded with the help of a meter scale from the base of the plant to the tip of the panicle after heading and expressed in cm. Tillers $hill^{-1}$ were recorded by counting tillers from the randomly selected hills at 80 DAS/DAT and then averaged. The days taken to 50% of the plants in each plot attained flowering was recorded by counting from the date of sowing/ transplanting and when half of all the plants had already flowered in all the plots visually. The days taken from the date of sowing to the physiological maturity were recorded from each net plot carefully by visual observation when plant leaves became completely yellow, grains become hard and turn to golden-yellow colour. The days to maturity in each plot were counted from the date of nursery raising and expressed as days to physiological maturity.

Leaf area

Leaf area per hill was calculated by the dry weight method. Leaf areas of two leaves were obtained by the graphical method and such leaves along with the remaining leaves were dried separately in a hot air oven at 80°C for 72 hrs. The dry weight of two leaves and the rest of the leaves were recorded and the leaf area was calculated by using the following formula.

$$\text{Leaf area} = (a \times w)/b + a \ \text{cm}^2\,\text{hill}^{-1}$$

Where,

a = Leaf area (cm^2) of 2 leaves.

b = Dry weight (mg) of 2 leaves.

w = Dry weight (mg) of the rest of the leaves.

Relative water content (%)

The relative water content was estimated by the method of Barrs and Weatherly (1962).

$$\text{RWC (\%)} = \frac{\text{Fresh weight - Dry weight}}{\text{Turgid weight- Dry weight}} \times 100$$

The protein content was estimated by the method of Bradford (1976) and chlorophyll content was estimated by the acetone method given by Arnon (1949).

Harvest index (%)

The harvest Index was calculated as per the below given formula given by Donald (1962).

$$\text{Harvest Index (\%)} = \frac{\text{Grain yield}}{\text{Biological yield}} \times 100$$

Statistical analysis

The experimental data were statistically analyzed by using the Co-Stat Software of analysis of variance (ANOVA) for split-plot design (Gomez and Gomez, 1984). The test of significance was carried out at a 5% level of significance by referring to the 'F' table values.

RESULTS AND DISCUSSION

Plant growth and developmental studies

The observations on growth attributes *viz*., plant height (cm), tillers per hill, leaf area per hill, days to 50% flowering and days to physiological maturity were recorded at the heading stage (80 DAT/DAS) and presented in Table 1. The plant height ranged from 88 cm in CE_4 [ZT rice-ZT wheat] to 78.7 cm in CE_1 [CT rice-CT wheat]. Tillers per hill was maximum in CE_4 [ZT rice-ZT wheat] (14.9) and minimum inCE_1 [CT rice-CT wheat] (9.4). Similarly, Leaf area was highest at 1088.3 cm^2 $hill^{-1}$ in CE_4 [ZT rice-ZT wheat] as compared to 856.5 cm^2 $hill^{-1}$ in CE_1 [CT rice–CT wheat]. The data on growth parameters showed more variations among crop establishment methods. The different crop establishment methods found a significant effect on growth parameters *viz*., plant height, tillers $hill^{-1}$ and leaf area in two years pooled data at the heading stage of crop growth. The maximum values were recorded in zero till DSR (CE_4) over conventional till puddled transplanted rice (CE_1) followed by CTDSR (CE_3). The days to 50% flowering and days to physiological maturity were reduced under zero-till DSR (CE_4) (69.3 and 112.8 days) and was maximum (77.9 and 118.4 days) in conventional till puddled transplanted rice (CE_1). Various nutrient management practices had a significant influence on growth attributes *viz*., plant height, number of tillers $hill^{-1}$, leaf area, days to 50% anthesis and days to physiological maturity in pooled data of both years. At the heading stage, significantly higher growth attributes were recorded by nutrient application based on RWCM- SSNM approach (N_3) compared to farmer's practice (N_1) followed by recommended fertilizer dose (N_2) treatment. Interaction failed to reach the level of significance except for the leaf area. Similar results were reported earlier by researchers (Hobbs *et al*., 2002; Yadav *et al*., 2014 and Singh *et al*., 2018).

Physiological and biochemical studies

The applicable data (Table 2) related to physiological and biochemical parameters *viz*., relative water content, total chlorophyll content and protein content as influenced by crop establishment methods and nutrient management practices were studied. The same were recorded at 80 DAS/DAT during both years of study. The first fully mature and expanded leaves were used for the analysis. The relative water content, chlorophyll content and protein content of leaves was recorded significantly highest in treatment CE_4 (ZT rice - ZT wheat) (96.84%, 1.61 mg g^{-1} FW and 6.31 mg g^{-1} FW) due to absorption of moisture in the soil by crop residues followed by CE_3 (96.03%, 1.51 mg g^{-1} FW and 5.92 mg g^{-1} FW)and the least was recorded in

Table 1: Effect of crop establishment methods and nutrient management on plant height, tillers $hill^{-1}$, leaf area $hill^{-1}$, days to 50% flowering and days to physiological maturity (Pooled data).

Treatments	Plant height (cm)	Tillers $hill^{-1}$	Leaf area (cm^2 $hill^{-1}$)	Days to 50% anthesis	Days to physiological maturity
Main plot	**Crop establishment methods (CE)**				
CE_1: CT rice-CT wheat	78.7	9.4	856.5	77.9	118.4
CE_2: CTDSR-CT wheat	82.1	12.1	932.1	75.3	116.8
CE_3: CTDSR-ZT wheat	85.1	13.5	1001.4	72.4	114.9
CE_4: ZT rice-ZT wheat	88.0	14.9	1088.3	69.3	112.8
SEm±	0.7	0.4	0.6	0.5	0.6
CD at 5%	2.5	1.7	2.3	1.9	1.9
Sub-plot	**Nutrient management (N)**				
N_1: Farmers practice	82.5	11.8	945.2	74.9	116.9
N_2: Recommended fertilizer dose	83.5	12.5	967.3	73.7	115.7
N_3: SSNM-RWCM recommendation	84.5	13.1	996.2	72.7	114.7
SEm±	0.6	0.2	0.8	0.8	0.8
CD at 5%	1.4	0.6	2.3	NS	NS
Interaction (CE × N)	**Crop establishment methods × Nutrient management**				
SEm±	1.1	0.4	1.5	1.6	1.7
CD at 5%	NS	NS	4.6	NS	NS

CT: Conventional till; ZT: Zero till; DSR: Direct seeded rice; SSNM-RWCM: Site-specific nutrient management-Rice-wheat crop manager; DAT: Days after transplanting; DAS: Days after sowing; SEM: Standard error mean; CD: Critical difference; NS: Non-significant.

Table 2: Effect of crop establishment methods and nutrient management on relative water content (%), total chlorophyll content and protein content of rice (Pooled data).

Treatments	Relative water content (%)	Total chlorophyll content (mg g^{-1} FW)	Protein content (mg g^{-1} FW)
Main plot	**Crop establishment methods (CE)**		
CE_1: CT rice -CT wheat	93.73	1.31	5.11
CE_2: CTDSR-CT wheat	94.85	1.42	5.49
CE_3: CTDSR-ZT wheat	96.03	1.51	5.92
CE_4: ZT rice-ZT wheat	96.84	1.61	6.31
SEm±	0.31	0.03	0.03
CD at 5%	1.05	0.11	0.11
Sub-plot	**Nutrient management (N)**		
N_1: Farmers practice	95.03	1.43	5.61
N_2: Recommended fertilizer dose	95.37	1.46	5.71
N_3: SSNM-RWCM recommendation	95.69	1.50	5.80
SEm±	0.34	0.04	0.04
CD at 5%	NS	NS	0.11
Interaction (CE × N)	**Crop establishment methods × Nutrient management**		
SEm±	0.68	0.73	0.75
CD at 5%	NS	NS	NS

CT: Conventional till; ZT: Zero till; DSR: Direct seeded rice; SSNM-RWCM: Site-specific nutrient management- Rice-wheat crop manager; DAT: Days after transplanting; DAS: Days after sowing; SEM: Standard error mean; CD: Critical difference; NS: Non-significant.

CE_1(93.73%, 1.31 mg g^{-1} FW and 5.11 mg g^{-1} FW). The pooled data of two years for crop establishment methods differed significantly at 80 DAS/DAT. Under sub plot *i.e.* nutrient management practices, RWC and total chlorophyll content did not differ significantly. The maximum values were recorded in N_3 (SSNM-RWCM) followed by N_2 (Recommended fertilizer dose) and the minimum was observed in N_1 (Farmers practice). Although the data obtained for protein content was found significant with 5.80mg g^{-1} FW in N_3 (SSNM-RWCM) and 5.65mg g^{-1} FW in N_1 (Farmers practice). The treatment combination of CE_4 with N_3 has higher values due to the optimum use of resources and efficient use of nutrients indirectly increasing the yield of the crop. Similar results were also found in Bhattacharya and Singh (1992).

Yield components and yield

The relevant data (Table 3 and 4) related to yield attributes *viz*., number of panicles, number of spikelets $panicle^{-1}$, test weight, number of filled grains $panicle^{-1}$, panicle length, fertility percentage, grain yield, straw yield, biological yield and harvest index as influenced by crop establishment methods and nutrient management practices were studied. The maximum yield was recorded in CE_4 followed by CE_3 and the least was recorded in CE_1 and among the subplots highest in N_3 (SSNM-RWCM) followed by N_2 (Recommended fertilizer dose) and least in treatment N_1 (Farmers practice). The enhanced values in yield components could be due to increasing leaf area leading to higher photosynthesis and accumulation of more assimilates which led to increased grains per panicle and fertility percentage (Balasubramanian and Hill, 2002). The number of panicles per hill, number of filled grains $panicle^{-1}$ and fertility percentage showed significant differences in CE methods and nutrient management practices in the pooled data of two years. The maximum number of panicles per hill,number of filled grains $panicle^{-1}$ and highest fertility percentage was recorded in CE_4 followed by $CE_3$and the least was recorded in $CE_1$and among the subplots highest in N_3 (SSNM-RWCM) followed by N_2 (Recommended fertilizer dose) and least in treatment N_1 (Farmers practice).Panicle length,numbers of spikelets $panicle^{-1}$ and test weight (g) did not differ significantly among treatments of CE methods and nutrient management practices in the pooled data of two years although the maximum number of spikelets per panicle and test weight was recorded in treatment CE_4 (ZT rice - ZT wheat) and N_3 (SSNM-RWCM) respectively.

The highest grain yield (kg $plot^{-1}$ and q ha^{-1}) showed significant differences in CE methods and nutrient management practices in the pooled data of two years. The highest grain yield (13.45 kg $plot^{-1}$and 49.21q ha^{-1}) was recorded in CE_4 followed by CE_3 and the least was recorded in CE_1 (11.21 kg $plot^{-1}$and 41.82q ha^{-1}) and among the subplots highest in N_3 (SSNM-RWCM) (12.61 kg $plot^{-1}$and 47.02 q ha^{-1}) followed by N_2 (Recommended fertilizer dose) and least in treatment N_1 (Farmers practice) (11.98 kg $plot^{-1}$ and 44.71 q ha^{-1}). The straw yield (q ha^{-1}) and biological yield (q ha^{-1}) also differed significantly in CE methods and nutrient management practices in both the years of study. The highest straw yield and biological yield was recorded in CE_4 followed by CE_3 and the least was recorded in CE_1

Table 3: Effect of crop establishment methods and nutrient management on panicles $hill^{-1}$, spikelet's $panicle^{-1}$, filled grains $panicle^{-1}$, test weight (g), fertility percentage and panicle length of rice (Pooled data).

Treatments	Panicles $hill^{-1}$	Spikelets $panicle^{-1}$	Filled grains $panicle^{-1}$	Test weight (g)	Fertility percentage (%)	Panicle length (cm)
Main plot			**Crop establishment methods (CE)**			
CE_1: CT rice-CT wheat	8.83	120.17	82.57	22.29	81.89	22.99
CE_2: CTDSR-CT wheat	10.83	122.06	86.67	22.18	83.35	23.75
CE_3: CTDSR-ZT wheat	12.94	123.28	88.21	22.32	84.21	23.78
CE_4: ZT rice-ZT wheat	14.72	124.94	90.05	22.46	85.48	24.01
SEm±	0.31	1.24	0.88	0.19	0.38	0.21
CD at 5%	1.08	NS	3.03	NS	1.32	NS
Sub-plot			**Nutrient management (N)**			
N_1: Farmers practice	11.12	122.1	85.75	22.33	82.29	23.34
N_2: Recommended fertilizer dose	11.75	123.6	86.75	22.29	83.68	23.64
N_3: SSNM-RWCM recommendation	12.62	124.37	88.12	22.32	84.09	23.92
SEm±	0.27	0.95	0.54	0.10	0.62	0.29
CD at 5%	0.81	NS	1.61	NS	1.84	NS
Interaction (CE × N)			**Crop establishment methods × Nutrient management**			
SEm±	0.53	1.90	1.75	0.21	1.10	0.57
CD at 5%	NS	NS	NS	NS	NS	NS

CT: Conventional till; ZT: Zero till; DSR: Direct seeded rice; SSNM-RWCM: Site-specific nutrient management- Rice-wheat crop manager; DAT: Days after transplanting; DAS: Days after sowing; SEM: Standard error mean; CD: Critical difference; NS: Non-significant.

Table 4: Effect of crop establishment methods and nutrient management on grain yield (kg plot^{-1} and q ha^{-1}), straw yield (q ha^{-1}), biological yield (q ha^{-1}) and harvest index (%) of rice (Pooled data).

Treatments	Grain yield (kg plot^{-1})	Grain yield (q ha^{-1})	Straw yield (q ha^{-1})	Biological yield (q ha^{-1})	Harvest index (%)
Main plot			**Crop establishment methods (CE)**		
CE_1: CT rice-CT wheat	11.21	41.82	62.81	104.65	39.93
CE_2: CTDSR-CT wheat	12.05	44.98	66.14	111.12	40.33
CE_3: CTDSR-ZT wheat	12.41	46.32	69.10	115.43	40.64
CE_4: ZT rice-ZT wheat	13.45	49.21	72.09	122.31	41.13
SEm±	0.14	0.51	0.28	0.52	0.31
CD at 5%	0.47	1.75	0.96	1.79	NS
Sub-plot			**Nutrient management (N)**		
N_1: Farmers practice	11.98	44.71	66.64	111.35	40.12
N_2: Recommended fertilizer dose	12.26	45.78	67.42	113.20	40.39
N_3: SSNM-RWCM recommendation	12.61	47.02	68.55	115.57	40.64
SEm±	0.12	0.47	0.41	0.74	0.23
CD at 5%	0.38	1.43	1.21	2.22	NS
Interaction (CE × N)			**Crop establishment methods x Nutrient management**		
SEm±	0.25	0.95	0.80	1.48	0.46
CD at 5%	NS	NS	NS	NS	NS

CT: Conventional till; ZT: Zero till, DSR: Direct seeded rice; SSNM-RWCM: Site-specific nutrient management- Rice-wheat crop manager; DAT: Days after transplanting; DAS: Days after sowing; SEM: Standard error mean; CD: Critical difference; NS: Non-significant.

and among the subplots highest in N_3 (SSNM-RWCM) followed by N_2 (Recommended fertilizer dose) and least in treatment N_1 (Farmers practice). The harvest index did not differ significantly among treatments of CE methods and nutrient management practices in both the year of study, although the highest harvest index was recorded in treatment CE_4 (ZT rice - ZT wheat) and N_3 (SSNM-RWCM) respectively.

CONCLUSION

Crop establishment methods and nutrient management practices treatments were continuously practiced in the same plots for the last nine years as part long-term study which resulted in substantive changes in the research plots. It is well understood that Zero tillage improves crop growth, water use efficiency and optimum nutrient use in rice-wheat cropping systems. Zero tillage with residue retention provides a healthy soil environment by reducing soil compaction and allowing water and roots to move to deeper soil layers. In our experiment it was found that the ZT rice-ZT wheat (CE_4) crop establishment method recorded highest growth, physiological, biochemical, yield attributes and grain yield of rice due to efficient crop resource use over CT rice-CT wheat (CE_1) and in respect of nutrient management practices as per SSNM-RWCM recommendation (N_3) enhanced growth, physiological, biochemical, yield attributes and grain yield of rice. It can be concluded that the ZT rice-ZT wheat (CE_4) crop establishment method with SSNM-RWCM recommendation (N_3) should be followed to achieve better growth, physiology, higher grain yield and harvest index in rice. However, further research needs to be carried out on the impact of different tillage practices under variable components of the rice-wheat cropping system.

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Conflict of interest

The authors declare that they have no conflicts of interest.

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