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Growth and physiological parameters of rice (*Oryza sativa* L.) as influenced by conservation agriculture-based crop establishment methods and nutrient management in R-W cropping system

Bhangare Rupali V, Pravin Prakash and UP Singh

Abstract
A field experiment was conducted during 2019-2020 and 2020-2021 at the Agricultural Research Farm, Banaras Hindu University, Varanasi (UP) India. Field experiments were laid out in split plot design replicated thrice with four crop establishment methods *viz*., CT (puddled transplanted) rice– CT (Conventional Tillage) wheat (CE_1), CTDSR rice–CT wheat (CE_2), CTDSR–ZT (Zero Tillage) 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 practices *viz*., FP (Farmers Practice) (164 kg N (Nitrogen), 50 kg P_2O_5 (Phosphate), 32 kg K_2O (Potassium) and 4 kg Zn ha^{-1}) (N_1), RFD (Recommended Fertilizer Dose) (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 treatments on crop establishment methods and nutrient management practices is being carried out in the same plots since 2011 as a long term study and our growth and physiological observations was recorded at 9th and 10th year of experimentation. Crop establishment methods and nutrient management practices differed significantly in respect to growth, physiological, some of the yield attributes and grain yield of rice. Among crop establishment methods, recorded data revealed that ZT rice–ZT wheat recorded maximum plant height, tillers $hill^{-1}$, functional leaves $hill^{-1}$, leaf area, total dry matter $hill^{-1}$, LAI, CGR, SLW, LAD, panicles $hill^{-1}$, fertility per cent, filled grains $panicle^{-1}$ and grain yield $hill^{-1}$ and the least values for above parameters were recorded in CT (puddled transplanted) rice– CT wheat. Spikelets $panicle^{-1}$ and test weight did not differ significantly among different crop establishment methods. SSNM (Site-Specific Nutrient Management)-RWCM (Rice-Wheat Crop Manager) (N_3) recorded significantly higher growth, physiological and yield attributes of rice over farmers' practice (N_1) and it was superior or at par with recommended fertilizer dose (N_2).

Keywords: Conservation agriculture, crop establishment methods, nutrient management practices, zero tillage, rice-wheat cropping system

1. Introduction

Rice is the most important staple food in Asia. More than 90% of the world's rice is grown and consumed in Asia, where 60% of the world's population lives. The 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) [13]. Multiple challenges associated with plough-based conventional production practices in rice-wheat rotation including declining factor productivity, shrinking farm profits due to increasing energy and labour costs, an emerging irrigation water crisis, and recent challenges of climate change are 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 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) [21]. 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. In addition, a hard pan at shallow depths created by repeated puddling inhibits root elongation of the post-rice crop, which can ultimately reduce crop yield (Boparai *et al*., 1992) [4]. Rice is direct-seeded either by dry seeding (DSR) 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 (TPR) followed by zero-till or conventional-tilled wheat (Hobbs *et al*., 2000) [11]. Published studies demonstrate an 8% reduction in wheat yield when sown after puddled transplanted rice compared with wheat sown after direct sown rice (DSR) in non-puddled conditions (Kumar *et al*., 2008) [15]. 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 (Conservation agriculture) 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. This has emerged as a way to transition to the sustainability of intensive cropping systems. Hence, several long-term studies have been conducted globally to introduce conservation agriculture technologies in selected cropping systems as a main way of improving crop yields, soil health, and income, whilst reducing the requirement of energy and environmental degradation with special emphasis on irrigated cropping systems in South Asia.

Resource-conserving technologies (RCTs) such as zero-tillage (ZT) and un-puddled transplanting have 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) [7, 8, 23]. 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) [2]. 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) [22]. 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) [12, 3]. 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, the adoption of zero tillage sowing of rice and wheat in a large area is mainly due to the associated management of nutrients.

2. Materials and Methods

2.1 Experimental site and soil: The experimental field was located at the Agricultural Research Farm, Institute of Agricultural Sciences, Banaras Hindu University, Varanasi (U.P.), India during the *Kharif* season of 2019 and 2020. Two years trial was carried out during 9th and 10th year of long term study involving various combinations of tillage, crop establishment methods, and nutrient management practices in a rice–wheat rotation. The geographical situation of the farm lies at 25°18' N latitude and 83°31' E longitude at an altitude of 75.7 meters from the mean sea level in the Northern Gangetic Alluvial plains. The soil of the experimental field was sandy clay loam in texture with a pH of 7.30. It was moderately fertile being low in organic carbon (0.43%) and available nitrogen (208.19 kg ha^{-1}), but medium in available phosphorus (24.80 kg ha^{-1}) and potassium (221.60 kg ha^{-1}). Climatologically Varanasi district falls in subtropical climate and is subjected to extremes of weather conditions *i.e.* extremely hot summer and cold winter. This region falls in a semi-arid to sub-humid type of climate. Normally the period for the onset of monsoon in this domain is the third week of June and it lasts up to the end of September or sometimes extends up to the first week of October. The area also experiences some winter showers due to cyclonic rains from December to February. The period between March to May is generally dry. Long term average of annual rainfall for this region amounts to 1081.5 mm of which 944.5 mm (87.33 percent) is received during the monsoon or rainy season (June to September) and 137.0 mm (12.67 percent) during the post-monsoon season or post rainy season.

2.2 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) {farmers practice}[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 gm a.i. ha^{-1} at 20 DAS/DAT in rice were applied with 500 L ha^{-1} of water with the help of a knapsack sprayer, fitted with a flatfan nozzle.

2.3 Crop management

2.3.1 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 the 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}. 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 20 days old seedlings were manually transplanted in line (farmer's practice) in both years.

2.3.2 Water and nutrient 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.

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. Under SSNM- RWCM recommendation for transplanted, DSR and zero till, the basal application of 39 kg N, 26.5 kg P_2O_5, 19.5 kg K_2O and 5.25 kg Zn ha^{-1}, whereas, at active tillering (AT) stage 45.5 kg N ha^{-1} and at panicle initiation (PI) stage 45.5 kg N ha^{-1} and 19.5 kg K_2O ha^{-1} were applied in 2019. The basal application of 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} for transplanted rice and in DSR and zero till basal application of 34.5 kg N, 36.0 kg P_2O_5, 19.5 kg K_2O, and 5.25 kg Zn ha^{-1}, and at AT 40 kg N ha^{-1} and at PI, 40 kg N and 19.5 kg K_2O ha^{-1} have been applied in rice during 2020.

2.4 Growth, Physiological and Yield Observations: Growth and physiological observations were recorded at physiological maturity i.e, 120 DAT/ DAS, and yield attributes and yield were taken at the harvest stage of rice.

Plant height: Five plants from each experimental plot were selected randomly and tagged. Plant height of the rice was recorded at 120 DAS/DAT with the help of a meter scale from the base of the plant to the tip of the panicle after heading, then averaged and expressed in cm.

Leaf area: Leaf area per hill was calculated by the dry weight method. Leaf area 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.

$$\text{Leaf area} = (a \times w)/ b + a$$

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

The leaf area obtained was expressed as cm^2 $hill^{-1}$.

Total dry matter: Total dry matter accumulation was recorded by the randomly selected hills at 120 DAS/DAT by cutting the above ground biomass. Samples were first dried in the sun and then oven dried at 65 °C till the constant dry weight was achieved. After drying, the samples were weighed for recording dry weight and expressed in g $hill^{-1}$.

Leaf area index: The leaf area index was calculated by employing the formula of Williams (1946).

LAI = Leaf area per hill / Ground area occupied per hill

Crop growth rate: The crop growth rate (CGR) was calculated by using the formula of Watson (1947) and expressed in g m^{-2} day^{-1}.

$$CGR = W_2 - W_1 / P\,(t_2 - t_1)$$

Were

W_1 and W_2 = Whole plant dry weight at time t1 and t2 respectively

t_1 and t_2= Time in days, P = Ground area occupied by plant (m^2)

Specific leaf weight*:* SLW = Leaf dry weight / Leaf area

Were

LW = leaf dry weight (g)

LA = leaf area (cm^2)

Leaf area duration: LAD was calculated using the following formula

$$LAD = (LAI_1 + LAI_2) / 2 \times T_2 - T_1$$

Were

LAI_1 and LAI_2 = Leaf area index at first and second sampling

T_1 and T_2 = Time of leaf area index 1 and 2 taken

2.5 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.

3. Results and Discussion

3.1 Effect on growth parameters: The observations on growth attributes *viz*., plant height (cm), tillers per hill, functional leaves per hill, leaf area per hill, and total dry matter accumulation (g $hill^{-1}$) were recorded at the physiological maturity stage *i.e.*120 DAT/DAS, and presented in Table 1. The data on growth parameters at 120 DAS/DAT showed more variations among crop establishment methods. At physiological maturity, the different crop establishment methods found significant effects on growth parameters *viz.*, plant height, tillers $hill^{-1}$, functional leaves $hill^{-1}$, leaf area, and total dry matter accumulation (g $hill^{-1}$), differed significantly during both years. The maximum values were recorded in zero till DSR (CE_4) over conventional till puddled transplanted rice (CE_1) followed by CTDSR (CE_3) during both the years. Various nutrient management practices had a significant influence on growth attributes *viz.*, plant height, tillers $hill^{-1}$, functional leaves $hill^{-1}$, leaf area, and dry matter accumulation (g $hill^{-1}$) during both the years of experimentation. At the physiological maturity 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 during both the years of study. Interaction failed to reach the level of significance except for the leaf area during both years of investigation. Similar results were reported earlier by researchers Habbs *et al.* (2002), Yadav *et al.* (2014), and Singh *et al.* (2018).

Table 1: **E**ffect of crop establishment methods and nutrient management on plant height, tillers hill^{-1}, functional leaves hill^{-1}, leaf area hill$^{-1,}$ and total dry matter accumulation at the physiological maturity stage of rice (Two years pooled data)

Treatments	**Plant height (cm)**	**Tillers hill^{-1}**	**Functional leaves hill^{-1}**	**Leaf area (cm^2 hill^{-1})**	**Total dry matter accumulation (g hill^{-1})**
Main plot	**Crop establishment methods (CE)**				
CE_1: CT rice – CT wheat	79.91	9.05	8.55	363.4	19.29
CE_2: CTDSR – CT wheat	82.99	11.2	10.33	441.5	23.11
CE_3: CTDSR – ZT wheat	85.86	12.5	12.61	526.8	26.83
CE_4: ZT rice – ZT wheat	88.73	14.5	14.12	595.5	30.75
SEm±	0.79	0.27	0.25	0.58	0.13
CD at 5%	2.73	0.93	0.86	2.15	0.45
Sub-plot	**Nutrient management (N)**				
N_1: Farmers Practice	83.44	11.2	10.42	453.4	23.71
N_2: Recommended Fertilizer Dose	84.31	11.8	11.29	484.8	24.88
N_3: SSNM-RWCM Recommendation	85.38	12.5	12.04	507.2	26.40
SEm±	0.34	0.28	0.21	0.84	0.14
CD at 5%	1.01	0.75	0.63	2.53	0.42
Interaction (CE x N)	**Crop establishment methods x Nutrient management**				
SEm±	0.62	0.55	0.42	1.68	0.28
CD at 5%	NS	NS	NS	5.61	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

3.2 Effect on physiological parameters: The observations on physiological studies *viz.*, leaf area index and specific leaf weight recorded at 120 DAS/DAT, whereas, crop growth rate and leaf area duration calculated for duration (80-120 DAS/DAT) are presented inTable.2. Since the stage of observation greatly differed from the establishment method (CT rice) to the establishment method (DSR), the data on physiological studies showed more variations among crop establishment methods. The crop establishment methods differed significantly in leaf area index, crop growth rate, specific leaf weight, and leaf area duration during both years. The maximum LAI, CGR, SLW, and LAD were recorded in ZT DSR (CE_4) followed by CTDSR (CE_3) and minimum values CT puddled transplanted rice (CE_1) during both the years. Various nutrient management practices had a significant influence on physiological studies *viz.*, leaf area index, crop growth rate, specific leaf weight, and leaf area duration during both years of experimentation. The maximum LAI, CGR, SLW, and LAD were recorded by nutrient application based on RWCM- SSNM approach (N_3) as compared to farmer's practice (N_1) followed by recommended fertilizer dose (N_3) treatment during both the year of study. Interaction failed to reach the level of significance in CGR and SLW however, interaction (CE x N) was found significantly differing for leaf area index and leaf area duration during both years of investigation.

Table 2: Effect of crop establishment methods and nutrient management on LAI, CGR, SLW and LAD at the physiological maturity stage of rice (Two years pooled data)

Treatments	**Leaf area index**	**Crop growth rate (g m^{-2} day^{-1})**	**Specific leaf weight (g m^{-2})**	**Leaf area duration (days)**
Main plot	**Crop establishment methods (CE)**			
CE1: CT rice–CT wheat	1.81	6.91	40.45	122.1
CE2: CTDSR–CT wheat	2.21	8.72	46.67	137.4
CE3: CTDSR–ZT wheat	2.63	10.81	54.23	152.8
CE4: ZT rice–ZT wheat	2.97	11.93	59.76	168.4
SEm±	0.01	0.39	0.11	0.75
CD at 5%	0.02	1.37	0.38	0.26
Sub-plot	**Nutrient management (N)**			
N1: Farmers Practice	2.26	8.81	48.12	139.9
N2: Recommended Fertilizer Dose	2.42	9.42	50.09	145.3
N3: SSNM-RWCM Recommendation	2.53	10.8	52.62	150.3
SEm±	0.01	0.22	0.28	0.12
CD at 5%	0.02	0.65	0.83	0.35
Interaction (CE x N)	**Crop establishment methods x Nutrient management**			
SEm±	0.01	0.43	0.39	0.23
CD at 5%	0.03	NS	NS	0.71

3.3 Effect on yield components and yield

Data revealed that there is a significant difference in panicles hill^{-1}, filled grainspanicle^{-1}, fertility percentage, and grain yield hill^{-1} whereas spikelets panicle^{-1} and test weight did not differ significantly among different establishment methods. However, CT puddled transplanted rice (CE_1) had the lowest panicles and ZT rice recorded comparatively higher panicles hill^{-1} during both the year of study. In general, all yield components and yield were higher during the second year as compared to the first year [Table 3]. In respect of nutrient management treatments, significant maximum yield components and yield recorded by nutrient application based on SSNM-RWCM recommendation (N_3) followed by RFD (N_1) and least in FP (N_1) during both years. Among nutrient management treatments, maximum panicles hill^{-1}, spikelets panicle^{-1}, filled grains panicle^{-1}, test weight, and grain yield were recorded by nutrient application based on SSNM-RWCM recommendation (N_3) as compared to farmers practice (N_1) followed by recommended fertilizer dose (N_2) during both the year of investigation. Interaction failed to reach the level of significance during both years of investigation. Similar results were reported earlier by researchers Habbs *et al.* (2002), Yadav *et al.* (2014) and Singh *et al.* (2018) [25, 10].

Table 3: Effect of crop establishment methods and nutrient management on panicles hill^{-1}, spikelets hill^{-1}, filled grains hill^{-1}, fertility percentage and grain yield (g/hill) at harvest stage of rice (Two years pooled data)

Treatments	Panicles hill^{-1}	Spikelets panicle^{-1}	Filled grains panicle^{-1}	Test Weight (g)	Fertility percentage (%)	Grain yield (g hill^{-1})
Main plot	**Crop establishment methods (CE)**					
CE_1: CT rice – CT wheat	8.83	120.17	82.57	22.29	81.89	12.15
CE_2: CTDSR – CT wheat	10.83	122.06	86.67	22.18	83.35	14.39
CE_3: CTDSR – ZT wheat	12.94	123.28	88.21	22.32	84.21	16.61
CE_4: ZT rice – ZT wheat	14.72	124.94	90.05	22.46	85.48	20.25
SEm±	0.31	1.24	0.88	0.19	0.38	0.16
CD at 5%	1.08	NS	3.03	NS	1.32	0.54
Sub-plot	**Nutrient management (N)**					
N_1: Farmers Practice	11.12	122.1	85.75	22.33	82.29	14.74
N_2: Recommended Fertilizer Dose	11.75	123.6	86.75	22.29	83.68	15.76
N_3: SSNM-RWCM Recommendation	12.62	124.37	88.12	22.32	84.09	17.04
SEm±	0.27	0.95	0.54	0.10	0.62	0.12
CD at 5%	0.81	NS	1.61	NS	1.84	0.37
Interaction (CE x N)	**Crop establishment methods x Nutrient management**					
SEm±	0.53	1.90	1.75	0.21	1.10	0.25
CD at 5%	NS	NS	NS	NS	NS	NS

4. Conclusion

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. The ZT rice–ZT wheat (CE_4) crop establishment method recorded higher tiller number, leaf area and total dry matter. As a result there was increase in number of panicles and improved growth analysis parameters such as LAI, CGR, SLW and LAD. Increase in resource use in Zero till resulted in significantly higher fertility percentage resulting in more filled grains per panicle. Thus increased yield attributes such as increase in number of panicles and more filled grains per panicle resulted in higher grain yield of rice in ZT rice–ZT wheat (CE_4) over CT rice-CT wheat (CE_1) and in respect of nutrient management practices as per SSNM-RWCM recommendation (N_3) enhanced crop growth, yield attributes and 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, and higher grain yield 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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Abbreviations: CA: Conservation agriculture, CE: Crop establishment method, ZT: Zero tillage, CT: Conventional tillage, DSR: Direct Seeded rice, FP: Farmers practice RFD: Recommended fertilizer dose, SSNM: Site-specific nutrient management, RWCM: Rice- wheat crop manager, N: Nitrogen, P_2O_5: Phosphate, K_2O: Potassium, Zn: Zinc sulfate, AT: Active tillering, PI: Panicle initiation, SOM: Soil organic matter