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EFFECTS OF AGRONOMIC MANIPULATIONS ON GROWTH, YIELD AND YIELD ATTRIBUTES OF SHORT DURATION RICE CULTIVARS IN *MAJHA* REGION OF PUNJAB, INDIA

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ABSTRACT

This study investigates the effects of seedling age and transplanting date on the phenological development, meteorological parameters, and productivity of rice at the Punjab Agricultural University's Dyal Bharang Research Station in Amritsar during the *kharif* seasons of 2018 and 2019. Our findings demonstrate that transplanting 3- and 4-week-old seedlings significantly enhances rice growth and yield compared to older seedlings (5- and 6-weeks old). Optimal transplanting dates of June 25 and July 10, combined with a crop geometry of 20 cm x 15 cm, resulted in superior growth and yield attributes compared to a denser 15 cm x 15 cm arrangement. A strong linear correlation was observed between grain yield and key growth parameters, including leaf area index (R^2 = 87.23 and 86.40) and plant height (R^2 = 96.35 and 96.4). For improved water conservation, sowing of PR 126 nursery can be conducted by June 20, with 25-30 day-old seedlings successfully transplanted up to July 10 at 20 cm x 15 cm spacing. These insights provide valuable guidance for optimizing rice cultivation practices in the region.

Key words: Crop geometry, Seedling age, Transplanting date, Water conservation

The rice (*Oryza sativa* L.) – wheat (*Triticum aestivum* L.) cropping system (RWCS) is a predominant and highly profitable agricultural system essential for food security and livelihoods in South Asia. In the agricultural year 2020-2021, India cultivated rice across an area of 46.28 million hectares, yielding a total production of 129.47 million tonnes. Within this context, Punjab alone accounted for 3.14 million hectares and produced 13.7 million tonnes, contributing significantly to the national rice pool with 12.2 million tonnes, representing 21.2% of the total (Anonymous, 2023). Consequently, ensuring the sustainability of rice production in Punjab is critical for both national and global food security. However, the over-exploitation of groundwater in rice-growing regions poses a significant challenge to the sustainability of agricultural practices in this area (Pandey *et al.*, 2021).

In addition to crop diversification, implementing water-saving interventions within rice cultivation can play a vital role in mitigating the challenges facing agricultural sustainability. Crop productivity results from complex interactions among genetic, environmental, and cultural management factors (Dhillon *et al.*, 2017). Among these, environmental factors are particularly influential as they are the least manageable, whereas genetic and cultural management aspects are more readily controlled by the grower. Among the cultural management practices for transplanted rice, selecting the appropriate genotype and transplanting seedlings at the optimal age with suitable crop geometry are critical decisions for enhancing productivity (Dhillon *et al.*, 2021). In Punjab, however, increasing labour shortages and limited irrigation availability for puddling during peak transplantation periods often lead to delays in transplanting nursery seedlings, resulting in older seedlings remaining in nursery beds for extended periods. This prolonged duration can cause the degeneration of primary tiller buds on the lower nodes of the main culm, which adversely affects the tillering potential of the crop. Transplanting older seedlings not only diminishes tiller production but also accelerates panicle initiation, leads to uneven flowering, shortens the vegetative phase, and ultimately reduces the number of grains per panicle (Jia *et al.*, 2014). Furthermore, pre-anthesis dry matter accumulation is crucial as it determines sink capacity and final grain yield. The optimal seedling age for transplanting varies among genotypes due to differences in crop duration, phenology, and tillering potential. As rice is a determinate plant that reaches the flowering stage at a relatively fixed time—largely dictated by genetic factors—variability in seedling age can significantly impact the timing of critical phenological events. Aligning crop phenology with favourable environmental conditions through appropriate cultural practices is essential for achieving higher yields. Therefore, studies were conducted to determine the optimal seedling age and appropriate transplanting times for various rice

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genotypes, with the aim of enhancing productivity.

MATERIALS AND METHODS

Field experiments were conducted over two years at the Research Station in Dyal Bharang, Amritsar, Punjab (31°37'N latitude; 74°51'E longitude; 237 m altitude), situated in the Indo-Gangetic Plains Region (IGPR) during the *kharif* seasons of 2018 and 2019. Meteorological data were collected from the observatory in Amritsar for these years (Fig. 1). The climate of the experimental site is characterized as subtropical and semi-arid, with an annual rainfall averaging 650 mm, approximately 80% of which occurs from June to September (Kaur *et al.*, 2016). During the cropping seasons, the total rainfall was significantly higher in 2019-20, with 862 mm recorded over 30 rainy days, compared to 437 mm over 26 rainy days in 2018-19. Notably, the rainfall during the 2019-20 crop season exceeded the normal average of 515.6 mm, calculated over the past 20 years. This variation in rainfall is crucial for understanding its impact on crop productivity and management practices in the region.

Treatments and experimental details: The experiment was conducted using a split plot design with four replications. The main plot treatments consisted of transplanting dates—25th June (D_1) and 10th July (D_2)—and two crop geometries: 25 cm x 15 cm (G_1) and 15 cm x 15 cm (G_2). The subplot treatments involved four age categories of seedlings: 3 weeks, 4 weeks, 5 weeks, and 6 weeks old. Each plot measured 6.0 m × 3.30 m, totaling 19.8 m². Seeds of the PR 126 variety were sown based on the different age categories, utilizing 20 kg of seed for transplanting one hectare. Prior to sowing, the seeds were soaked in 25 liters of water containing 50 g of Bavistin 50 WP (carbendazim) and 1 g of Streptocycline for 8-10 hours. The recommended fertilizer application consisted of 105 kg of nitrogen (N), 30 kg of phosphorus (P_2O_5), and 30 kg of potassium (K_2O) per hectare, sourced from urea, single super phosphate (SSP), and muriate of potash (MOP). All P_2O_5 and K_2O were applied before the final puddling, while nitrogen was applied in three equal splits: one-third before the final puddling, with the remainder applied three weeks and six weeks after transplanting. The soil at the experimental site was classified as clayey loam, exhibiting low available nitrogen status (206 kg ha^{-1}), high available phosphorus (19.0 kg ha^{-1}), medium available potassium (188.7 kg ha^{-1}), and a soil organic carbon (SOC) level of 0.30%. The number of irrigations applied was recorded as follows: for D_1G_1 and D_1G_2, 16 and 19 irrigations were applied, respectively, while for D_2G_1 and D_2G_2, 14 and 17 irrigations were applied during the 2018 and 2019 growing seasons. Leaf area index (LAI) was measured at the 50% flowering stage using a Digital Plant Canopy Imager (CID, Inc. CI-110/CI-120).

Micrometeorological observations

Photosynthetically active radiation interception (PARI)

On clear sunny days, measurements of incoming and outgoing radiation at the top of the canopy, as well as the radiation transmitted to the ground surface, were taken at monthly intervals using a LI-COR-LINE Quantum Sensor Photometer. Observations were collected randomly from two locations within each plot between 12:30 and 13:30 hours. The Photosynthetically Active Radiation (PAR) interception was calculated as follows (Dhillon *et al*., 2021):

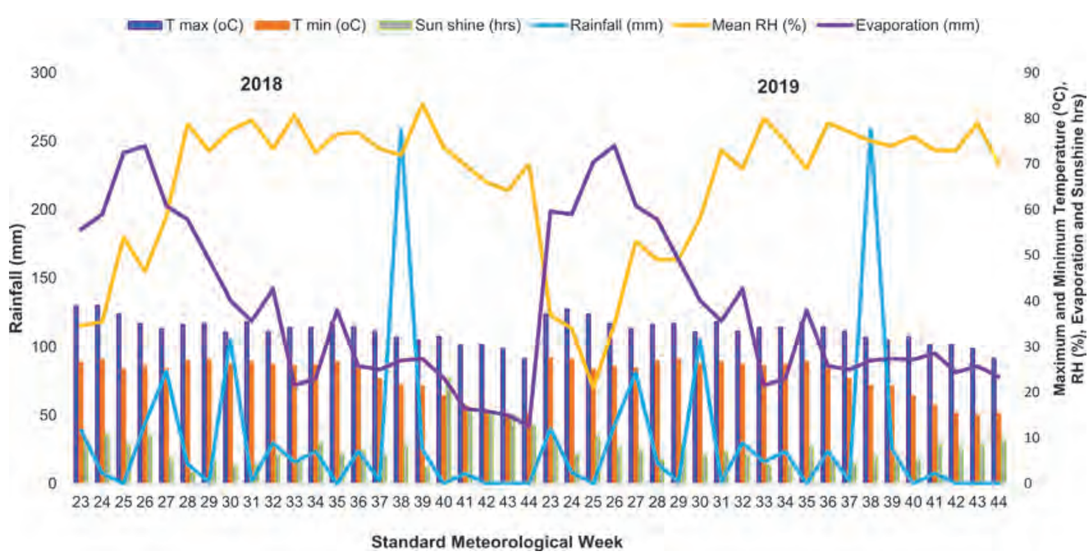

Fig. 1. Variability of daily agro-meteorological parameters at Dyal Bharang, Amritsar, India during rice seasons of 2018 and 2019

$$\text{PAR interception (\%)} = \frac{\text{PAR (I)-PAR (T)-PAR (R)}}{\text{PAR (I)}} \times 100$$

where,

PAR (I) = Total PAR incoming above the canopy, Wm^{-2}.

PAR (T) = PAR transmitted to ground, Wm^{-2}.

PAR (R) = PAR reflected from the canopy, Wm^{-2}.

Canopy temperature

Canopy air temperature data were collected using dry bulb readings recorded at both the top and ground levels of the crop canopy. Measurements were taken with a digital temperature indicator during two time intervals: from 9:00 AM to 10:00 AM and from 3:00 PM to 4:00 PM. The mean values for each day were then calculated and presented.

Crop phenology

Days taken to panicle exertion

The number of days taken for panicle exertion in paddy was recorded as the duration from transplanting to the date when the panicle emerged. This was assessed on five of the ten randomly tagged plants in each plot.

Days taken to 50 and 100 per cent panicle emergence stage

The days taken to reach the 50% and 100% panicle emergence stages in paddy were recorded when 50% and 100% of the panicles had emerged on five of the ten tagged plants in each plot.

Days taken to maturity

The number of days to maturity of paddy was recorded from the date of transplanting to the date when 50% of the plants exhibited yellowing or drying of the straw.

For panicle weight and grain weight per panicle, five panicles were randomly selected from each experimental unit. To determine grain yield, the grains harvested from each net plot were sun-dried, winnowed, cleaned, and weighed using an electronic balance. For accurate comparison of different treatments, moisture content in the grains was measured using a moisture meter. The grain yield was adjusted to 14% moisture content and expressed as quintals per hectare (q ha^{-1}). Additionally, the weight of straw from each net plot was recorded three days after harvest to estimate straw yield, which was also expressed as quintals per hectare (q ha^{-1}).

Harvest Index

The harvest index of rice was calculated by dividing the economic yield of the crop by its biological yield, and the result was expressed as a percentage.

Statistical analysis

To assess the statistical significance of treatment effects, Analysis of Variance (ANOVA) was performed for the parameters studied in the experiment. The General Linear Model (GLM) procedure in SAS® 9.4 (version 6.1.7061 for Windows; SAS Institute, 2013) was utilized for the statistical analysis of the experimental data.

RESULTS AND DISCUSSION

Micrometeorological observations

Photosynthetically active radiation interception (PARI)

At the grain filling stage, the Photosynthetically Active Radiation Interception (PARI) was significantly increased by 4.36% and 2.74% with D_2G_1 and D_1G_1, respectively, compared to D_1G_2. Notably, PARI under D_2G_1 was comparable to that of D_1G_1. The lowest PARI was recorded in the treatment D_2G_2 during both years of the study (Table 2). A similar trend in PARI was observed at physiological maturity across both years. Among the different seedling ages, the maximum PARI was recorded for 3-week-old seedlings, which was comparable to that of 4-week-old seedlings. Additionally, the results indicated that PARI values were relatively higher at the grain filling stage than at physiological maturity in both years.

Canopy temperature (°C)

At the maximum tillering stage, the canopy temperature (°C) was found to be non-significant with respect to different transplanting dates, crop geometries, and seedling ages (Table 2). However, a significantly lower canopy temperature was observed with the D_2G_1 treatment compared to D_1G_2 and D_2G_2, while D_2G_1 was comparable to D_1G_1. The highest canopy temperature was recorded in the D_2G_2 treatment during both years of the study. Among the various seedling ages, the minimum canopy temperature was associated with 3-week-old seedlings. In contrast, the highest canopy temperature was noted for 6-week-old seedlings at the grain filling stage during both 2018 and 2019. The results further indicated that canopy temperatures were relatively higher at the grain filling stage compared to physiological maturity in both years of the study.

Leaf area index (LAI)

Leaf area index (LAI) is a crucial parameter for plant growth, enhancing the source-sink relationship and determining a plant's capacity to capture solar energy for photosynthesis. Analysis of the data

Table 1. Plant height (cm) and leaf area index of rice at different seedling ages, transplant dates, and crop geometry during *kharif* 2018 and 2019

Treatments	Plant height (cm)								Leaf area index					
	30 DAT*		60 DAT		90 DAT		At harvest		Maximum tillering stage		Grain filling stage		Physiological maturity	
	2018	2019	2018	2019	2018	2019	2018	2019	2018	2019	2018	2019	2018	2019
A. Date of transplanting and crop geometry														
D_1G_1**	69.5[a]	69.8[a]	81.0[a]	81.1[a]	99.7[a]	99.9[a]	101.3[a]	103.5[a]	1.92[a]	2.10[a]	4.19[a]	4.72[a]	3.70[a]	3.92[a]
D_1G_2	67.4[a]	67.9[a]	78.3[b]	78.5[b]	97.3[b]	97.5[b]	100.1[a]	101.8[b]	1.87[a]	1.90[a]	4.05[b]	4.49[b]	3.38[b]	3.51[b]
D_2G_1	68.1[a]	68.6[a]	78.9[b]	79.2[b]	97.4[b]	97.8[b]	100.4[a]	103.0[a]	1.89[a]	1.94[a]	4.16[a]	4.63[a]	3.60[a]	3.81[a]
D_2G_2	67.2[a]	66.9[a]	77.1[c]	77.5[c]	94.9[c]	95.5[c]	97.1[b]	98.8[c]	1.85[a]	1.83[a]	3.69[c]	3.86[c]	2.45[c]	2.54[c]
B. Age of seedlings														
A_1 (3 week)	69.5[a]	70.0[a]	81.6[a]	82.0[a]	100.2[a]	100.4[a]	102.1[a]	103.9[a]	1.93[a]	2.07[a]	4.31[a]	4.73[a]	3.91[a]	4.13[a]
A_2 (4 week)	69.0[a]	69.5[a]	81.3[a]	81.6[a]	99.0[a]	99.2[a]	100.5[a]	102.9[a]	1.90[a]	2.01[a]	4.28[a]	4.65[a]	3.64[a]	3.77[a]
A_3 (5 week)	67.2[a]	67.7[a]	77.1[b]	77.3[b]	96.0[b]	96.4[b]	99.1[a]	101.3[a]	1.88[a]	1.86[a]	3.81[b]	4.23[b]	3.03[b]	3.13[b]
A_4 (6 week)	66.5[a]	66.0[a]	75.3[c]	75.5[c]	94.1[c]	94.6[c]	96.9[a]	99.0[a]	1.83[a]	1.82[a]	3.69[c]	4.07[c]	2.54[c]	2.74[c]

*DAT: Days after transplanting
**D_1 = 25 June, D_2 =10 July; G_1 = 20x15 cm, G_2 = 15x15 cm
Within a column, figures followed by the same letter do not differ significantly at *p≤0.05* after Tukey's multi comparison test.

(Table 1) revealed that LAI values increased steadily, reaching their maximum at the grain filling stage, after which they decreased as the crop progressed toward physiological maturity. This decline is likely attributed to the senescence of lower leaves. The reduction in LAI at maturity may be linked to leaf senescence and the degradation of chlorophyll content (Dhillon *et al.*, 2021). At the grain filling stage, significantly higher LAI values (4.19 and 4.72) were observed with the D_1G_1 treatment, followed by D_2G_1, D_1G_2, and D_2G_2. Notably, the LAI under D_2G_1 was comparable to that of D_1G_1. The lowest LAI (3.69 and 3.86) was recorded in the D_2G_2 treatment during 2018 and 2019, respectively. The increase in LAI can be attributed to a rise in tiller count, the number of leaves per tiller, and the size of the leaves. These findings are consistent with those of Kaur and Mahal (2018).

Among the various seedling ages, the maximum LAI (4.31 and 4.73) was recorded for 3-week-old seedlings, which was comparable to that of 4-week-old seedlings (4.28 and 4.65). The results also indicated that LAI values were relatively higher at the grain filling stage than at physiological maturity in both years. This phenomenon may result from the enhanced root and photosynthetic activity of younger seedlings, leading to increased leaf area and greater dry matter accumulation compared to older seedlings (Salem *et al.*, 2011).

Phenological observations

Days taken to panicle initiation

Among the various dates of transplanting and crop geometries, it was observed during 2018 and 2019 that the D_1G_2 treatment (51.8 and 53.3 days) required a greater number of days for both panicle initiation and 50% panicle emergence compared to the other treatments, namely D_1G_1, D_2G_2, and D_2G_1 (Table 3). On the other hand, D_2G_1 treatment (50.3 and 51.9 days) recorded significantly fewer days to panicle emergence than the other treatments across both years of the study.

The age of seedlings also had a significant impact on panicle emergence. Days taken to panicle initiation were notably higher for 3-week-old seedlings, which were 8.62% and 7.55% longer than those for 6-week-old seedlings. In contrast, the days required for panicle initiation were significantly lower in 6-week-old seedlings (48.7 and 50.3 days) compared to the other treatments during both 2018 and 2019. Kaur and Mahal (2018) also reported that panicle initiation occurred later in early-sown crops (25[th] June), while 50% flowering was observed earlier in late-sown crops (10[th] July).

Days taken to 50 % panicle emergence

The maximum number of days required to attain 50% panicle emergence was observed in the D_1G_2 treatment, followed by D_1G_1 and D_2G_2, while the least number of days was recorded for D_2G_1 during both 2018 and 2019. The age of seedlings significantly influenced the timing of 50% panicle emergence in rice across both years of the study. Notably, 3-week-old seedlings took the longest duration, requiring 67.0 days from transplanting to achieve 50% panicle emergence, compared to 65.3 days for 4-week-old seedlings, 61.8 days for 5-week-old seedlings, and 58.5 days for 6-week-old seedlings. Similar findings were reported by

Table 2. Photosynthetically Active Radiation Interception and Canopy Temperature (°C) of rice at varying seedling ages, transplant dates, and crop geometry during *kharif* 2018 and 2019

Treatments	PARI (%)						Canopy temperature (°C)					
	Maximum tillering		Grain filling Stage		Physiological maturity		Maximum tillering		Grain filling Stage		Physiological maturity	
	2018	2019	2018	2019	2018	2019	2018	2019	2018	2019	2018	2019
A. Date of transplanting and crop geometry												
D_1G_1*	58.0[a]	60.2[a]	83.0[a]	82.4[a]	63.7[a]	63.2[a]	31.9[a]	32.0[a]	33.8[c]	34.7[c]	32.0[c]	33.5[c]
D_1G_2	54.0[a]	56.8[a]	81.7[c]	80.2[b]	60.8[b]	61.7[b]	33.0[a]	32.5[a]	34.9[b]	35.8[b]	34.0[b]	34.2[b]
D_2G_1	57.0[a]	58.5[a]	82.9[b]	83.7[a]	62.4[a]	63.1[a]	32.8[a]	33.0[a]	33.7[c]	34.6[c]	33.0[c]	33.0[c]
D_2G_2	51.0[a]	53.5[a]	77.8[d]	80.9[c]	55.3[c]	59.2[c]	33.0[a]	33.9[a]	35.0[a]	35.0[a]	35.7[a]	34.0[a]
B. Age of seedlings												
A_1 (3 week)	57.0[a]	59.4[a]	83.8[a]	83.5[a]	64.6[a]	63.8[a]	31.8[a]	32.0[a]	33.7[d]	34.6[d]	32.6[d]	33.2[c]
A_2 (4 week)	57.0[a]	58.2[a]	82.6[a]	83.0[a]	62.9[a]	62.9[a]	32.5[a]	32.1[a]	33.4[c]	34.5[c]	33.5[c]	34.2[b]
A_3 (5 week)	55.0[a]	56.5[a]	81.2[b]	82.0[b]	57.9[b]	61.7[b]	32.6[a]	33.5[a]	34.8[b]	35.9[b]	33.5[b]	34.5[b]
A4 (6 week)	51.0[a]	54.7[a]	77.7[c]	78.6[c]	56.8[c]	58.8[c]	33.8[a]	33.8[a]	35.5[a]	35.1[a]	35.1[a]	32.5[a]

*D_1 = 25 June, D_2 =10 July; G_1 = 20x15 cm, G_2 = 15x15 cm
Within a column, figures followed by the same letter do not differ significantly at $p \leq 0.05$ after Tukey's multi comparison test.

Dhillon *et al.* (2021).

Days taken to physiological maturity

Among the various seedling ages, the number of days taken to reach physiological maturity was significantly higher for 3-week-old seedlings, followed by 4-week-old, 5-week-old, and 6-week-old seedlings. In contrast, 6-week-old seedlings required significantly fewer days to attain physiological maturity during both 2018 and 2019. Specifically, 3-week-old seedlings reached physiological maturity in 93.3 to 94.6 days, whereas 6-week-old seedlings completed this stage in 82.9 to 84.6 days. This trend aligns with findings reported by Sattar *et al.* (2017) in transplanted rice. Additionally, Vishwakarma *et al.* (2016) noted that the timing of 100% flowering and physiological maturity was significantly influenced by delays in transplanting. Older seedlings, having spent more time in the nursery, required fewer days after transplanting to reach maturity.

Yield attributing characters

Among the different dates of transplanting and crop geometries, the number of effective tillers per square meter and panicle length were significantly lower in the D_2G_2 treatment compared to the other treatments, namely D_1G_1, D_1G_2, and D_2G_1 (Table 4). Among different seedling ages, yield-attributing characteristics of rice were significantly higher in 3-week-old seedlings compared to 5- and 6-week-old seedlings, with values for 3-week-old seedlings being comparable to those of 4-week-old seedlings. On the other hand, the number of effective tillers per square meter and panicle length were significantly lower in 6-week-old seedlings compared to all other treatments during both 2018 and 2019. This highlights the importance of seedling age at the time of transplanting for achieving uniform stand establishment in rice. If seedlings are older than optimal, they tend to produce fewer tillers due to a reduced vegetative period, resulting in lower yields (Bashir *et al.*, 2010). The decrease in tiller numbers associated with older seedlings may stem from their negative impact on crop establishment, as well as a shorter tillering period and overall crop duration in the main field compared to 3- and 4-week-old seedlings (Dhillon *et al.*, 2021). The reduction in panicle length may be attributed to the limited time available for older seedlings to undergo vegetative growth, causing them to transition rapidly into the reproductive phase and produce shorter panicles.

Grain yield

The data on grain yield of rice indicated significant variations with respect to different dates of transplanting, crop geometries, and seedling ages (Table 4). During 2018 and 2019, the grain yield was notably lower in the D_2G_2 treatment compared to the other treatments, specifically D_1G_1, D_1G_2, and D_2G_1. The D_1G_1 treatment recorded the highest grain yield, 78.3 q ha^{-1} in 2018 and 78.9 q ha^{-1} in 2019, which was comparable to the yield from D_2G_1 (76.9 q ha^{-1} in 2018 and 77.2 q ha^{-1} in 2019). This was followed by D_1G_2, which yielded 74.7 q ha^{-1} in 2018 and 75.0 q ha^{-1} in 2019.

Among the various seedling ages, the highest grain yield was observed in 3-week-old seedlings (78.8 q ha^{-1} and 79.0 q ha^{-1}), which was comparable to that of 4-week-old seedlings. In contrast, the grain yield for 6-week-old seedlings was significantly lower

Table 3. Phenological observations and lodging (%) of rice at different seedling ages, transplant dates, and crop geometry during *kharif* 2018 and 2019

Treatments	Phenology: Days taken to: Panicle initiation		50 % panicle emergence		Physiological maturity		Lodging (%)	
	2018	2019	2018	2019	2018	2019	2018	2019
A. Date of transplanting and crop geometry								
D_1G_1*	51.3^b	52.6^b	61.6^b	63.3^b	90.3^b	91.6^b	2	2
D_1G_2	51.8^a	53.3^a	62.0^a	63.8^a	91.5^a	92.8^a	9	8
D_2G_1	50.3^d	51.9^d	60.2^d	62.5^d	85.3^d	87.6^d	3	2
D_2G_2	51.1^c	52.5^c	61.0^c	63.0^c	87.4^c	89.1^c	10	10
B. Age of seedlings								
A_1 (3 week)	52.9^a	54.1^a	65.5^a	67.0^a	93.3^a	94.6^a	2	3
A_2 (4 week)	51.9^b	53.5^b	63.8^b	65.3^b	91.2^b	92.5^b	3	3
A_3 (5 week)	51.0^c	52.5^c	60.3^c	61.8^c	87.1^c	89.4^c	8	7
A_4 (6 week)	48.7^d	50.3^d	55.3^d	58.5^d	82.9^d	84.6^d	11	9

*D_1 = 25 June, D_2 =10 July; G_1 = 20x15 cm, G_2 = 15x15 cm
Within a column, figures followed by the same letter do not differ significantly at *p≤0.05* after Tukey's multi comparison test.

(70.6 q ha⁻¹ and 71.2 q ha⁻¹) than that of the younger seedlings during both years. The increased grain yield in 3-week-old seedlings can be attributed to several factors, including a higher plant population, greater leaf area index, enhanced light interception, and a greater number of effective tillers per square meter. Additionally, improvements in yield-contributing factors such as the number of effective tillers per hill, panicle length, spikelets per panicle, and test weight also played a role in yield enhancement. The superior grain yield observed in the younger 3-week-old seedlings may be due to their vigorous and healthy growth, which promotes the development of more productive tillers and leaves, thereby ensuring better resource utilization compared to older seedlings (Pramanik and Bera, 2013). Furthermore, younger seedlings facilitate improved phyllochron development and enhanced tillering, contributing to increased final grain yield (Dhillon *et al.*, 2021).

Straw yield and harvest index

Straw yield was significantly lower in the D_2G_2 treatment compared to the other treatments, namely D_1G_1, D_1G_2, and D_2G_1 (Table 4). The D_1G_1 treatment,

Table 4. Yield attributes, grain yield, straw yield and harvest index of rice at different seedling ages, transplant dates and crop geometry during *kharif* 2018 and 2019

Treatments	Effective tillers (m^{-2})		Panicle length (cm)		Grain yield (q ha^{-1})		Straw yield (q ha^{-1})		Harvest index (%)	
	2018	2019	2018	2019	2018	2019	2018	2019	2018	2019
Date of transplanting and crop geometry										
D_1G_1*	320.9^a	324.9^a	25.1^a	25.9^a	78.3^a	78.9^a	114.9^a	117.7^a	40.5^a	40.1^a
D_1G_2	314.9^b	318.8^b	24.0^a	24.2^b	74.7^b	75.0^b	110.4^b	112.9^b	40.4^a	39.9^a
D_2G_1	319.1^a	323.0^a	24.8^a	25.3^a	76.9^a	77.2^a	113.6^a	115.9^a	40.4^a	40.0^a
D_2G_2	292.6^c	298.7^c	23.1^a	23.7^c	71.1^c	72.2^c	106.1^c	108.9^c	40.1^a	39.9^a
Age of seedlings										
A_1 (3 week)	325.9^a	328.8^a	26.2^a	26.4^a	78.8^a	79.0^a	115.4^a	118.1^a	40.6^a	40.1^a
A_2 (4 week)	323.2^b	326.5^b	25.4^a	26.0^a	76.9^a	77.6^a	113.6^a	116.4^a	40.4^a	40.0^a
A_3 (5 week)	308.1^c	312.3^c	23.4^a	23.9^b	74.8^b	75.4^b	110.1^b	112.9^b	40.5^a	40.0^a
A_4 (6 week)	290.1^d	297.7^d	22.1^a	22.8^c	70.6^c	71.2^c	105.9^c	108.1^c	40.0^a	39.7^a

*D_1 = 25 June, D_2 =10 July; G_1 = 20x15 cm, G_2 = 15x15 cm
Within a column, figures followed by the same letter do not differ significantly at *p≤0.05* after Tukey's multi comparison test.

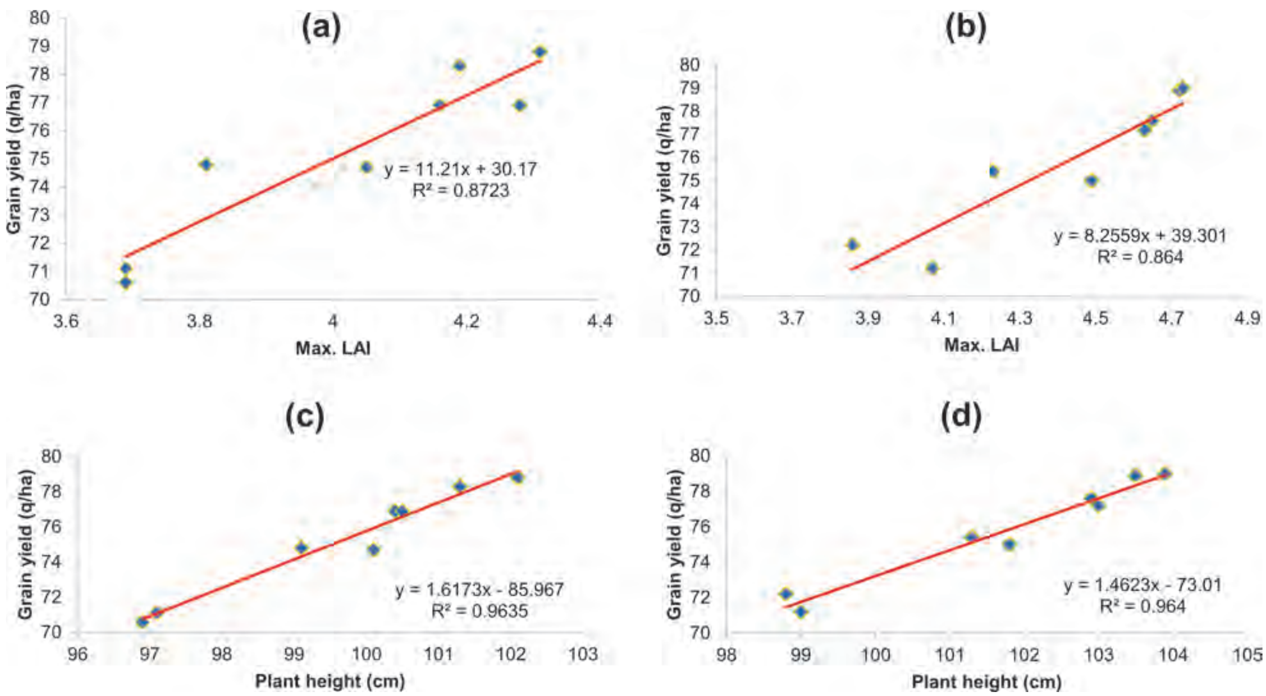

Fig. 2. Relationship between grain yield and growth parameters of rice during 2018 (a, c) and 2019 (b, d)

however, recorded a significantly higher straw yield than all other treatments, with the exception of D_2G_1, which was statistically comparable, followed by D_1G_2. The increased straw yield in D_1G_1 can likely be attributed to greater dry matter accumulation per unit area, resulting from improved nutrient absorption from the soil. This enhancement in nutrient uptake boosts metabolic processes, light absorption, photosynthetic activity, and leaf development. Among the different seedling ages, straw yield was significantly higher in 3-week-old seedlings, which was comparable to that of 4-week-old seedlings, and was followed by 5- and 6-week-old seedlings. In contrast, straw yield was significantly lower in 6-week-old seedlings during both years of the study.

The highest harvest index was observed in the D_1G_1 treatment, followed by D_2G_1, D_1G_2, and D_2G_2. This higher harvest index may be attributed to better partitioning of photosynthates from the vegetative parts to the reproductive parts of the plant. Furthermore, the harvest index decreased with increasing seedling age. The elevated harvest index in 3-week-old seedlings can be linked to optimal crop growth and development, along with efficient assimilate synthesis in the grains (Pramanik and Bera, 2013).

Relationship between growth parameters and grain yield

Regression analysis was performed to establish a linear response function between grain yield and growth parameters, specifically maximum leaf area index and plant height in the rice crop (Fig. 2). The analysis revealed a strong correlation between grain yield and growth components, highlighting that yield is influenced by the cumulative effects of various growth factors. A linear increase in grain yield was observed with increases in leaf area index (R^2 = 87.23 and 86.40) and plant height (R^2 = 96.35 and 96.40) during both years of the study.

A critical analysis of the data indicated that the growth and productivity of short-duration rice crop were enhanced by transplanting younger seedlings (3 and 4 weeks) compared to older seedlings (6 weeks). Transplanting rice on June 25 and July 10 using a 20 cm × 15 cm crop geometry yielded better growth, yield attributes, and overall yield compared to a 15 cm × 15 cm geometry. Notably, rice transplanted on July 10 required fewer irrigations (14 and 17) than the June 25 transplanted crops (16 and 19), resulting in water savings of 12.5% and 10.5% during 2018 and 2019, respectively, without any reduction in yield. To optimize irrigation water usage, it is recommended that the nursery of PR 126 be sown by June 20, allowing for the transplantation of 25-30 day-old seedlings by July 10 at a spacing of 20 cm × 15 cm. Further research is needed to explore genotype-specific planting windows in relation to seedling age to enhance understanding of the climatic factors influencing yield formation in various rice genotypes.

CONCLUSION

In conclusion, this study highlights the critical role of transplanting practices, particularly the age of seedlings and crop geometry, in enhancing the growth, yield attributes, and overall productivity of rice. The findings demonstrate that younger seedlings (3 and 4 weeks old) significantly outperform older seedlings (6 weeks old) in terms of grain yield, straw yield, and harvest index. Transplanting rice on June 25 or July 10 using a 20 cm × 15 cm crop geometry optimizes growth and minimizes irrigation requirements, resulting in notable water savings without compromising yield. The strong linear relationships observed between grain yield and growth parameters, such as leaf area index and plant height, further reinforce the importance of these factors in determining crop success. Keeping in view the increasing pressure on water resources and the need for sustainable agricultural practices, the recommendations for nursery sowing by June 20 and transplanting 25-30 day-old seedlings by July 10 offer a viable pathway for improving resource efficiency. Future research should focus on genotype-specific planting windows and seedling ages to further elucidate the climatic factors influencing yield across different rice varieties. This integrated approach will contribute to the sustainability and productivity of rice cultivation in the region, ensuring food security for the growing population.

Authors' contribution

Conceptualization of research work and designing of experiments (PK, KS); Execution of field/lab experiments and data collection (PK); Analysis of data and interpretation (PK); Preparation of manuscript (PK, KS, KK)

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