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PREDICTING RICE GROWTH AND YIELD USING CERES-RICE MODEL: A COMPARATIVE STUDY OF TRANSPLANTED AND DIRECT-SEEDED RICE CULTIVATION SYSTEMS

SAMAR JAVED
Department of Agronomy, University of Agriculture, Faisalabad 38000, Punjab, Pakistan.

SYED AFTAB WAJID
Department of Agronomy, University of Agriculture, Faisalabad 38000, Punjab, Pakistan.

LUBNA ANJUM
Department of Irrigation and Drainage, University of Agriculture, Faisalabad 38000, Punjab, Pakistan.

SAMREEN ASLAM
Institute of Botany, University of the Punjab, Lahore 54000, Pakistan.

MUNTAHA MUNIR
Institute of Botany, University of the Punjab, Lahore 54000, Pakistan.

MUDASSIR SABRI
Department of Zoology, University of Education, Township Campus, Lahore 54000, Pakistan.

HAFIZ MUHAMMAD BILAWAL AKRAM*
Department of Agronomy, University of Agriculture, Faisalabad 38000, Punjab, Pakistan. ***Corresponding Author Email: bilawalakram48@gmail.com**

Abstract

Global food instability, driven by increasing population and climate change, poses significant challenges to food production and distribution. A field trial was conducted at the Agronomic Research Farm, University of Agriculture Faisalabad in 2023, using the CERES-Rice Model to evaluate the performance of rice hybrids under different sowing methods. The study aimed to assess the feasibility of direct-seeded rice (DSR) as an alternative to conventional transplanted rice (TPR) in terms of water conservation, labor reduction, greenhouse gas (GHG) mitigation, and climate adaptation. The experiment was designed in a Randomized Complete Block Design (RCBD) with split plots and three replications, involving two rice hybrids (Basmati-515 Fine and FMC-1) and two sowing methods (DSR and TPR). Growth and yield data, including total dry matter, crop growth rate, leaf area index, leaf area duration, and net assimilation rate, were recorded and analyzed using ANOVA and LSD test at a 5% significance level. Results showed that sowing method significantly influenced the number of tillers (m-2), biological yield, panicle length, and grain yield. FMC-1 hybrid produced the highest kernel yield (5615.47 kg ha-1) under the transplanted method, attributed to favorable nutrient availability and higher productive tillers and kernel weight. The study concludes that FMC-1 hybrid rice under transplanting provides the highest yield in the agro-ecological conditions of Faisalabad, with implications for optimizing rice cultivation practices.

Keywords: Global Food Instability, Rice Hybrids, CERES-Rice Model, Sowing Methods, Direct-Seeded Rice, Transplanted Rice, Greenhouse Gas Mitigation.

INTRODUCTION

The agricultural sector stands as a vital pillar in the economies of developing nations, where it plays a critical role in generating employment, providing raw materials to industries, and sustaining food security (Akram et al., 2023). However, despite its importance, the sector faces immense challenges in meeting the growing food demands of an increasing global population. One of the most pressing concerns is global hunger and food insecurity, which are compounded by malnutrition in impoverished nations. Given these challenges, this research focuses on improving rice production methods to enhance food security and optimize water usage in rice farming, with particular attention to the practices of Direct Seeding and the management of agricultural inputs like nitrogen (Adnan et al., 2020).

Rice is a staple crop for over half of the world's population, providing a significant portion of daily calories. It is produced on approximately 11% of the world’s agricultural land and is the second most consumed cereal crop globally, after wheat. In regions like Asia, rice constitutes the main food source, especially for 2.7 billion people who rely on it for 50–60% of their nutritional intake (Khan et al., 2016). However, rice cultivation faces several constraints including abiotic stresses such as drought, salt, and submergence, as well as water scarcity. The crop requires substantial water for optimal growth, and in many regions, freshwater availability has become a limiting factor for rice production (Kim et al., 2020). The traditional rice farming methods, including puddled transplanting, are resource-intensive and often lead to poor soil conditions for future crops. Moreover, with increasing water shortages, the traditional methods are becoming less viable. This has led to a shift toward alternative farming practices like Direct Seeding, which shows promise in improving water efficiency and reducing labor costs, offering a more sustainable solution (Hussain et al., 2021). However, these practices come with challenges such as weed management, which can significantly reduce yields if not addressed effectively (Khaliq & Matloob, 2011).

The global population continues to rise, and with it, the demand for rice. Yet, the traditional methods of rice farming are unsustainable due to their high water and labor requirements. Additionally, the prevalence of weeds in Direct Seeding systems presents a major challenge, often leading to substantial yield losses. In regions with water scarcity, optimizing water productivity and enhancing crop yields are critical to ensuring food security. The current agricultural practices are inadequate to meet these goals, and there is a need for innovative approaches to improve both the sustainability and productivity of rice cultivation (Ladha et al., 2009).

This research aims to evaluate the efficiency and sustainability of Direct Seeding Rice (DSR) techniques, with a particular focus on Dry Direct Seeding Rice (DDSR). The study will explore the effects of these methods on water productivity, rice yields, and labor requirements compared to traditional transplanted rice (TPR) methods. Additionally, the research will address the challenges of weed management in DSR, particularly focusing on the timing and effectiveness of weed control strategies. By analyzing the interplay between irrigation practices, soil conditions, and crop management, the study seeks to provide actionable insights for improving rice production in water-scarce regions (Hussain et al., 2021).

The increasing challenges of water scarcity, labor shortages, and the rising costs of agricultural inputs necessitate the exploration of more sustainable rice farming practices. Direct Seeding methods, particularly DDSR, offer a potential solution by reducing water usage and labor demands while maintaining or even increasing yields. These methods are increasingly being adopted in regions where traditional practices are becoming less feasible due to environmental constraints and economic pressures. By investigating the effectiveness of DDSR and the critical aspects of weed management, this research could contribute valuable knowledge to enhance rice productivity, reduce water consumption, and improve the overall sustainability of rice farming (Sureshkumar 2016).

Furthermore, as rice cultivation is essential for food security, the outcomes of this research will help address the broader goals of the United Nations Sustainable Development Goal (SDG) 2, which aims to end hunger, achieve food security, improve nutrition, and promote sustainable agriculture. This study will not only benefit farmers but also contribute to the global effort to mitigate food insecurity and malnutrition in developing nations (Abbas et al., 2022). This research will employ a mixed-methods approach, combining both qualitative and quantitative analysis. The first phase will involve a field experiment comparing traditional TPR with DDSR under varying irrigation practices and weed management strategies. The second phase will include a detailed survey of farmers who have adopted DDSR to assess labor requirements, water usage, and yield outcomes. Data on soil moisture levels, irrigation methods, weed management, and crop yields will be collected and analyzed to determine the efficiency and sustainability of each method. Statistical tools will be used to evaluate the correlation between different agricultural practices and water productivity.

This study hypothesizes that DDSR methods will result in higher water productivity and comparable or improved yields compared to traditional transplanted rice, with reduced labor inputs. Additionally, the research will investigate whether early and effective weed management in DDSR systems can mitigate yield losses due to weed competition. This paper is structured into several key sections. After this introduction, the literature review will discuss the current state of rice production, the challenges faced by the agricultural sector, and the emerging alternatives to traditional farming practices, including Direct Seeding and hybrid rice varieties.

The methodology section will outline the experimental design, data collection procedures, and analytical techniques used in this study. The results and discussion section will present the findings of the field experiment and survey, followed by a critical analysis of the implications for rice farming. Finally, the conclusion will summarize the key findings, discuss their significance in the context of sustainable agriculture, and suggest recommendations for future research.

2. MATERIALS AND METHODS

2.1. Experimental Location

The planned experiment was conducted at the Agronomic Research Farm of the University of Agriculture Faisalabad during the Kharif season of 2023. The farm is located in Faisalabad, with geographical coordinates at 31°25’ N latitude and 73°04’ E longitude, at an altitude of 184.4 meters above sea level.

The soil at the site is classified as Lyallpur, a fine loamy, mixed, hyperthermic Typic Haplocambids, according to the USDA soil series classification. The climatic zone of the region is characterized as dry semi-arid, which influences the agronomic conditions under which the experiment was carried out.

2.2. Soil Analysis

Samples from the experimental site were taken by using soil auger before the crop was planted. 30 smc of dirt was dug up to collect a composite soil sample. Table 2.2 contains more information on the soil analysis.

Table 2.1: Soil Attributes of Experimental Site

Parameters	Units	Value	Status
Sampling depth	cm	0-30	
PH			Alkaline
Texture		8	Sandy loam
EC	dSm-1	1.1	Normal
Organic matter	%	0.91	Low
Sand	%	33.7	
Silt	%	34.2	
Clay	%	32.1	
Nitrogen	ppm	0.059	Low
Phosphorus	ppm	11.5	Low
Potassium	ppm	174	Sufficient

2.3. Climatic Conditions of Experimental Site

The graphical depiction highlights Faisalabad's climatic patterns, demonstrating significant temperature variations throughout the year. In winter, temperatures notably decrease, while summer brings a sharp increase, reflecting the region's distinct seasonal shifts.

This temperature behavior aligns with solar radiation levels, which are at their peak during the bright, sunny months of summer and diminish during the shorter, potentially cloudier days of winter. Precipitation trends in the graph indicate a clear seasonal rhythm, with a pronounced increase during the monsoon season, crucial for the area's agriculture and water supply.

Together, these elements provide a detailed insight into the climatic conditions of Faisalabad, emphasizing the critical phases of warmth, sunlight, and rainfall that have a direct impact on the region's environment, agricultural cycles, and the daily lives of its inhabitants.

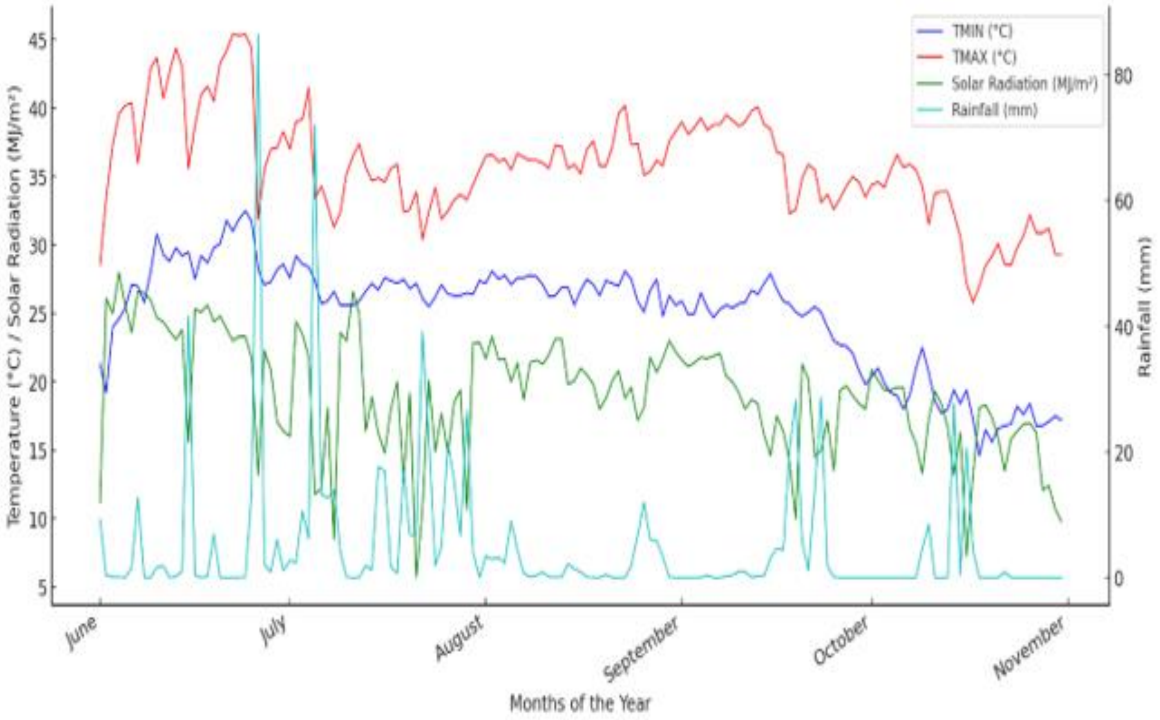

Figure 2.1: Weather Dynamics in Faisalabad: A Comparative Analysis of Temperature, Solar Radiation, and Rainfall Patterns

Table 2.2: Mean Weather Data For Rice Growing Season 2023

Months	Mean Temperature (°C)	Rainfall (mm)	Relative Humidity (%)	Sunshine Radiation (Hours)
June	30.51	2.93	45.74	23.78
July	32.5	6.30	66.22	18.75
August	34.72	0.78	50.20	21.31
September	33.08	1.75	48.53	19.46
October	26.93	1.18	46.63	16.82

2.4. Treatments Description

Factor A: Sowing Methods (S) (Main Plot)

Two sowing methods were chosen to evaluate their efficiemcy.

S1= Direct Seeded Rice (DSR)

S2= Transplanted Rice (TPR)

Factor B: Cultivars (Sub Plots)

Two cultivars were chosen to check the difference

Hybrid= FMC-1 (Hybrid Grain)

Fine= Basmati-515 (Fine Grain)

2.5. Crop Husbandry

The study was conducted at the Agronomy Research Farm of University of Agriculture, Faisalabad in the Kharif season 2023. Treatments were comprised of two sowing methods (Direct seeded and transplanted) with two cultivars (Basmati-515 Fine and FMC-1 Hybrid).

The field was prepared using a rotavator, followed by two cultivations and planking, and then divided into two halves, one for DSR and second one for Transplaanted rice. A Randomized Complete Block Design was implemented in a Split Plot arrangement with three replications. The net plot dimension was 6m x 1.8m.

2.6. Sowing to Harvesting

Field preparation involved rotavating, ploughing twice, and planking. The field was split into two sections for DSR and transplanted rice, both seeded at a rate of 20 kg ha^{-1}.

Sowing occurred on June 1, 2023, with DSR sown using a drill and transplanted rice in puddled water. Fertilizer applications included 125 kg ha^{-1} phosphorus, 80 kg ha^{-1} potassium, and nitrogen at tillering and panicle stages.

Zinc was sprayed 20 days after sowing. Irrigation was applied 14 times for DSR and 16 times for transplanted rice, with a water depth of 1.5-3 inches maintained for transplanted rice. Harvesting occurred when the crop reached 23-25% moisture.

2.7. Data Collection

Data collection occurred 30 days after sowing through destructive sampling, with samples taken from each plot's 30 cm row area every 15 days. Each sample was sun-dried, and a sub-sample was taken with components (leaf and stem) separated.

Weights of fresh and dried components were recorded separately and converted to m^2 to calculate the overall dry weight. Conventional methods were used to record growth and yield data. The following parameters were recorded during the rice crop experiment.

2.7.1. Crop Growth Parameters

- TDM (gm^{-2})
- CGR ($gm^{-2}d^{-1}$)
- LAI
- LAD (days)

- NAR ($gm^{-2}d^{-1}$)
- RUE ($g\ Mj^{-1}$)

a) Total Dry Matter (TDM) (gm^{-2})

TDM refers to the percentage of dry matter in a given sample of a substance, which is obtained by removing all the moisture content. It is commonly used in agriculture to measure the dry matter content of crops amd animal feed. We can calculate TDM by the following formula after measuring the fresh weight and oven dry weight of the sample.

$$\mathrm{TDM} = \frac{\mathrm{Wd}}{\mathrm{Wf}} \times \mathrm{Wt}$$

Where,

TDM= Total Dry Matter

Wd= Total Fresh Weight

Wf= Fresh sub-sample weight taken from oven dry

Wt= Oven dried weight of sub-sample

b) Crop Growth Rate (CGR) ($g\ m^{-2}\ d^{-1}$)

CGR measures the increase in dry weight of a crop per unit of time and is used to evaluate crop growth. It is calculated by dividing the difference in dry weight between two time periods by the time passed. The methodology from Hunt (1978) was used for this calculation. The formula for calculating CGR is as follows.

$$\mathrm{CGR} = \frac{\mathrm{W_2} - \mathrm{W_1}}{\mathrm{t_2} - \mathrm{t_1}}$$

Where,

W1= Sample’s dry weight at first harvest

W2= Sample’s dry weight at second harvest

t1= Date at which first dry matter was observed

t2= Date at which second dry matter was observed

c) Leaf Area Index (LAI)

It measures the total leaf area of all the plants in a certain region in relation to the surface area of the ground (Hunt, 1978). LAI can be calculated by various methods, including direct and indirect measurement and remote sensing. The leaf area index was calculated by using a sun scanner.

$$\mathrm{LAI} = \frac{\text{Leaf Area}}{\text{Land Area}}$$

d) Leaf Area Duration (LAD) (days)

LAD is a measure of the total duration of time during which a plant canopy or population has leaves with a certain areas. It is typically expressed in squar meters per dy or per growing season. LAD is used in various applications, including crop modeling, ecosystem modeling and remote sensing. The method described by Hunt (1978) was used to calculate LAD.

$$\mathrm{LAD} = \frac{\mathrm{LAI}_1 + \mathrm{LAI}_2}{2} \times \mathrm{t}_2 - \mathrm{t}_1$$

Where,

LAD = Leaf area duration

$\mathrm{LAI}_1 =$ Leaf area index at first harvest

$\mathrm{LAI}_2 =$ Leaf area index at second harvest

$t_1 =$ Date of first leaf area observation

$t_2 =$ Date of final leaf area observation

e) Net Assimilation Rate (NAR) ($gm^{-2}d^{-1}$)

The rate at which plants absorb carbon through photosynthesis is measured by NAR, which is expressed as a unit of leaf area. It is a crucial physiological factor that influences the growth and yield of plants. The Hunt (1978) method was used to calculate the average net assimilation rate (NAR).

$$\mathrm{NAR} = \frac{\mathrm{Final\ TDM}}{\mathrm{Final\ LAD}}$$

Where,

NAR = Net assimilation rate

LAD = Leaf area index

TDM = Total dry matter

f) Radiation Use Efficiency (RUE) ($g\ Mj^{-1}$)

Radiation use efficiency (RUE) measures how efficiently plants convert absorbed light into biomass through photosynthesis. It is quantified as the ratio of biomass production to radiation absorption. RUE is essential in crop modeling to calculate potential crop productivity under different environmental conditions. TDM RUE and grain yield were observed for each plot during the study.

$$\mathrm{RUE}_{\mathrm{TDM}} = \mathrm{TDM} / \sum \mathrm{Sa}$$

$$\mathrm{RUE}_{\mathrm{GY}} = \mathrm{Grain\ Yield} / \sum \mathrm{Sa}$$

During the season, Sa was used to manage the value of captured PAR (Sa) by recreating good aspects of Fi with regular incident PAR (Si). By simulating all captured PAR (Sa) characteristics recorded during a fifteen-day period, the cumulative captured PAR was calculated.

$$Sa = Fi \times Si$$

The terms "Si" and "Fi" in this context refer to the regular incidence of PAR

(Photosynthetically active radiation) and the proportion of solar radiation, respectively.

Following Beer's law, "Fi" is determined as follows.

$$Fi = 1 - \exp(-k \times L.AI)$$

In this equation, "K" stands for the leaf area index and "LAI" for the extinction coefficient for total solar radiation, which is set at 0.5 for rice. The following equation is used to calculate the value of "Si".

$$Si = Total\ Rs / 2$$

Using Angstrom's formula, the radiation caused by sunlight, designated as "Rs," is computed in this context.

Angstrom’s formula

$$Rs = [a + b\ (^{n} N)] \times Ra$$

Angstrom's constants "a" and "b" are designated in the context as having values of 0.25 and 0.5, respectively. The ratio of real daylight hours (n) to the total number of daylight hours (N) is denoted as "n/N" while "Ra" stands for extraterrestrial radiation.

2.7.2. Yield Attributes

- 1000 grain weight (g)
- Biological yield (kg ha^{-1})
- Straw yield (kg ha^{-1})
- Paddy yield (kg ha^{-1})
- Harvest index (%)

➢ 1000 Grain Weight (g)

1000 grains were removed from each plot after the harvesting of crop and then their weight was determined by using a weighing balance.

➢ Biological Yield (kg ha^{-1})

Each plot was manually harvested by using a sickle when the crop achieved physiological maturity. The reaped crop was then collected into bundles.

Then the grain was dried in the sun for five days in each of the specified plot. Biological yield of each plot was measured independently by using a computerized electrical balance. The yield was recorded in killogrammes.

- **Straw Yield (kg ha^{-1})**

The total amount of above ground plant material that is generated by the rice crop, excluding the grains, is reffered as straw yield. Straw yield was measured after removing the kernels from the sample and the yield was calculated in kg ha^{-1}.

- **Paddy Yield (kg ha^{-1})**

The crop was sun dried before threshing and it was done manually by hand on a plastic sheet by using sticks. Yield of each plot was calculated in killogrammes per acre.

- **Harvest Index (%)**

The harvest index had been determined by using the ratio of biological yield to grain yield with the help of Beadle formula.

$$\mathrm{HI} = \frac{\text{Grain Yield}}{\text{Biological Yield}} \times 100$$

2.8. Statistical Analysis

The data was statistically analyzed using the variance technique. To compare the means of different treatments, the LSD approach was used at a 5% probability level (Steel *et al.,* 1997).

3. RESULTS AND DISCUSSION

3.1. Crop Growth Parameters

Crop growth parameters involved leaf area index (LAI), total dry matter (TDM), leaf area duration (LAD), crop growth rate (CGR), net assimilation rate (NAR) and radiation use efficiency (RUE).

a) Leaf Area Index (LAI)

Leaf area index (LAI) measures the ratio of leaf area to ground surface and is crucial for simulating mass and energy transfers (Yin et al., 2017). The Sun Scanner was used to measure LAI, with transplanting conditions showing the highest LAI (4.87) and direct-seeded rice the lowest (0.40).

Cultivar FMC-1 outperformed Super Basmati 515 in both sowing methods. The higher LAI in FMC-1 and super hybrid rice suggests improved photosynthesis and productivity (Yan et al., 2019). LAI peaked at 75 days after sowing, then declined due to leaf senescence.

Table 3.1: Effect of Panting Methods on Leaf Area Index (LAI) for Rice

Analysis of Variance

Source	DF	SS	MS	F
Replication (A)	2	0.17372	0.08686	
SM (B)	1	0.13021	0.13021	3.75^{NS}
Error A*B	2	0.06952	0.03476	
Varieties (C)	1	0.51667	0.51667	67.61**
B*C	1	0.02521	0.02521	3.3^{NS}
Error A*B*C	4	0.03057	0.00764	
Total	11	0.94589		

SOV: Source of Variational DF: Degree of freedom on SS: Sum of Squared

MS: Mean * = Significant ** = Highly Significant NS= Non-significant, Critical value for varieties comparison = 2.77

Individual Comparison of Treatment Means

Treatments	Sowing Methods		MEAN
	DSR	Transplanting	
Super Basmati-515	4.24	4.36	4.30 B
FMP-1	4.57	4.87	4.72 A
MEAN	4.41 B	4.61 A	

Figure 3.1: Effect of Rice Hybrids on Leaf Area Index

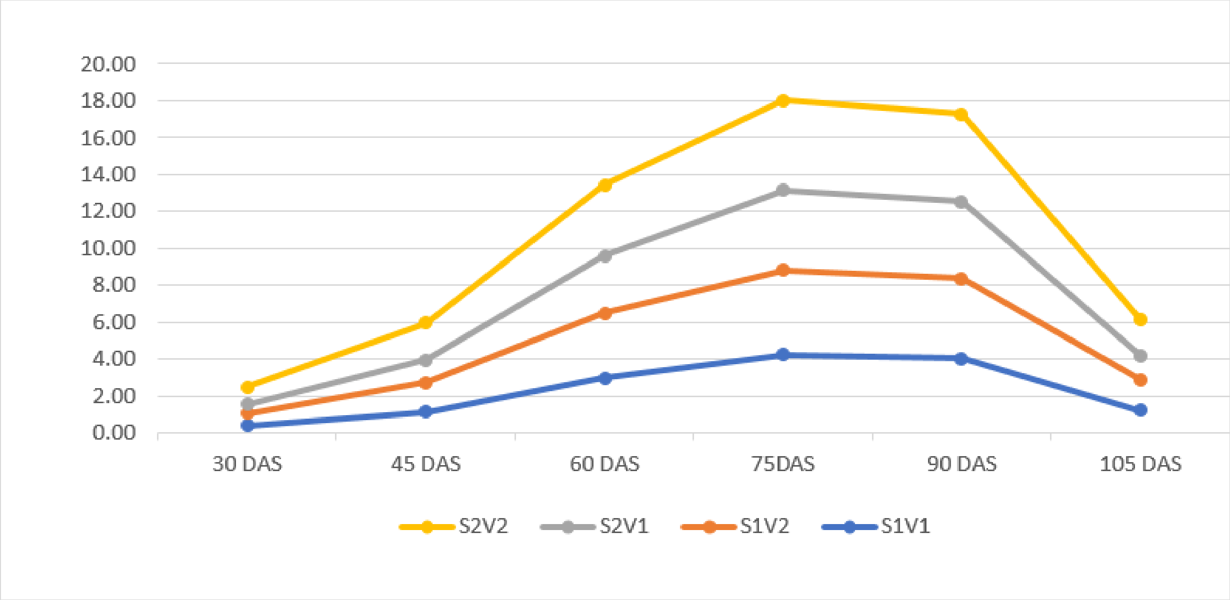

Figure 3.2: Effect of Planting Methods on Leaf Area Index

b) Leaf Area Duration

Leaf Area Duration (LAD) is crucial for assessing photosynthetic capability, carbon dioxide uptake, biomass accumulation, and crop yield (Chen et al., 2014). Table 4.2 shows that sowing methods and cultivars have highly significant individual effects, while their interaction is non-significant.

FMC-1 hybrid under transplanting had the maximum LAD (268.95), while Super Basmati 515 under direct seeding had the minimum (193.28). FMC-1 performed better than Super Basmati 515 in both sowing methods. The higher LAD in FMC-1 may be due to its plant architecture, optimizing light interception and canopy development (Haque et al., 2015).

Table 3.2: Effect of Planting Methods on Leaf Area Duration (LAD) for Rice

a. Analysis of Variance

Source	DF	SS	MS	F
Replication	2	454.68	227.34	
SM	1	824.19	824.19	12.7^{NS}
Error replication*SM	2	129.78	64.89	
Varieties	1	4621.3	4621.3	143.99**
SM*varieties	1	252.54	252.54	7.87*
Error replication*SM*varieties	4	128.38	32.09	
Total	11			

SOV: Source of Variational DF: Degree of freedom on SS: Sum of Squared
MS: Mean * = Significant ** = Highly Significant NS= Non significant

b. Individual comparison of Treatment Means

Treatments	**Sowing Methods**		**MEAN**
	DSR	**Transplanting**	
Super Basmati-515	198.15	205.55	201.86 B
FMC-1	228.23	253.98	241.10 A
MEAN	213.19 B	229.76 A	

Critical value for SM*varieties comparison = 2.77
Critical value for Varieties comparison = 2.77

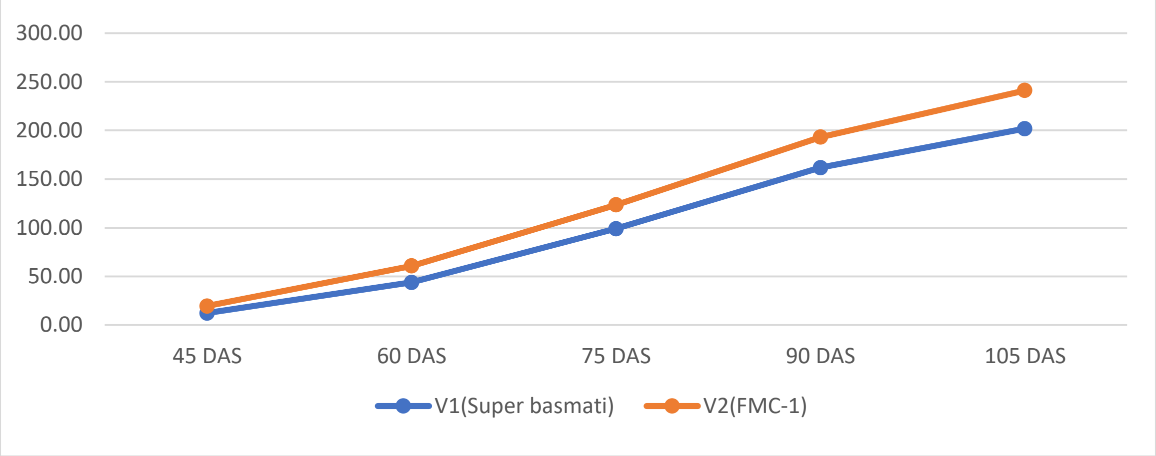

Figure 4.3: Effect of Rice Hybrids on Leaf Area Duration

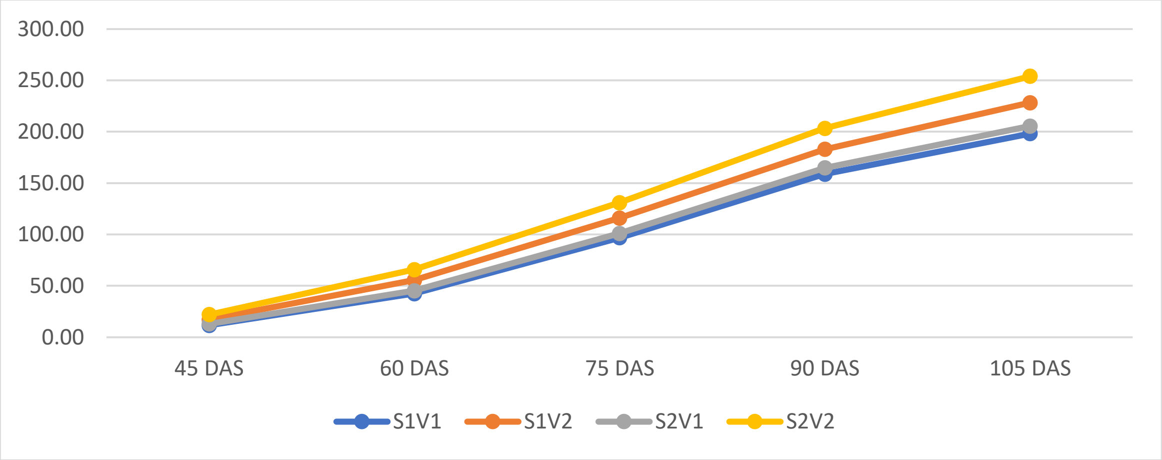

Figure 4.4: Effect of Planting Methods on Leaf Area Duration

c. Crop Growth Rate ($gm^{-2}d^{-1}$)

Crop growth rate (CGR) measures how quickly a crop increases biomass over a specific time frame and is crucial for assessing agricultural output and plant development (Singh and Maiti, 2016). CGR was calculated using Hunt’s method. The interaction between sowing techniques and cultivars was found to be insignificant, but individual effects were significant ($P < 0.05$). The maximum CGR (16) was achieved by FMC-1 hybrid rice under transplanting conditions, while the minimum (6.01) was observed in Super Basmati-515 under direct seeding. FMC-1 showed better growth, likely due to improved photosynthetic efficiency, including traits like larger leaf area and better carbon assimilation, as supported by Huang et al. (2016).

Table 3.3: Effect of planting methods on Crop Growth Rate (CGR) for Rice

a) Analysis of Variance

Source	DF	SS	MS	F
Replication	2	0.154	0.07702	
SM	1	1.477	1.47701	19.68*
Error Replication*SM	2	0.1501	0.07506	
Varieties	1	8.0197	8.01967	59.19**
SM*Varieties	1	0.4524	0.45241	3.34^{NS}
Error Replication*SM*Varieties	4	0.542	0.13549	
Total	11	10.7952		

SOV: Source of Variational DF: Degree of freedom on SS: Sum of Squared
MS: Mean * = Significant ** = Highly Significant NS= Non significant

b) Individual Comparison of Treatment Means

Treatments	Sowing Methods		MEAN
	DSR	TPR	
Super Basmati-515	13.36	13.67	13.51 B
FMC-1	14.60	15.69	15.14 A
MEAN	13.98 B	14.68 A	

Critical value for SM comparison = 4.30
Critical value for Varieties comparison = 2.77

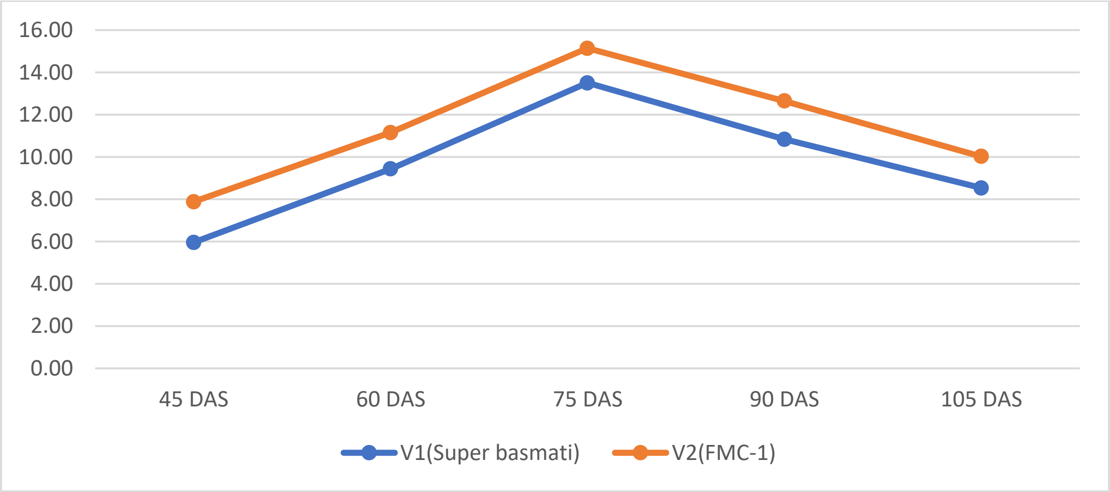

Figure 4.5: Effect of Rice Hybrids on Crop Growth Rate

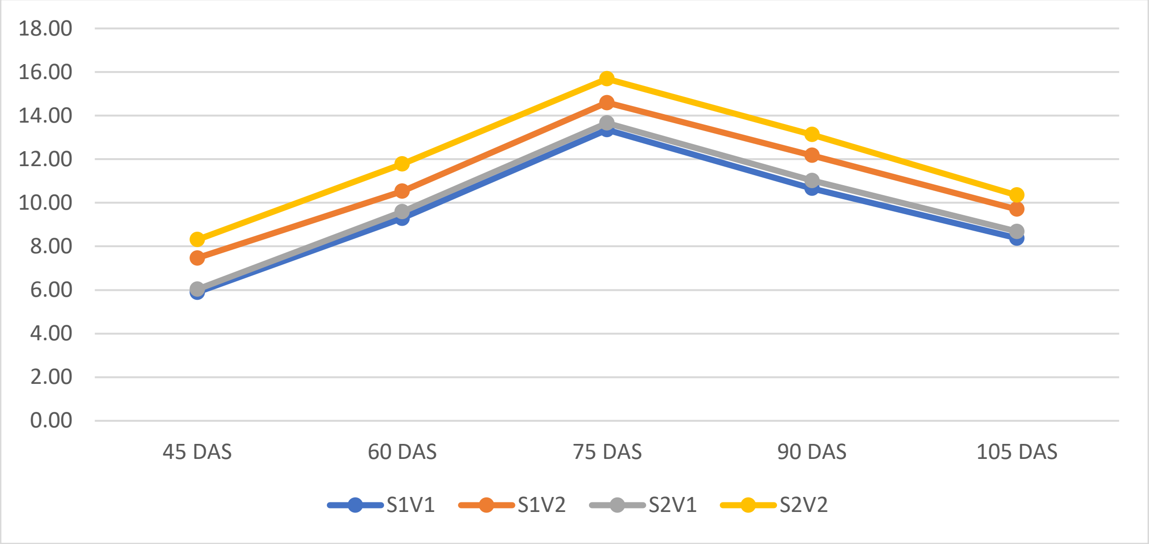

Figure 4.6: Effect of Planting Methods on Crop Growth Rate

- **Total Dry Matter (kg ha^{-1})**

Total dry matter (TDM) measures the accumulated biomass of plant material after drying, reflecting the plant's organic matter, including leaves, stems, roots, and seeds. TDM indicates potential biomass output, yield, and crop performance (Qiao et al., 2013).

The interaction between sowing methods and cultivars was non-significant, but both individual effects were significant ($P < 0.05$). Maximum TDM (1039 kg ha^{-1}) was observed in FMC-1 hybrid under transplanting, while the minimum (811 kg ha^{-1}) occurred in Super Basmati-515 under direct seeding.

FMC-1 outperformed Super Basmati-515, consistent with Ji et al. (2012). Figure 3.4 shows that FMC-1 produced more TDM, with maximum yield at 105 days post-sowing.

Table 3.4: Effect of Planting Methods on Total Dry Matter (TDM) for Rice

a) Analysis of Variance

Total	DF	SS	MS	F
Replication	2	4305	2152.7	
SM	1	16060	16060.1	23.95*
Error Replication*SM	2	1341	670.6	
Varieties	1	76960	76960.1	66.33**
SM*Varieties	1	3040	3040.1	2.62^{NS}
Error Replication*SM*Varieties	4	4641	1160.3	
Total	11	106348		

SOV: Source of Variational DF: Degree of freedom on SS: Sum of Squared
MS: Mean * = Significant ** = Highly Significant NS= Non significant

b) Individual Comparison of Treatment Means

Treatments	Sowing Methods		MEAN
	DSR	TPR	
Super Basmati-515	186.37	217.67	202.02 B
FMC-1	218.00	276.00	247.00 A
MEAN	202.18 B	246.83 A	

Critical value for SM comparison = 4.30
Critical value for Varieties comparison = 2.77

Figure 4.7: Effect of Rice Hybrids on Total dry Matter

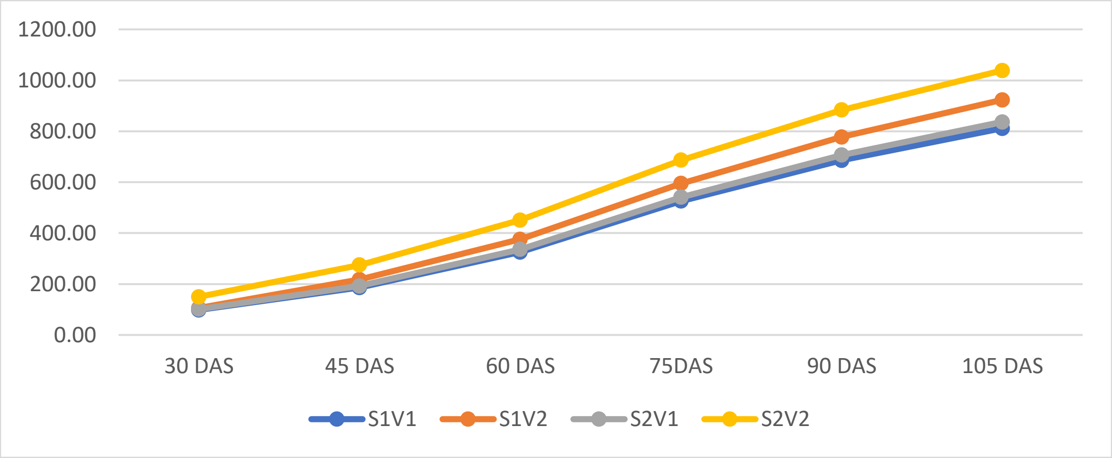

Figure 4.8: Effect of Planting Methods on Crop Growth Rate

➢ Net Assimilation Rate

Net assimilation rate (NAR) measures how efficiently a plant converts absorbed energy into biomass through photosynthesis, reflecting carbon dioxide incorporation for growth (Roy et al., 2012). The crop growth rate was calculated using Hunt's method. The interaction between cultivars and sowing methods was nonsignificant, but individual effects were significant ($P < 0.05$). The maximum NAR (4.99) was achieved in LP-18 super hybrid, while the minimum (4.08) occurred in FMC-1 hybrid. LP-18 outperformed FMC-1 under both sowing methods. The higher NAR in transplanted rice may be due to factors like early growth, better root development, and reduced water stress, consistent with Huang et al. (2018).

Table 3.5: Effect of Planting Methods on Net Assimilation Rate (NAR) for Rice

a) Analysis of Variance

Source	DF	SS	MS	F
Replication	2	0.06747	0.03373	
SM	1	0.08288	0.08288	0.53^{NS}
Error Replication*SM	2	0.31185	0.15593	
Varieties	1	0.33004	0.33004	9.78*
SM*Varieties	1	0.05104	0.05104	1.51^{NS}
Error Replication*SM*Varieties	3	0.10126	0.03375	
Total	10			

SOV: Source of Variational DF: Degree of freedom on SS: Sum of Squared
MS: Mean * = Significant ** = Highly Significant NS= Non significant

b) Individual Comparison of Treatment Means

Treatments	Sowing Methods		MEAN
	DSR	TPR	
Super Basmati-515	4.10	4.07	4.09 A
FMC-1	4.05	4.10	4.07 B
MEAN	4.07 B	4.09 A	

Critical value for SM comparison = 3.182

3.2 Crop Yield Parameters

➢ Biological Yield (t ha^{-1})

Biological yield refers to the total plant material produced by a crop, including leaves, stems, roots, and reproductive components like flowers or fruits (Srujana et al., 2017). The maximum biological yield (15.17 t ha^{-1}) was achieved in FMC-1 hybrid under transplanting, while the minimum (12.85 t ha^{-1}) occurred in FMC-1 hybrid under direct seeding. Individual effects of sowing methods and cultivars were highly significant ($P < 0.05$), but the interaction between the two was nonsignificant. FMC-1 performed better under transplanting compared to direct-seeded rice. Liang et al. (2017) reported similar findings.

Table 3.7: Effect of Planting Methods on Biological Yield (t ha^{-1}) for Rice

a) Analysis of Variance

Source	DF	SS	MS	F
Replication	2	0.95015	0.47507	
Sowing method	1	0.51253	0.51253	17.19*
Error Replication*Sowing method	2	0.05962	0.02981	
Varieties	1	0.06453	0.06453	0.24^{NS}
Sowing method*Varieties	1	0.49613	0.49613	1.85^{NS}
Error Replication*SM*Varieties	4	1.06983	0.26746	
Total	11	3.1528		

SOV: Source of Variational DF: Degree of freedom on SS: Sum of Squared
MS: Mean * = Significant ** = Highly Significant NS= Non significant

b) Individual Comparison of Treatment Means

Treatments	Sowing Methods		MEAN
	S1 (DSR)	S2(TPR)	
Super Basmati-515	14.22	14.23	14.22 A
FMC-1	13.67	14.49	14.08 B
MEAN	13.94 B	14.36 A	

Critical value for SM comparison = 4.303

➢ Kernel Yield (t ha^{-1})

Kernel yield, or grain yield, refers to the total amount of harvested grains from a crop, typically expressed in weight or volume (Upadhyay and Jaiswal, 2015). The interaction between sowing methods and cultivars was nonsignificant, but individual effects were highly significant ($P < 0.05$). The maximum yield (6.30 t ha^{-1}) was achieved by FMC-1 hybrid under transplanting, while the lowest yield (4.62 t ha^{-1}) was observed in Super Basmati-515 under direct seeding. FMC-1 outperformed Super Basmati-515 in both sowing methods. Increased yield was attributed to higher numbers of grains per panicle, active tillers, panicle length, and 1000-kernel weight. Wei et al. (2017) reported similar findings.

Table 3.8: Effect of Planting Methods on Kernal Yield for Rice

a) Analysis of Variance

Source	DF	SS	MS	F
Rep	2	0.02207	0.01103	
Sowing	1	0.42563	0.42563	10.93^{NS}
Error Replication*Sowing	2	0.07787	0.03893	
Varieties	1	4.44083	4.44083	151.13**
Sowing*Varieties	1	0.35363	0.35363	12.04*
Error Replication*Sowing*Varieties	4	0.11753	0.02938	
Total	11	5.43757		

SOV: Source of Variational DF: Degree of freedom on SS: Sum of Squared

MS: Mean * = Significant ** = Highly Significant NS= Non significant

b) Individual Comparison of Treatment Means

Treatments	Sowing Methods		MEAN
	DSR	TPR	
Super Basmati-515	4.59	4.63	4.61 B
FMC-1	5.47	6.19	5.83 A
MEAN	5.03 B	5.41 A	

➢ Harvest Index (%)

The harvest index compares biological yield to paddy yield as a percentage, reflecting a plant's ability to mobilize photosynthetic products into economically valuable organs (Amanullah et al., 2017). The maximum harvest index (42.25) was achieved by FMC-1 hybrid under transplanting, while the minimum (32.12) occurred under direct-seeded rice. Individual effects of sowing methods and cultivars were significant and highly significant ($P < 0.05$), but the interaction between them was nonsignificant. Factors like better plant height, crop growth rate, and net absorption rate contributed to the improved harvest index under transplanting. Deng et al. (2022) reported similar results.

Table 3.9: Effect of Planting Methods on Harvest Index (%) for Rice

a) Analysis of Variance

Source	DF	SS	MS	F
Replication	2	39.725	19.863	
Sowing method	1	9.205	9.205	20.71*
Error Replication*Sowing method	2	0.889	0.445	
Varieties	1	122.305	122.305	10.42*
Sowing method*Varieties	1	69.649	69.649	5.94^{NS}
Error Replication*SM*Varieties	4	46.935	11.734	
Total	11	288.708		

SOV: Source of Variational DF: Degree of freedom on SS: Sum of Squared
MS: Mean * = Significant ** = Highly Significant NS= Non significant

b) Individual Comparison of Treatment Means

Treatments	Sowing Methods		MEAN
	DSR	TPR	
Super Basmati-515	32.30	33.81	33.05
FMC-1	33.81	39.88	36.84
MEAN	33.05	36.84	

Critical value for SM comparison = 4.303
Critical value for varieties comparison = 2.77

➢ Straw Yield (t ha^{-1})

Straw yield refers to the above-ground plant material, including stems and leaves, left after grain harvest, and is often expressed in weight or volume (Matías et al., 2019). Super Basmati-515 produced the highest straw yield (9.64 t ha^{-1}) under transplanting, while

FMC-1 hybrid produced the least (8.60 t ha⁻¹) under direct-seeded rice. The individual effect of seeding techniques was significant ($P < 0.05$), but the interaction between rice cultivars and planting methods was nonsignificant.

The higher straw yield in transplanting may be due to increased tiller production and better nutrient utilization. Wang et al. (2022) found similar results.

Table 3.10: Effect of Planting Methods on Straw Yield (t ha^{-1}) for Rice

a) Analysis of Variance

Source	DF	SS	MS	F
Replication	2	0.03727	0.01863	
Sowing method	1	0.22963	0.22963	5.14^{NS}
Error Replication*Sowing method	2	0.08927	0.04463	
Varieties	1	0.3675	0.3675	11.85*
Sowing method*Varieties	1	0.1875	0.1875	6.05^{NS}
Error Replication*SM*Varieties	4	0.124	0.031	
Total	11	1.03517		

SOV: Source of Variational DF: Degree of freedom on SS: Sum of Squared
MS: Mean * = Significant ** = Highly Significant NS= Non significant

b) Individual Comparison of Treatment Means

Treatments	Sowing Methods		MEAN
	DSR	TPR	
Super Basmati-515	9.63	9.60	9.61 A
FMC-1	9.53	9.00	9.26 B
MEAN	9.58 A	9.30 B	

Critical value for varieties comparison = 2.77

➢ Thousand Kernel Weight (g)

Thousand grain weight is an important indicator of both grain yield and quality, as well as seedling vigor, and is measured in grams (Xie et al., 2019). The individual effects of planting techniques on thousand kernel weight were highly significant, while cultivars had an insignificant effect ($P < 0.05$).

The combined effect of cultivars and sowing methods was not significant. The highest thousand grain weight (35.04 g) was observed under transplanting, while the lowest (22.40 g) occurred with direct-seeded rice. FMC-1 hybrid showed a higher thousand kernel weight compared to Super Basmati-515, with larger grain size contributing to the higher weight under transplanting.

Table 3.11: Effect of Planting Methods on Thousand Kernel Weight (g) for Rice

a) Analysis of Variance

Source	DF	SS	MS	F
Replication	2	2.442	1.221	
Sowing method	1	1.695	1.695	0.57*
Error Replication*Sowing method	2	5.939	2.97	
Varieties	1	344.648	344.648	918.31*
Sowing method*Varieties	1	43.739	43.739	116.54^{NS}
Error Replication*SM*Varieties	4	1.501	0.375	
Total	11	399.964		

SOV: Source of Variational DF: Degree of freedom on SS: Sum of Squared
MS: Mean * = Significant ** = Highly Significant NS= Non significant

b) Individual Comparison of Treatment Means

Treatments	S1 (DSR)	S2(TPR)	MEAN
Super Basmati-515	19.27	22.33	20.80 B
FMC-1	33.81	29.23	31.52 A
MEAN	26.54 A	25.78 B	

Critical value for SM comparison = 4.303
Critical value for varieties comparison = 2.77

➢ Radiation Use Efficiency (gMJ-^{1}) for TDM

Radiation use efficiency (RUE) measures how effectively plants convert solar radiation into biomass, represented by dry matter produced per unit of absorbed photosynthetically active radiation (PAR) (Liu et al., 2019). Maximum RUE for total dry matter (TDM) was 1.96 in LP-18 super hybrid, while the minimum (1.82) was observed in FMC-1 hybrid. Both sowing techniques and cultivars had a highly significant impact on RUE, but their combined effect was nonsignificant. The highest RUE for TDM occurred under transplanting, while the lowest was under direct-seeded rice, a finding supported by Kumar et al. (2018).

➢ Radiation Use Efficiency (gMJ-1) for Grain

Radiation use efficiency (RUE) of grain yield measures the amount of grain produced per unit of absorbed photosynthetically active radiation (PAR) and varies based on factors like variety, weather, and crop growth stage (Slattery and Ort, 2015). The highest RUE for grain (0.74) was found in FMC-1 hybrid, while Super Basmati-515 had the lowest (0.63). The effects of sowing methods and cultivars were highly significant at the 5% level. However, the interaction between sowing methods and cultivars had a nonsignificant impact on RUE for grain. FMC-1 hybrid outperformed Super Basmati-515 under both sowing methods, as supported by Ullah et al. (2019).

Table 3.12: Effect of Planting Methods on Net Radiation Use Efficiency of TDM (RUETDM) for Rice

a) Analysis of Variance

Source	DF	S0S	MS	F
Replication (A)	2	0.009	0.004	
Sowing (B)	1	0.035	0.035	81.25**
Error A*B	2	0.001	0.001	
Varieties (C)	1	0.004	0.004	26.45**
B*C	1	0.001	0.001	0.45^{ns}
Error A*B*C	4	0.006	0.007	
Total	11	0.051		

SOV: Source of Variational DF: Degree of freedom on SS: Sum of Squared
MS: Mean Square * = Significant ** = Highly Significant

b) Individual Comparison of Treatment Means

Hybrids	Sowing Methods		MEAN
	DSR	Transplanting	
Super Basmati-515	1.86	1.96	1.91 A
FMC-1	1.82	1.93	1.87 B
Mean	1.84 B	1.95 A	

Critical value for SM comparison = 4.303
Critical value for varieties comparison = 2.77

Table 3.13: Effect of Planting Methods on Radiation Use Efficiency of Grain Yield (RUE Yield) for Rice

a) Analysis of Variance

Source	D.F	S.S	M.S	F,
Replication. (A)	2	0.008	0.004	
Sowing (B)	1	0.017	0.017	68.26**
Error A*B	2	0.001	0.002	
Varieties (C)	1	0.002	0.003	15.06**
Error A*B*C	4	0.005	0.014	8.47*
Total	11	0.030		

SOV: Source of Variational DF: Degree of freedom on SS: Sum of Squared
MS: Mean Square * = Significant ** = Highly Significant

b) Individual Comparison of Treatment Means

Hybrids	Sowing Methods		MEAN
	DSR	Transplanting	
Super Basmati-515	0.64 c	0.73 a	0.69
FMC-1	0.63 c	0.69 b	0.66
Mean	0.64	0.71	

Critical value for SM comparison = 4.303

Critical value for varieties comparison = 2.77

3.3 Model Calibration and Validation

The CERES-Rice model was successfully calibrated to simulate phenology, grain yield, and biomass with minimal variations from reported values for both rice varieties (Table 4.18). The model predicted the number of days to anthesis with a mean ratio of 1 and a mean difference of 0 for both hybrids. Paddy yield simulations showed a mean ratio of 1.05 and a mean difference of 350 for FMC-1 hybrid and Super Basmati-515. The biological yield simulation closely matched observed values, with a mean ratio of 0.98 and a mean difference of -202. The leaf area index simulation was also accurate, with a mean ratio of 0.85 and a mean difference of -0.7. The simulation of maturity days exactly matched the observed value with a mean ratio of 1.0 and a mean difference of 4 for both cultivars.

Table 3.14: Summary of Observed and Simulated Values during Model Calibration for Transplanted Rice of Different Cultivars

Variable	Unit	Obs.	Sim.	Mean ratio	Mean. Diff
Anthesis	Day	95	95	1	0
Tops Wt	Kg/ha	17405	17203	0.989	-202
Mat Yield	Kg/ha	9857	10059	1.175	202
LAI		4.89	4.18	0.856	-0.7
Maturity	Day	146	146	1.004	4

LAI = Leaf Area Index
Mat yield = Grain Yield
Tops wt. = Biological Yield
Obs. = Observed
Sim. = Simulated

Table 3.15: Evaluation of Simulated and Observed Days to Anthesis of Transplanted Rice of Different Cultivars

Varieties	Obs.	Sim.	Mean ratio	Mean. Diff.
FMC 1	95	95	1	0
Super Basmati-515	95	95	1	0

RMSE = 0
d-index = 0
r-Square = 1

Table 3.16: Evaluation of Simulated and Observed Tops weight of Transplanted Rice of Different Cultivars

Varieties	Obs.	Sim.	Mean ratio	Mean. Diff.
FMC 1	18070	17985	0.979	-385
Super Basmati-515	16740	16721	0.999	-19

RMSE = 272.56
d-index = 0.945
r-Square = 1

Table 3.17: Evaluation of Simulated and Observed Mat Yield of Transplanted Rice of Different Cultivars

Varieties	Obs.	Sim.	Mean ratio	Mean. Diff.
FMC 1 Hybrid	7980	7740	0.97	-240
Super Basmati-515	7110	8050	1.13	940
RMSE = 686.0 d-index = 0.26 r-Square = 1				

Table 3.18: Evaluation of Simulated and Observed Leaf Area Index of Transplanted Rice of Different Cultivars

Varieties	Obs.	Sim.	Mean ratio	Mean. Diff.
FMC 1	5.01	4.22	0.842	-0.79
Super Basmati-515	4.77	4.15	0.87	-0.62
RMSE = 0.71 d-index = 0.26 r-Square = 1				

Table 3.19: Evaluation of Simulated and Observed Days to Maturity of Transplanted Rice of Different Cultivars

Varieties	Obs.	Sim.	Mean ratio	Mean. Diff.
FMC 1	146	151	1.034	5
Super Basmati-515	146	142	0.973	-4
RMSE = 4.528 d-index = 0 r-Square = 1				

4. CONCLUSIONS AND RECOMMENDATIONS

The field trial revealed that rice cultivars and sowing techniques significantly affected growth and yield parameters, though their interaction was non-significant. FMC-1 hybrid rice outperformed Super Basmati-515 in terms of plant height, tiller count, panicle length, kernel yield, biological yield, and leaf area index, especially under transplanted conditions. Transplanted rice exhibited higher productivity, including improved 1000-kernel weight, leaf area duration, and dry matter production compared to direct-seeded rice. Maximum growth and yield values, such as biological yield (14.49 t ha-1) and kernel yield (6.19 t ha-1), were achieved with FMC-1 under transplanting. Sowing methods significantly impacted the number of tillers and dry matter production, with transplanting showing better results overall.

Based on the findings, farmers are advised to prefer transplanting, particularly when cultivating FMC-1 hybrid rice, for improved growth and yield. FMC-1 hybrid is recommended for higher productivity, particularly in terms of kernel yield and biological yield. While direct seeding offers faster crop establishment, transplanting generally provides better outcomes for overall yield and growth. Further research is recommended to examine the long-term effects of sowing methods on soil health and sustainability. Hybrid rice cultivars, especially FMC-1, should be prioritized to maximize leaf area index and dry matter production.

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