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PREDICTING AND SIMULATING RICE GROWTH AND YIELD: A COMPARATIVE MODELING STUDY ON THE IMPACT OF DIVERSE PRODUCTION SYSTEMS

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Abstract

Rice (Oryza sativa) is a vital cereal crop, feeding half of the world's population, with Pakistan ranking tenth globally in production. Despite its significance, rice cultivation in Pakistan faces challenges related to water scarcity and labor-intensive practices, highlighting a need for sustainable solutions. This study aims to address these challenges by evaluating the growth, phenology, and yield of fine (Basmati-515) and coarse (KSK-133) rice cultivars under different planting strategies, using the Decision Support System for Agro-technology Transfer (DSSAT). Conducted at the University of Agriculture Faisalabad, the experiment employed a randomized complete block design with a split-plot arrangement. Transplanted rice (TPR) and direct-seeded rice (DSR) were the main plot factors, and rice cultivars served as sub-plot factors. Data on crop growth and yield characteristics were collected following established procedures, with the CERES-Rice model calibrated and validated using soil, weather, and crop management data. Statistical analysis revealed that TPR with KSK-133 achieved the highest grain yield and related parameters, while DSR exhibited benefits like early flowering and reduced resource use but faced challenges in weed management and crop establishment. DSR demonstrated significant potential for water and labor savings, making it suitable for resource-constrained regions. The study underscores the need for sustainable rice production through advanced agronomic practices, selective cultivation of high-yielding varieties, and policy incentives promoting DSR adoption. These findings contribute to improving rice productivity and ensuring food security in Pakistan, addressing environmental challenges and economic resilience. Further research is recommended to optimize DSR implementation.

Keywords: Rice Cultivation, Sustainable Agriculture, Direct-seeded Rice (DSR), Transplanted Rice (TPR), Rice Productivity, Decision Support System for Agro-technology Transfer (DSSAT).

1. INTRODUCTION

Climate change is a major concern due to the increasing population and food supply. Climate factors like temperature and rainfall significantly impact crop production, with rice production negatively impacted (Pickson et al., 2022). The causes of climate change, such as human activity and emissions of greenhouse gases, as well as the observed changes in the patterns of precipitation and temperature by (Raza et al., 2024).

Since 1960, rice yield has decreased by 12.24% due to climate change. High variability in floods and droughts also decreases rice yield in arid or semi-arid regions by 6-18% (Abbas et al., 2022). The increase in temperature and yield of rice is negatively correlated in regions like Punjab, Pakistan. Rice is the most widely consumed staple food, consumed by 3 billion people worldwide. However, meeting population growth demands presents numerous challenges.

The rapid growth of land and water resources and the migration of young people from rural to urban areas are decreasing the supply of farm labor. Rice is the most affected crop due to its high labor and water requirements (Prasad et al., 2017). Economic development has led to a labor shortage and higher wages in agriculture, particularly in non-agricultural industries. Water scarcity is a significant issue in rice agriculture, affecting nearly 18 million hectares of irrigated rice by 2025. To maintain yield potential while reducing water and manpower requirements, technology must be developed (Xu et al., 2019).

Rice, the world's leading staple food, is the second-biggest export good after cotton and contributes 0.4% of GDP and 1.9% of value added in agriculture. However, its production has increased due to hybrid varieties being planted. In 2022-2023, rice production decreased by 15.9% from 3,537 thousand hectares in 2021-2022 to 7.322 million tons. This decrease in output has led to an increase in paddy prices. Rice production consists of 34% of basmati (fine) types and 66% of coarse types (Pakistan Economic Survey 2022-23).

Pakistan's limited rice output is attributed to various issues such as high input prices, suboptimal plant population and nutrition, lack of competent labor, weeds, pest infestation, and a decline in local market prices. Rice crop growth and yields are influenced by various techniques, with cultivar type also impacting plant growth and development, affecting yield.

Pakistan's low rice yields are primarily due to factors like inadequate water supply, weed growth, insect pests, and improper sowing techniques. Transplantation is a common method in Asian nations, but direct sowing is not practical due to limited water availability. Effective weed control in transplanted rice yields higher economic yields. Direct sowing is more costly, time-consuming, and labor-intensive, while transplanting requires just two-man hours to cover the same area in seeds (Kausar et al., 2020).

Indica rice, grown in the Indo-Pak subcontinent, is categorized into two types: Fine and Coarse, with Fine being medium-grain and non-aromatic, and Coarse being long-grain

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and aromatic. (Farooq et al., 2009). Transplanting is the dominant method in rice production, cultivated 75% of the world's rice area, while direct seeding is used for the remaining areas, both significantly impacting rice growth and yield. (Nawaz et al., 2022). Pakistan lacks a sustainable cropping system to optimize rice land use. Traditional methods require significant water and labor costs, while dry rice technology, a contemporary, cost-saving method, has recently been introduced in rice-growing regions. This method not only conserves water but also enhances farmers' productivity and efficiency (Ehsanullah et al., 2007).

The primary method of growing rice in Pakistan is transplanting it into puddled soil. This technique offers advantages such as better nutrient availability and reduced water percolation losses but negatively impacts the physical properties of the soil, making it less suitable for rotating non-rice upland crops. However, transplanting is labor-intensive, especially during hot weather, posing significant challenges.

The rising scarcity and cost of both labor and water further reduce the profitability of rice cultivation. While many countries have adopted mechanized transplantation to address these issues, challenges such as uneven land leveling and the high cost of transplanters have hindered its widespread adoption in Pakistan (Ali et al. 2020; Bhattacharyya & Prakash, 2021; Singh & Yadav, 2021).

Traditional rice transplanting methods like puddling can cause soil degradation, excessive water loss, and decreased soil permeability, consuming up to 30% of the total water needed for rice production. Puddling offers benefits like minimizing water percolation losses, suppressing weed growth, accelerating seedling establishment, and improving nutrient availability through anaerobic conditions. However, there are divided opinions on its overall advantages. Research suggests that traditional transplanting systems promote growth, increased dry matter accumulation, and higher yields, making them crucial for improving rice production (Kumar et al.2022; Ahmad et al. 2023; Patel et al. 2023).

Direct-seeded rice (DSR) is a method of rice production that reduces greenhouse gases like methane and nitrous oxide by planting pre-germinated seeds on a prepared field. This method offers advantages over traditional transplanting techniques, including reduced labor costs, environmental benefits, and water conservation. DSR allows for easier sowing, earlier crop maturity, increased water efficiency, resistance to water deficit, lower methane emissions, and higher profits, especially in areas with guaranteed water supplies (Nawaz et al., 2022).

DSR rice is a type of rice with three varieties: water-seeded, dry-seeded, and wet-seeded. Wet-seeded rice is spread using standing water, preventing pests and weeds while providing moisture for seed germination. It saves water and labor costs. China and India are the most used countries for dry-seeded DSR rice (Sagare et al., 2020).

Direct-seeded rice (DSR) has advantages over conventional transplanting but also has drawbacks like lower yields due to poor crop stand and severe weed infestation (Dhaliwal

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et al, 2021). Researchers have identified herbicides for preplant/burn-down, pre-emergence, and post-emergence weed control in DSR, crucial for controlling weed populations and enhancing agricultural productivity. Further research is needed to refine methodologies, enhance crop yield, and address constraints. Crop residue-based mulches show potential in reducing DSR-related problems (Anwar et al., 2012; Gopal et al., 2019; Singh et al., 2021).

Direct-seeded rice (DSR) is a hybrid rice cropping method that offers higher yields but requires more labor. It can decrease labor costs by 25% compared to transplanted rice. DSR promotes timely crop sowing, preserves soil health, supports rice-wheat cropping, and yields economic benefits. It also improves soil physical conditions and reduces soil penetration resistance. Under certain conditions, DSR can yield comparable to transplanted rice with 5.33% more grain and 25-30% less water usage. Farmers are transitioning to DSR due to chemical weed control, early maturing cultivars, and better nutrient management techniques (Patel et al. 2022; Ahmad et al. 2022; Gupta et al. 2023; Zhao et al. 2023).

Over the past 40 years, rice production has grown due to high-yielding varieties and high fertilizer levels, particularly nitrogen. However, excessive nitrogen use has led to environmental issues like ozone layer depletion, surface and groundwater eutrophication, and greenhouse warming. To address these issues, rice application rates for nitrogen must be decreased. Direct-seeded rice is proposed as a suitable replacement for conventional puddled-transplanted rice, as it is efficient in saving water, requires less labor, reduces greenhouse gas emissions, and offers increased nutrient availability and weed suppression benefits (Bhandaria et al 2020). Farmers face challenges in adopting Direct-Seeded Rice (DSR) due to weed infestation, yield stagnation, lack of specially bred varieties, panicle sterility, nutrient availability, pests, diseases, and water management.

Despite time and labor savings, DSR cannot be adapted to a large scale due to increased weed infestation, disease/pest attack, less yield, fertilizer requirement, and lodging factors. Traditional transplanted crop yields were estimated to be 11% higher than DSR, but the benefit cost ratio difference was non-significant. Both methods may be alternatives depending on labor, water, and soil type availability (Latif et al., 2017). Direct seeded rice (DSR) faces challenges due to lodging, a phenomenon caused by shallow root dispersion and buried culm depth, which can reduce grain yield and quality by one ton per hectare. Obstacles to DSR implementation include weed infestation, lack of enhanced cultivars, panicle sterility, static yield, and nutrient availability (Sharma et al., 2021).

The IPCC reports that agriculture and land-use changes contributed 23% of global greenhouse gas emissions from 2007 to 2016, including CO2, CH4, and N2O. By 2050, this figure is expected to rise to 21%-37%. Rice production is a significant human-induced source of methane emissions, with wetland paddy fields accounting for 10-20% and 53% of N2O. In Pakistan, the agricultural sector contributed 34% of total GHG emissions in 2017, with CH4 being the most prevalent greenhouse gas (Akram et al., 2018; Mir et al.,

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2021). The use of crop modeling as a tool for assisting crop development, scientific research, and the analysis of strategy has become increasingly important (Akram et al., 2023). The DSSAT is a computer-based crop simulation model that estimates crop growth and yield, including 33 models, including the DSSAT-CERES-Rice model.

It accurately simulates upland and lowland rice growth and yield, influencing climate conditions and crop management. DSSAT has been used since the 1990s to forecast rice yield, with models like ORYZA (v3) now including CERES-rice. ORYZA accounts for genotype data, weather, soil conditions, and agronomic management data, including water and fertilizer management, establishment date, and nitrogen levels.

Direct Seeded Rice (DSR) methods have shown promise in addressing water scarcity and labor challenges in rice production, particularly in water-limited regions like Pakistan. However, there is limited research on the effectiveness of different DSR systems on crop growth, yield, and environmental impact in diverse agro-climatic conditions. This study aims to assess and simulate outcomes of wet and dry DSR methods to determine their potential as sustainable alternatives for efficient rice production in water-limited regions.

The hypothesis is that adopting DSR methods, particularly Dry-DSR with zero or minimum tillage, will reduce water use and labor requirements without compromising rice yield. Additionally, DSR methods will generate lower greenhouse gas emissions than traditional transplanted rice systems, supporting a more sustainable approach to rice cultivation in water-scarce regions.

2. MATERIALS AND METHODS

2.1. Experimental Site Description

The planned experiment was carried out at the Agronomic Research Farm at the University of Agriculture Faisalabad during the Kharif season of 2023. The tables contain information regarding the experimental site. The research site is in Faisalabad, with the geographical coordinates of 31°25’ latitude North and 73°04’ longitude East. The altitude of the site is 184.4 meters above sea level. The soil at the location belongs to the Lyallpur series, which is characterized as fine loamy, mixed, hyperthermic, and classified as Typic Calciagids or Typic Haplocambids under the USDA soil classification system. This area falls within a dry semi-arid climatic zone, indicating a climate with limited rainfall and higher temperature variability. This combination of location, soil properties, and climate influences the agricultural practices and crop growth in the region.

2.2 Soil Physico-chemical Properties Analysis

The collection of soil samples was carried out using a soil auger, an instrument specifically designed for this purpose. A composite sample of soil was taken from a depth of 30 cm at the experimental site, ensuring a representative and comprehensive analysis. The area being studied in Faisalabad exhibited a soil structure characterized as sandy clay loam. This type of soil tends to retain water, with limited percolation. Based on prior

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research and studies on Aromatic rice, sandy clay loam is identified as the optimal soil composition for cultivating rice, utilizing both transplanting and direct seeding methods.

Soil characteristics were gathered from the Soil Department laboratory at the University of Agriculture, Faisalabad. Chemical testing of soils is imperative as soil properties significantly impact the growth and yield of rice crops. The interaction between soil and crops plays a pivotal role in predicting optimal growth and yield, as well as determining the suitability of the soil for specific crop types. The chemical composition of the soil in the research area was obtained from the Meteorological Department at the University of Agriculture, Faisalabad.

Therefore, the research was conducted considering all crucial soil factors essential for crop growth. The soil parameters of the study site indicate the following characteristics: These characteristics suggest that while the soil is suitable for cultivation, its fertility can be improved with amendments such as organic matter and phosphorus-rich fertilizers to support sustainable crop growth.

Table 1: Soil Attributes of Experimental Site

Parameters	Units	Value	Status
Sampling depth	cm	0-30	
pH		8	Alkaline
Texture			Sandy loam
EC	dSm^{-1}	1.1	Normal
Organic Matter	%	0.91	Low
Sand	%	33.7	
Silt	%	34.2	
Clay	%	32.1	
Nitrogen	%	0.059	Low
Phosphorus	ppm	11.5	Low

2.3 Climatic Data

Data on meteorological conditions during the crop's growth season in 2023 was sourced from the Agro-meteorology wing of the Department of Agronomy at the University of Agriculture, Faisalabad. The recorded climate information throughout the experimental period, covering June 2023 to October 2023, is detailed in the provided table.

Table 2: Mean Weather Data for Rice Growing Season 2023

Months	Mean Temp. (°C)	Rainfall (mm)	Relative humidity (%)	Sunshine (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

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2.4 Land Preparation

The field preparation began with the utilization of a rotavator, followed by two ploughings and planking. Subsequently, the field was divided into two sections: one designated for Direct Seeded Rice (DSR) and the other for transplanted rice. For DSR, an irrigation system was employed to ensure suitable moisture levels for rainfed conditions. This was followed by four ploughings and two rounds of planking to achieve the desired soil structure for direct seeding. In contrast, for transplanted rice, flood irrigation was utilized to create puddled conditions.

Afterward, the field was left to settle for a day to facilitate proper soil cohesion. This allowed for adequate support for newly transplanted seedlings, reducing the risk of uprooting.

2.5 Nursery Establishment

The transplanted rice method is widely practiced and serves as the conventional approach to rice cultivation across the country. Various nursery-raising techniques are employed, taking into account factors such as soil type, local customs, and water availability. Establishing a healthy and pest-free nursery is crucial for achieving optimal yields. Nursery beds were prepared on June 3rd and June 17th for KSK-133 and Basmati-515, respectively.

Seeds were sown on the same dates using the dry method. Subsequently, heavy irrigation was applied to the dry cultivated soil. Seeds were broadcasted at a rate of 1 kg for KSK-133 and 500-750 g for Basmati-515. Irrigation was initially applied to a depth of 1 inch at the time of broadcasting, followed by drainage the next morning. This process was repeated for a week, after which the irrigation depth was increased to 3 inches as the nursery grew. Following this method, the nursery was typically ready for transplanting after 25-30 days.

2.6 Treatments Description

The investigation took place during the summer (Kharif) season of 2023 at the Agronomy research farm within the Department of Agronomy, University of Agriculture, Faisalabad. The study comprised two sowing methods (Direct Seeded Rice - DSR and transplanted rice) and two rice cultivars (Super Basmati - Fine and KSK 133 - Coarse) as treatments.

Field preparation involved utilizing a Rotavator, followed by two cultivations and planking. Subsequently, the field was split into two sections, allocating one for DSR and the other for transplanted rice. A Randomized Complete Block Design was employed, arranged in a Split plot configuration with three replications. The size of each net plot measured 6.0 meters by 2.25 meters.

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Table 3: Treatments Description

Factor	Details	Values
Main plot factor	Sowing methods (S)	S1: Direct seeded, S2: Transplanting
Sub plot factor	Rice cultivar (V)	V1: Basmati-515 (Fine), V2: KSK-133 (Coarse)
Design	RCBD under split plot	
Replication	3	
Transplanted rice method	Seed rate:	Fine: 12 kg ha-1, Coarse: 16 kg ha-1
	Nursery seed rate	Fine: 12 kg ha-1, Coarse: 16 kg ha-1
	Nursery sowing & transplanting dates	KSK-133: 3 June 2023, Transplanting: 28 June 2023. Super Basmati: 17 June 2023, Transplanting: 12 July 2023
Direct seeded rice method	Seed rate	Fine: 20 kg ha-1, Coarse: 25 kg ha-1
	Sowing dates	KSK-133: 3 June 2023, Super Basmati: 17 June 2023
	Row to Row distance	22.5 cm
	Fertilizer rate	NPK: 172.5, 102, 80 kg ha-1
Other Details	Additional Info	Net Plot: 6 m x 1.8 m, Gross Plot: 7 m x 1.8 m, Canal Path: 1 m, Sub Water Channel: 1.5 m, Area Required: 314.6 m2

2.7 Nursery Transplanting

After 30 days of nursery establishment, the nursery seedlings reached a suitable height for transplanting. The seedlings were then transplanted at the age of 30 days into a puddled field. Row-to-row and plant-to-plant distances were maintained at approximately 22.5 cm in accordance with recommended spacing guidelines. Eight lines were sown per plot. Adequate irrigation was applied immediately after transplanting. Any missing gaps in the planting were filled within a week to achieve the desired population density.

2.8 Sowing in Direct Seeded Rice

Direct seeding of rice commenced manually on June 3, 2023, coinciding with nursery sowing, with rows spaced 22.5 cm apart. Dry seeds were sown onto previously ploughed and harrowed dry soil, which was immediately irrigated. Before sowing, the seeds underwent overnight soaking to enhance germination, followed by shade drying to prevent adhesion to the hand drill. Sowing depth was maintained at 2-3 cm to facilitate robust rooting and crop establishment. Fine rice had a seed rate of 18 kg per hectare, while Coarse rice had a rate of 16 kg per hectare.

2.9 Irrigation Management

In the Direct Seeded Rice (DSR) plots, irrigation was carefully managed to ensure thorough germination and to prevent moisture stress during critical growth phases. Following the application of pre-emergence herbicides on the evening of sowing, the first irrigation was administered the following day. Subsequent irrigations were provided as

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necessary, particularly when soil cracking was observed. Initially, irrigation was carried out 2-3 times per week during the early stages until seedling establishment. Later, irrigation frequency was adjusted based on the crop's requirements. During tillering, panicle initiation, and grain filling stages, the plots were kept flooded to mitigate moisture stress. The final irrigation was applied 20 days prior to harvesting. For the transplanting method, water depth was maintained at 1.5 to 3 inches for the first 15 to 20 days, after which the field was kept in a saturated condition. A total of 16 irrigations were administered throughout the crop's growth period.

2.10 Fertilizer Application

In both sowing techniques, the recommended dose of 125 kilograms of nitrogen (N), 80 kilograms of phosphorus (P), and 65 kilograms of potassium (K) fertilizers was applied. The entire amount of phosphorus and potassium, along with a 40% portion of nitrogen, was applied as a starter dose onto the soil surface. The remaining nitrogen was top-dressed: 30 days after sowing (DAS) in Direct Seeded Rice (DSR) and 20 days after transplanting (DAT) in Transplanted Rice (TPR), during the middle tillering stage and panicle initiation (PI) stage. Zinc was applied in the form of zinc sulfate as part of the starter dose.

2.11 Pre-Emergence and Post-Emergence Weed Management

Weeds in both Direct Seeded and Transplanted rice were managed through the application of pre-emergence and post-emergence herbicides. Specifically, "Butachlor" was applied at a rate of 800 milliliters per acre at the time of sowing and transplanting to control weeds. Additionally, "MCPA and Minista" were applied in combination as post-emergence herbicides for further weed control.

2.12 Plant Protective Measure

To minimize extraneous factors, cultural and agronomic practices such as hoeing, weeding, irrigation, and plant protective measures were kept consistent throughout the experiment. Weeds were controlled using both pre- and post-emergence herbicides. Data were collected at different stages of crop growth using recommended methods. The objective of this study was to compare the performance of different planting methods and rice varieties in terms of growth and yield**.**

2.13 Harvesting and Threshing

Harvesting before the rice crop reaches full maturity may lead to the development of porous and underdeveloped kernels, while delaying harvesting may cause over-matured spikelet to shatter. Manual harvesting was conducted by skilled laborers using sickles when the crop reached physiological maturity, indicated by a moisture level of approximately 23-25% in the panicles. Harvesting involved randomly selecting a 1m^2 quadrat and cutting all the plants within that area. The harvested plants were then bundled and left to dry for a period of five days.

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2.14 Sampling Procedure

Destructive sampling was conducted after 30 days of transplanting in the transplanted method and 55 days after sowing in DSR. Sampling intervals occurred every 15 days from a 30 cm row area at ground level within each plot. The fresh weight of each sample was measured using a weighing balance, and subsamples of 10 g for vegetative parts and 15 g for panicles were oven-dried and weighed individually. The weights of all components were then combined and converted to per square meter (m^2) to determine the total dry weight.

2.15 Growth Parameters

- Leaf area index (LAI)
- Leaf area duration (LAD)
- Total dry matter (TDM) (gm^{-2})
- Crop growth rate (CGR) ($gm^{-2}d^{-1}$)
- Net assimilation rate (NAR) ($gm^{-2}d^{-1}$)

Leaf Area Index (LAI)

To determine the leaf area index (LAI) value, a sun scanner device was employed. The sun scanner was installed vertically and leveled at the central part of the field (under shade of leaves). The data was collected for a predetermined period of time, and then processed using software to calculate the LAI.

$$LAI = \frac{leaf\ \ area}{land\ \ area}$$

It is the ratio of leaf area to land area

Leaf Area Duration

It is the ratio of leaf area index at 1st harvest and leaf area index at final harvest to the observation date of 1st leaf area index minus the observation date of final leaf area index.

It can be calculated by using the formula of Hunt (1998).

$$LAD = \frac{(LAI1 + LAI2)}{2} \times (t2 - t1)$$

Were, LAD = leaf area duration, LAI_1 = leaf area index at 1st harvest, LAI_2 = leaf area index at final harvest T1= first leaf area index date of observance T_2 = final leaf area index date of observance

Total Dry Matter (gm^{-2})

A three plant samples from each plot were harvested at ground level fortnightly. The fresh weight of different plant fractions was measured on an electric balance. Then a 15 g

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subsample from each plot was dried under the sun for 24 hours and then dry weight was determined after oven drying at 70°C until constant weight.

The following growth parameters will be calculated.

- Fresh weight
- Dry weight of plant fractions

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

Crop growth rate is a measure of the increase in size, mass, or number of crops over some time. CGR represents dry weight gained by a unit area of crop in a unit time expressed as "g" m-2 day-1. Plants from 0.5 m2 were harvested to avoid destructive sampling and oven-dried for 24 hours and CGR was calculated by using the following formula of Hunt (1978). Crop growth rate will be estimated by using the formula, given by Hunt (1998).

$$CGR = \frac{W_2 - W_1}{t2 - t1}$$

Where W2 and W1 are weights (dry) harvested at times t_1 and t_2, respectively.

W_1 = Total dry matter at 1st harvest

W_2 = Total dry matter at final harvest

T_1 = first total dry matter date of observance

T_2 = final total dry matter date of observance

Net Assimilation Rate (g m^{-2} d^{-1})

To estimate the average Net Assimilation Rate (NAR) using the formula provided by Hunt (1998), we need to first determine the change in dry weight per unit leaf area per unit time. Then, we can calculate NAR as the quotient of this change in dry weight and the corresponding change in leaf area over the same period.

The formula for NAR, according to Hunt (1998), is typically expressed as:

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

This formula quantifies the rate at which the plant can convert assimilates into new biomass per unit leaf area over time. TDM = Total dry matter LAD = Leaf area duration

2.16 Agronomic Parameters

- Plant height at maturity (cm)
- length of panicle (cm)
- No of tillers (m^{-2})
- No. of productive tillers (m^{-2})

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- branches per panicle
- Paddy yield (t ha^{-1})
- Straw yield (t ha^{-1})
- Biological yield (t ha^{-1})
- 1000-grain weight (g)
- Harvest index (%)

Plant Height (cm)

Upon reaching plant maturity, plant height was measured manually using a measuring tape. Three plants were randomly selected from each plot and the tape was placed from the base of the soil up to the tip of the longest leaf (flag leaf). The average height of the three plants was then calculated and recorded.

Panicle Length (cm)

To assess panicle length, three plants were randomly chosen from each plot and measured using a measuring tape. The panicle length was determined from the last node to the tip of the panicle, and the average measurement was recorded in centimeters.

No. of Tillers (m^{-2})

To ascertain the number of tillers, three identified plants were randomly chosen from a designated area of 1 square meter within each plot. The tillers on each plant were manually counted, and the cumulative number of tillers for the three plants was tallied and documented.

Number of Productive tillers (m^{-2})

During harvesting, three plants were randomly picked from each plot within a 1 square meter area. The number of panicle-bearing tillers on each selected plant was counted and noted. Subsequently, the average number of tillers per plant was computed and presented as the number of tillers per plant.

Branches per Panicle

Three panicles were randomly chosen from each tiller within every plot, and the number of branches on each of these panicles was counted. The average number of branches per panicle was then computed and documented for each plot.

Grain Yield (t ha^{-1})

A random 1 square meter area was harvested from each plot, ensuring avoidance of any border effects. The harvested rice was subsequently sun-dried and threshed to obtain the grain yield. The yield obtained from each plot was recorded and expressed in metric tons per hectare (t ha^{-1}).

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Straw Yield (t ha^{-1})

To determine the straw yield, the biomass from the whole rice plant, including the grains, was collected from each plot. The samples were sun-dried and then weighed to determine the total biomass yield. The weight of the grain was then subtracted from the total biomass yield to obtain the straw yield. The straw yield was expressed in t ha-1.

Biological Yield (t ha^{-1})

At physiological maturity of the rice crop, manual harvesting was conducted using sickles. The harvested rice was bundled and left to sun-dry for a period of 5 days. Subsequently, the dried rice was weighed using an electronic balance. The biological yield for each plot was then calculated and expressed in metric tons per hectare (t ha^{-1}).

Harvest Index (%)

The Harvest Index (HI) was computed as the ratio of grain yield to the total dry matter (TDM) yield and then expressed as a percentage.

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

2.17 Statistical Analysis

The variance technique was employed in the statistical analysis of the data. The LSD (Least Significant Difference) technique was utilized at a 5% probability level to compare the means of various treatments.

2.18 Model Calibration:

The model calibration process involved ensuring that the genetic coefficients (P1, P2O, P2R, P5, G1, G2, G3, PHINT, THOT, G4, G5) accurately represented the real system within predefined criteria. Genetic coefficients were selected based on their performance against various treatments in field experiments. The most suitable set of genetic coefficients was determined using an effective method outlined by Hunt *et al*. (1993).

Table Breakdown of Genetic Coefficients of Model

Varieties	P1	P2R	P5	P2O	G1	G2	G3	G4
Ksk-133	158.0	253.0	767.9	11.05	78.00	0.029	0.600	1.00
Basmati-515	208.0	264.3	687.6	11.28	72.34	0.029	1.030	1.00

P1: Time period (expressed as growing degree days [GDD] in oC-d above a base temperature of 9C) from seedling emergence during which the rice plant is not responsive to changes in photoperiod.

P2O: Critical photoperiod or the longest day length (in hours) at which development occurs at a maximum rate. Developmental rate slows down at values higher than P2O.

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E-Publication: Online Open Access
Vol: 67 Issue 11 | 2024
DOI: 10.5281/zenodo.14219950

P2R: Extent to which phasic development leading to panicle initiation is delayed (expressed as GDD in oC-d) for each hour increase in photoperiod above P2O.

P5: Time period (in GDD oC-d) from beginning of grain filling (3 to 4 days after flowering) to physiological maturity with a base temperature of 9oC.

G1: Potential spikelet number coefficient estimated from the number of spikelets per gram of main culm dry weight at anthesis.

G2: Single grain weight (in grams) under ideal growing conditions.

G3: Tillering coefficient (scalar value) relative to the IR64 cultivar under ideal conditions.

PHINT: Phyllochron Interval (oC-d). Time interval in degree-days for each leaf-tip to appear under non-stressed conditions.

THOT: Temperature (oC) above which spikelet sterility is affected by high temperature.

2.19 Model Evaluation:

Data evaluation will involve comparing observed growth data with simulated data. The model will be executed against the remaining treatments, excluding one used in the calibration process. Simulated results will be assessed by comparing them with static indices such as the root mean square error (RMSE), as proposed by Wallach and Goffinet (1989).

$$\text{RMSE} = \sqrt{\frac{\sum_{i=1}^{n}(P_i - O_i)^2}{n}}$$

$$d = 1 - \frac{\sum_{i=1}^{n}(P_i - O_i)^2}{\sum_{i=1}^{n}(|P_i - \bar{O}| + |O_i - \bar{O}|)^2}, \quad 0 \leq d \leq 1$$

$$\text{MPD} = \frac{100}{n}\sum_{i=1}^{n}\frac{|P_i - O_i|}{O_i} \qquad R^2 = 1 - \frac{\sum_{i=1}^{n}(P_i - O_i)^2}{\sum_{i=1}^{n}(O_i - \bar{O})^2}$$

MPD= Mean predicted deviation

d= index of agreement

n= Number of observations

Pi=Predicted values of the variable under study

Oi= Observed values of the variable under study

R^2= Coefficient of determination

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Vol: 67 Issue 11 | 2024
DOI: 10.5281/zenodo.14219950

3. RESULTS AND DISCUSSIONS

3.1 Growth Parameters

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) were the measures used to measure crop growth.

3.1.1 Total Dry Matter (gm^{-2})

The weight of the plant material as a whole after all water has been extracted is referred to as total dry matter. It symbolizes the quantity of the plant's solid, organic matter, such as the leaves, stems, roots, and any fruits or seeds. It represents the quantity of biomass that a plant has collected through photosynthesis and other metabolic activities, making it a crucial indicator of plant development and production. As shown in Table 3.1, the interactive effect of sowing methods along with the cultivars was found to be highly significant also the individual influence of sowing methods and cultivars was found to be highly significant, respectively, at $p \leq 0.05$. The maximum Total dry matter (1045.27 gm^{-2}) was noticed in puddled transplanted paddy by cultivar KSK 133. While the lowest total dry matter attained in direct seeded paddy (812.70 gm^{-2}) by super basmati. The mean comparison table (3.2) shows that the best performance of Cultivar KSK-133 was recorded over cultivar super basmati and both cultivars differ significantly at 5 % probability level. The interactive effect of both cultivars and sowing methods was highly significant, as described in Table 3.1. The results are supported by Chen et al. (2009) and Kumar et al. (2018).

Table 3.1 Analysis of Variance of TDM

Source	DF	SS	MS	F
Rep	2	30.9	15.5	
Sowing	1	15745.6	15745.6	23625.7
Error Rep*Sowing	2	1.3	0.7	
Cultivars	1	76908.8	76908.8	13601.1
Sowing*Cultivars	1	7150.2	7150.2	1264.49
Error Rep*Sowing*Cultivars	4	22.6	5.7	
Total	11	99859.4		

DF = degree of freedom SS = Sum of square MS = Mean square

** = Highly Significant Probability level of 5% was kept for the construction of ANOVA

Table 3.2 of Treatment Means for TDM

Treatments	Sowing Methods		Mean
	DSR	TPR	
C1(Basmati-515)	812.7	836.33	824.51 B
C2 (KSK-313)	924	1045.27	984.63 A
MEAN	868.35 B	940.8 A	

LSD value for cultivars* sowing methods = 4.6016

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Vol: 67 Issue 11 | 2024
DOI: 10.5281/zenodo.14219950

Figure 3.1 demonstrates the relation of cultivars with the total dry matter. A linear graphical relation occurred as the crop developed till 105 DAS illustrating that total dry matter starts increasing linearly throughout, from early stage till ripening. KSK-133 produced more dry matter yield (984.63 gm^{-2}) than super basmati (824.51 gm^{-2}) as illustrated in figure 3.1. Figure 3.2 describes the interactive relationship of cultivars and planting methods with the total dry matter at 25 days interval. The graph shows that highest curve recorded in TPR method. It formed a linear graph till 105 DAS illustrating that time course increases throughout, from early stage till ripening, first it slows then increase linearly. KSK 133 shows maximum total dry matter accumulation in TPR method obtained highest peak (1045.00 gm^{-2}) while super basmati shows minimum value (812.70 gm^{-2}) in DSR method, fig 3.2.

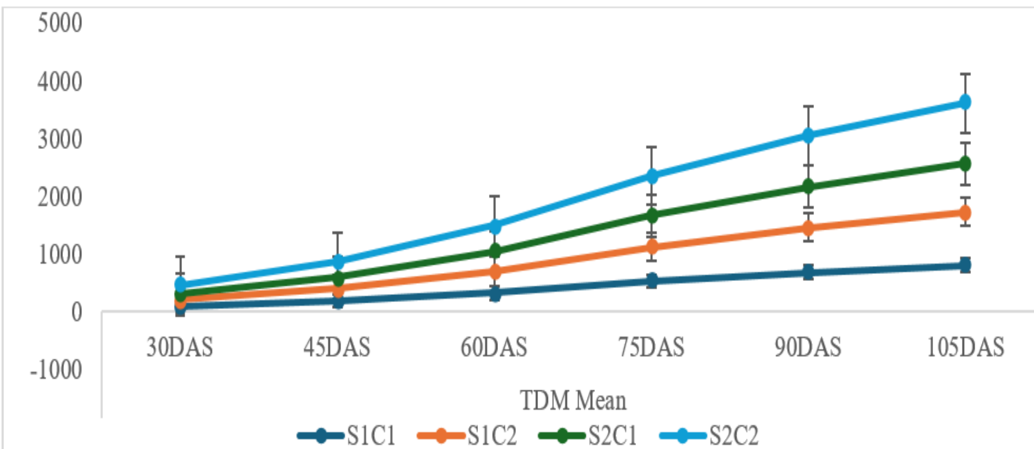

Figure 3.1: Response of Total Dry Matter (TDM) to Varying Planting Methods for Coarse and Fine Rice

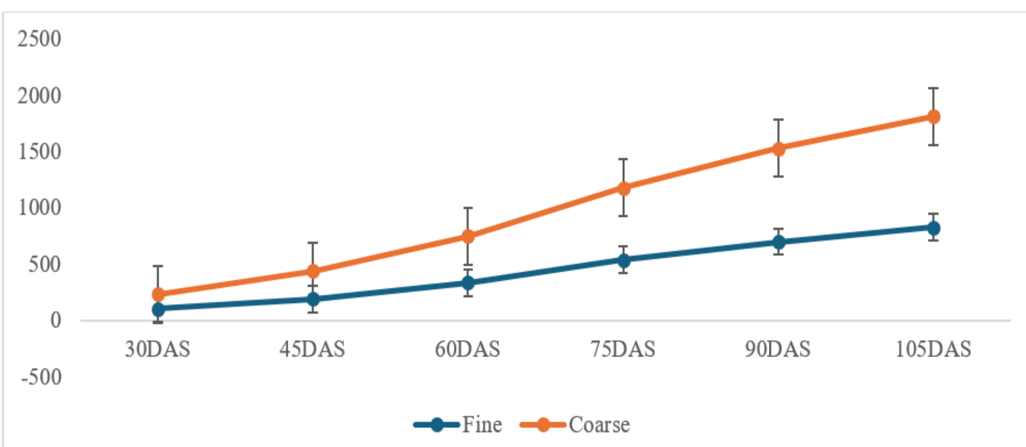

Figure 3.2: Response of Total Dry Matter (TDM) to Varying Planting Methods for Coarse and Fine Rice

ISSN: 1673-064X
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Vol: 67 Issue 11 | 2024
DOI: 10.5281/zenodo.14219950

3.1.2 Leaf Area Index

The efficiency of the photosynthetic process and the size of the photosynthetic surface are measured by the leaf area index, a frequently employed metric for describing the vegetation's canopy structure. It is a crucial indication of vegetation productivity and energy exchange with the atmosphere and is defined as the total leaf area per unit ground area (Stroppiana et al., 2006). For numerous applications, including crop modelling, ecological modelling, and climate modelling, LAI is an essential variable (Wang et al., 2007). The plant's photosynthetic region is called the LAI. Under subtropical climate conditions, it grew steadily until the growth stage and then gradually decreased till harvest (Rajput et al., 2017). As shown in table 3.3, the individual effects of sowing methods and cultivars were found to be non-significant, while the combined effect of sowing methods and cultivars was found to be non-significant at p ≤0.05. The mean comparison table (3.3) indicates that there is a significant relationship between the varieties; the KSK 313 cultivar recorded the highest value of LAI (4.92), while Super Basmati attained the lowest value of LAI of 4.51 in the DSR. In terms of cultivar comparison, KSK 133 outperformed Super Basmati. In terms of sowing methods, there was no significant interaction; the TPR method produced the greatest LAI values (4.99), while the DSR method produced the lowest LAI values (4.48). Results are corroborated by Mohanta's findings. The results of Lutao et al. (2020), where the transplanted approach shows greatest LAI, corroborate the conclusions. The response of the Leaf Area Index (LAI) to different planting techniques for coarse and fine rice is shown in figure 4.4The graph displays the maximum curve ever found using the TPR method. The time course growth is shown by the sigmoid curve of LAI, which begins slowly and exhibits a linear connection with DAS before increasing quickly and reaching its maximum value approximately 75 days after sowing (DAS). Following this peak, when leaf withering commences during the ripening phases, the LAI curve starts to fall. According to our findings, Super Basmati had a lesser LAI value of 3.3 in the DSR method, whereas KSK 133 fared well, achieving the greatest LAI value of 5.0 in the TPR method.

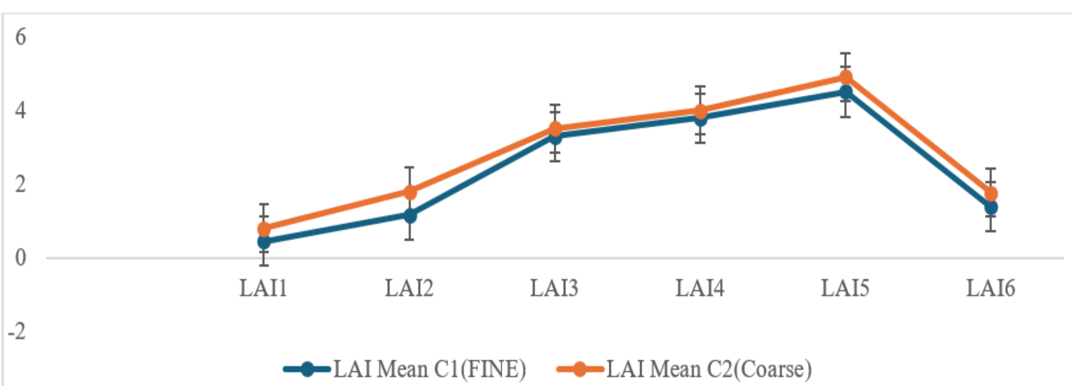

Figure 3.3: Response of Leaf Area Index (LAI) to Varying Planting Methods

ISSN: 1673-064X
E-Publication: Online Open Access
Vol: 67 Issue 11 | 2024
DOI: 10.5281/zenodo.14219950

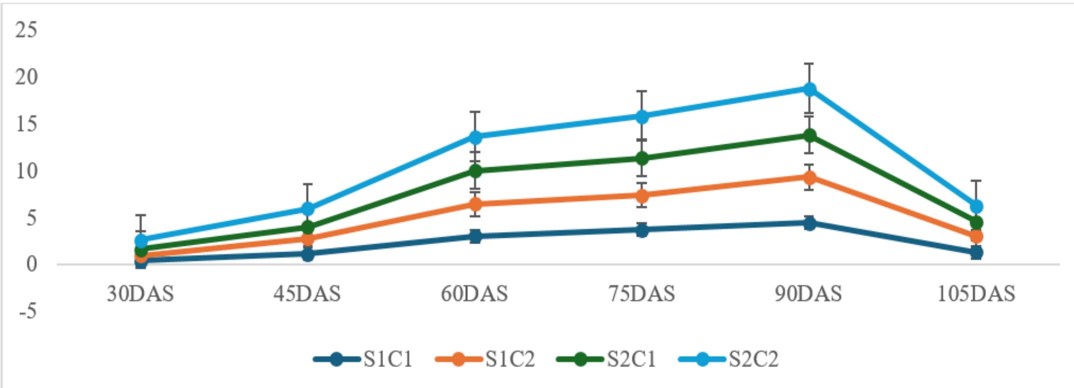

Figure 3.4: Response of Leaf Area Index (LAI) to Varying Planting Methods for Coarse and Fine Rice

Table 3.3: Analysis of Variance of Leaf Area Index

Source	DF	SS	MS	F
Rep	2	0.5657	0.02829	
Sowing	1	0.0816	0.0816	0.76
Error Rep	2	0.21589	0.10794	
Cultivars	1	0.74529	0.74529	17.2
Sowing*Cultivars	1	0.0592	0.0592	1.37
Error Rep*Sowing*Cultivars	4	0.17336	0.04334	
Total	11			

DF = degree of freedom SS = Sum of square MS = Mean square

** = Highly Significant ns = non-Significant Probability level of 5% was kept for the construction of ANOVA, LSD value for cultivars = 0.1851, Means sharing contrasting letters symbolize statistical significance at $P \leq 0.05$

3.1.3 Leaf Area Duration (LAD) (days)

For rice crops, leaf area duration (LAD) is a crucial variable since it has a direct impact on biomass production and yield potential. According to Hunt (2012), LAD is the time when the crop canopy absorbs solar radiation and helps with photosynthesis. The interactive effect of cultivars and sowing methods was found to be very significant at $p \leq 0.05$, as table 4.5illustrates.

The cultivar KSK 133 produced a puddled transplanted paddy with the longest leaf area duration (250.35 days), as indicated by the mean comparison table (3.4). However, super basmati achieved the lowest leaf area duration (204.25 days) in direct seeded paddy Figure 3.5. Khalid et al.'s research conclusions from 2022, which assessed that transplanted rice seedlings generally outperformed direct dry-seeding in terms of leaf area duration, corroborate the trial's findings.

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Vol: 67 Issue 11 | 2024
DOI: 10.5281/zenodo.14219950

Table 3.4: Analysis of Variance for Leaf Area Duration

Source	DF	SS	MS	F
Rep	2	526.08	263.04	
Sowing	1	1346.31	1346.31	6.68
Error Rep	2	403.34	201.67	
Cultivars	1	144.43	144.43	0.35
Sowing*Cultivars	1	169.65	169.65	0.41
Error Rep*Sowing*Cultivars	4	1659.31	414.83	
Total	11			

DF = degree of freedom SS = Sum of square MS = Mean square

** = Highly Significant Probability level of 5% was kept for the construction of ANOVA. LSD value for cultivars* sowing methods = 1.1068

Means sharing contrasting letters symbolize statistical significance at $P \leq 0.05$.

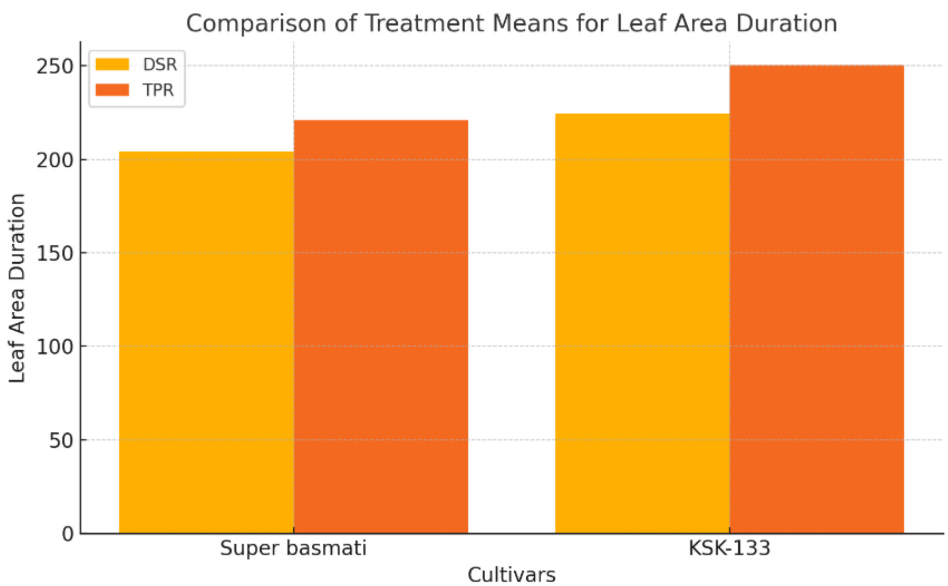

Figure 3.5: Comparison of Treatment Means for Leaf Area Duration

3.1.4 Crop growth rate ($gm^{-1}day^{-1}$).

Hunt defined crop growth rate (CGR) in 1978 as the rate at which the total plant dry weight increases instantaneously per area and over time. It is a crucial metric in the measurement of plant growth and is used to measure the pace of crop growth at various developmental stages. CGR can change during a crop's growth, usually exhibiting varying growth rates at different phases of the crop's development (Takai et al., 2006). According to Horie et al. (2003), there is a substantial correlation between rice grain yield and CGR during the late reproductive stage. They also emphasized the significance of greater CGR during this period for the ultimate grain output since it affects spikelet development and NSC accumulation.

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The interactive effect of cultivars and sowing methods was found to be very significant at p ≤0.05, as table 3.5 illustrates. The maximum crop growth rate (15.57 gm-1day-1) was observed in puddled transplanted paddy by cultivar KSK 133, as indicated by the mean comparison figure 3.6. Direct planted paddy yielded the lowest crop growth rate (13.44 gm-1day-1) when compared to super basmati. The trial's outcomes are corroborated by Khalid et al.'s research conclusions (2022) as anticipated, evaluated crop growth rate (CGR) increased steadily during the active growth phase for all treatments. In all plots, CGR peaked 75–90 days after planting and began to fall at physiological maturity (Khalid et al., 2022). Additionally, it was discovered that the cultivars KSK 133 had much higher CGR, which might be explained by the cultivars' high tillering and high dry matter buildup.

Table 3.5 Analysis of Variance for Crop Growth Rate (CGR) to Varying Planting Methods for Coarse and Fine Rice.

Source	DF	SS	MS	F
Rep	2	0.18935	0.09467	
Sowing	1	1.13468	1.13468	14.24
Error Rep*Sowing	2	0.15935	0.07968	
Varieties	1	6.88568	6.88568	48.05
Sowing*Varieties	1	0.20021	0.20021	1.4
Error Rep*Sowing*Varieties	4	0.57317	0.14329	
Total	11	9.14243		

DF = degree of freedom SS = Sum of square MS = Mean square

** = Highly Significant Probability level of 5% was kept for the construction of ANOVA.

LSD value for cultivars* sowing methods = 0.1397, Means sharing contrasting letters symbolize statistical significance at P ≤ 0.05.

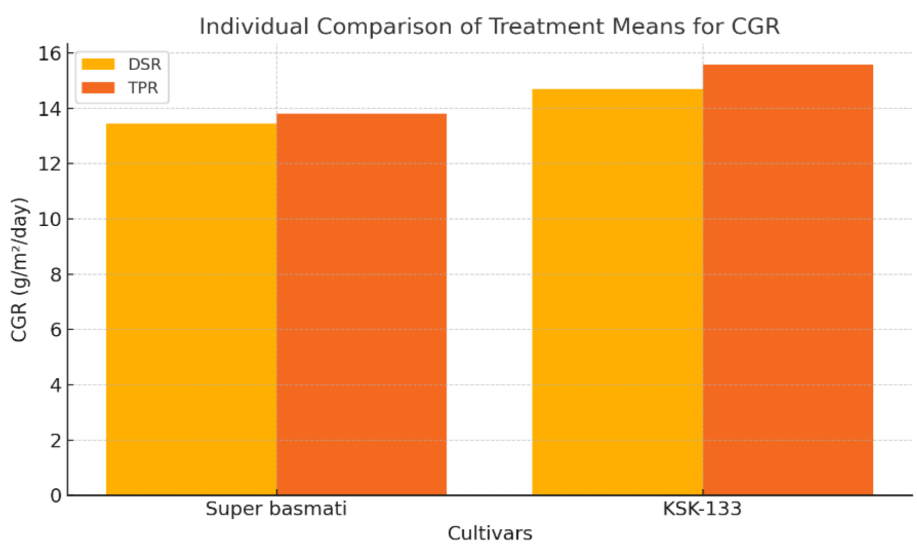

Figure 3.6: Comparison of Treatment Means for Crop growth rate

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3.1.5 Net assimilation rate (g cm^{-2} day^{-1})

According to Williams (1946), NAR is the dry matter increase per unit leaf area or per unit leaf dry weight per unit of time. This physiological indicator (g cm-2 day-1) tells us how much biomass the plant has accumulated per unit of leaf area at a specific time. The average photosynthetic efficiency of leaves within a crop community is measured by the NAR. During the phase of active growth, NAR represents the plant's capacity to transform photosynthetic products into fresh biomass and is impacted by various factors like temperature, light intensity, and nutrient availability the interacting effect of cultivars and sowing methods was determined to be non-significant at p ≤0.05, as indicated in table 3.6. Additionally, it was discovered that the individual effects of cultivars and seeding techniques were not significant at p ≤0.05. The maximum Net assimilation rate (4.10 g cm-2 day-1) was observed in direct seeded paddy by cultivar super basmati, according to the mean comparison figure 3.7. On the other hand, KSK 133 achieved the lowest Net Assimilation Rate in TPR paddy (4.02 g cm-2 day-1).

Table 3.6 Analysis of Variance Response of Net Assimilation Rate (Nar) to Varying Planting Methods for Coarse and Fine Rice

Source	DF	SS	MS	F
Rep	2	0.09035	0.04518	
Sowing	1	0.0147	0.0147	0.21
Error Rep*Sowing	2	0.13745	0.06872	
Varieties	1	0.2028	0.2028	8.76
Sowing*Varieties	1	0.0507	0.0507	2.19
Error Rep*Sowing*Varieties	4	0.0926	0.02315	
Total	11	0.5886		

DF = degree of freedom SS = Sum of square MS = Mean square
Probability level of 5% was kept for the construction of ANOVA Means sharing contrasting letters symbolize statistical significance at P ≤ 0.05.

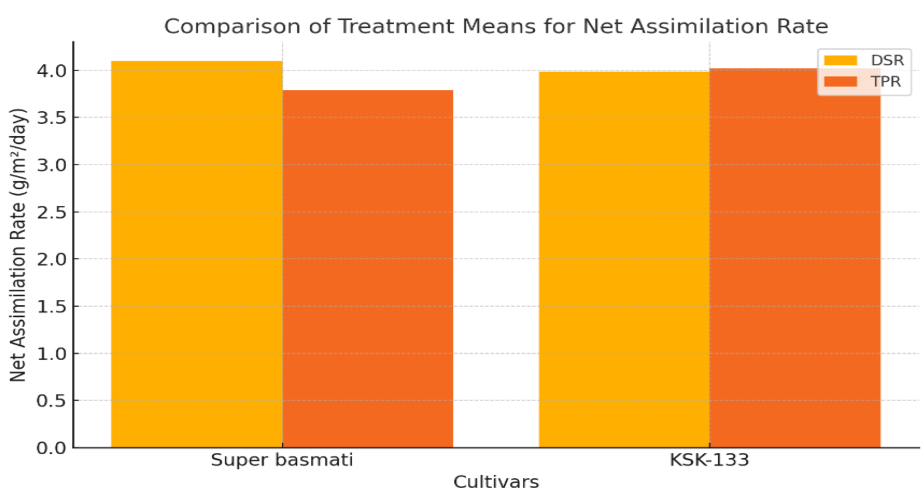

Figure 3.7: Comparison of Treatment Means for Net Assimilation Rate

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3.1.6 Radiation Use Efficiency for TDM

For every treatment, TDM was fitted into intercepted PAR using the least squares method. The interaction of treatment (sowing methods and rice cultivars) in the experiment did not substantially affect radiation usage efficiency for TDM at P<0.05.

The radiation use efficiency for TDM varies significantly depending on the rice cultivar and the manner of sowing. In comparison to direct seeded rice, the transplanted rice production system had the highest radiation use efficiency for TDM, according to the trial. Conversely, the coarse-type cultivar KSK133 demonstrated the highest radiation use efficiency for TDM when compared to super basmati.

Table 3.7: Impact of Different Planting Techniques on Rice RUETDM (g/MJ) cultivators.

Source	DF	SS	MS	F
Rep	2	0.007	0.003	
Sowing	1	0.023	0.023	15.08 **
Varieties	1	0.002467	0.02467	12.16**
Sowing*Varieties	1	0.00067	0.00067	0.63^{ns}
Total	11	0.04049		

** = Highly Significant ns = non-significant Means sharing contrasting letters symbolize statistical significance at P ≤ 0.05.

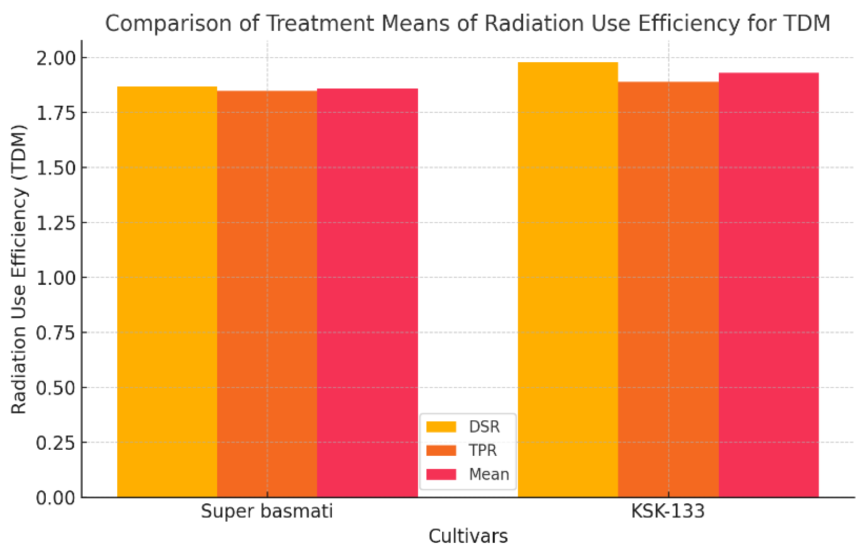

Figure 3.8: Comparison of Treatment Means of Radiation Use Efficiency for TDM

3.1.7 Radiation Use Efficiency for Grain Yield

For every treatment, Grain Yield was fitted into intercepted PAR using the least squares method. The interaction of treatment (sowing methods and rice cultivars) with radiation use efficiency for grain yield was not significant at P<0.05. Both rice cultivars and sowing

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Vol: 67 Issue 11 | 2024
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technique significantly influence radiation use efficiency for grain yield. When comparing transplanted rice to direct seeded rice, the investigation revealed that the transplanted rice production system had the maximum radiation usage efficiency for grain yield. Conversely, the coarse-type cultivar KSK133 demonstrated the highest radiation use efficiency for TDM when compared to super basmati.

Table 3.8: Influence of Varying Planting Methods on RUE_{GY} (g/MJ) for Rice Cultivars

Source	DF	SS	MS	F
Rep	2	0.0002	0.0001	
Sowing	1	0.0088	0.0088	10.61**
Varieties	1	0.057	0.057	17.16**
Sowing*Varieties	1	0.00067	0.00067	0.87^{ns}
Rep	4	0.0033	0.00207	
Total	11	0.03059		

** = Highly Significant ns = non-significant Means sharing contrasting letters symbolize statistical significance at P ≤ 0.05.

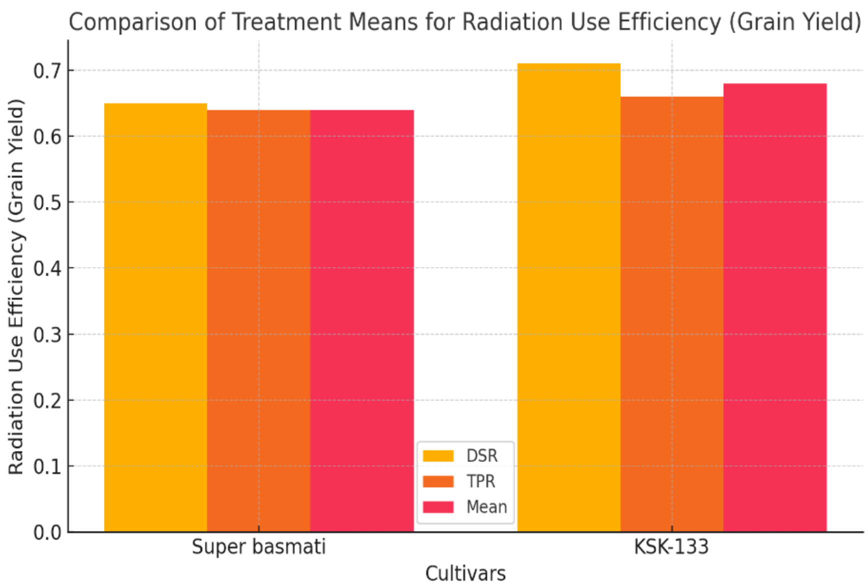

Figure 3.9: Comparison of Treatment Means for Radiation Use Efficiency for Grain Yield

3.2 Crop Development

3.2.1 Days Taken to Maturity

Compared to TPR, the DDSR crop reached harvest maturity 4–8 days earlier and matured a little earlier. Compared to KSK 133, Super Basmati reached harvest maturity 4–10 days earlier. The rice cultivars and rice establishment techniques had a highly substantial impact on the number of days to maturity. Table 3.9. At every stage of crop

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Vol: 67 Issue 11 | 2024
DOI: 10.5281/zenodo.14219950

growth, the cultivar KSK 133's puddled rice took the longest to mature (148 days), while super basmati's direct sowing took 140 days. The findings of Lutao et al. (2020) and Ishfaq et al. (2020) are consistent, indicating that all rice types matured significantly earlier under direct row sowing than under transplanting. The mean value of Days taken to maturity of tested rice varieties as affected by sowing methods at different growth stages are presented in (Figure. 3.10).

Table 3.9: Analysis of Variance for Days Taken to Maturity of Rice Cultivars as Affected by Varying Planting Methods for Coarse and Fine Rice

Source	DF	SS	MS	F
Rep	2	1.5	0.75	
Sowing	1	108	108	144
Varieties	1	108	108	86.4
Sowing*Varieties	1	12	12	9.6
Error R*S*V	4	5	1.25	
Total	11	236		

DF = degree of freedom SS = Sum of square MS = Mean square

** = Highly Significant A probability level of 5% was kept for the construction of ANOVA.

LSD value for cultivars = 1.7940 LSD value for sowing methods = 2.1547, Means sharing contrasting letters symbolize statistical significance at P ≤ 0.05.

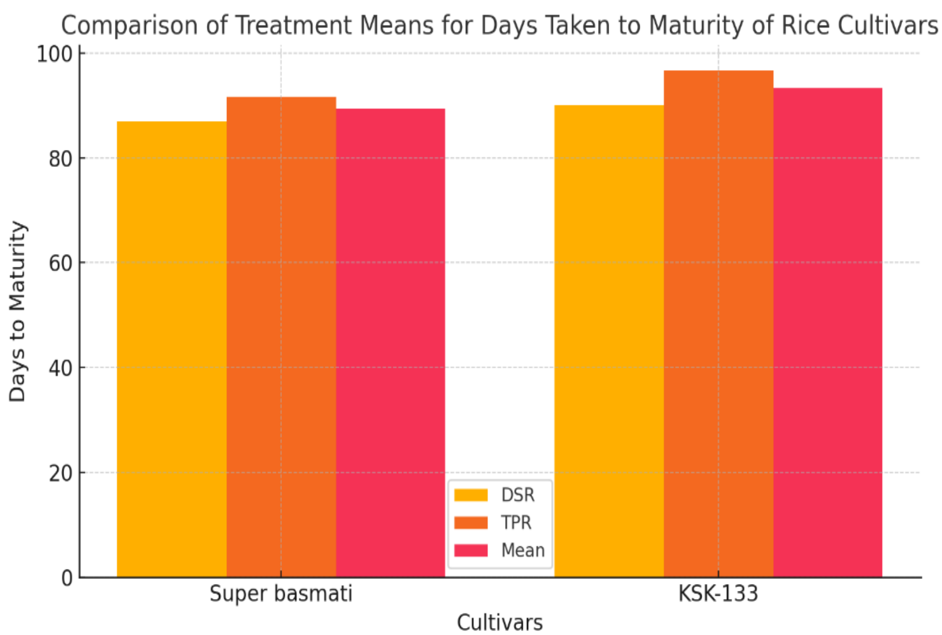

Figure 3.10: Comparison of Treatment Means for Days Taken to Maturity of Rice Cultivars as Affected by Varying Planting Methods for Coarse and Fine Rice

ISSN: 1673-064X
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Vol: 67 Issue 11 | 2024
DOI: 10.5281/zenodo.14219950

3.3 Yield Attributes

3.3.1 Plant Height at Harvest (cm)

As shown in Table 3.10, the experiment conducted revealed no discernible variation in plant height among the investigated rice types as impacted by the planting techniques. This suggests that the sowing techniques used had no discernible impact on the various kinds' mean values of plant height.

Nonetheless, there were notable differences in plant height amongst the various rice cultivars, with KSK-313 showing the lowest height of 97.32 cm and super basmati showing the highest height of 109.33 cm. In addition, compared to coarse rice KSK-313, taller plants were produced by super basmati fine rice. Plant height was also greatly influenced by planting methods; the transplanted approach produced a maximum height of 109.33 cm, while the direct seeded method produced a height of 105.7 cm.

In this experiment, the interaction between cultivars and seeding techniques had no discernible effect on plant heights. These results are consistent with those of Maqsood (1998), who noted comparable patterns in their field research, where transplanted rice showed higher heights than direct seeding on level ground.

Soriano et al. (2018), Aslam et al. (2008), and Birhane et al. (2013) all reported consistent results showing that rice plants established using the transplanted system had higher health and vigor and that conventionally transplanted crops displayed greater plant height compared to directly seeded plants.

The average plant height values for the examined rice varieties, which were impacted by the techniques of sowing at various growth phases, are displayed in Figure 3.10.

Table 3.10: Analysis of Variance of Height (cm) of Rice Cultivars as Affected by Varying Planting Methods for Coarse and Fine Rice

Source	DF	SS	MS	F
Rep	2	2.138	1.069	
Sowing	1	65.147	65.147	39.79
Error Rep*Sowing	2	3.275	1.637	
Cultivars	1	161.921	161.92	39.18
Sowing*Cultivars	1	3.162	3.162	0.77
Error Rep*Sowing*Cultivar	4	16.531	4.133	
Total	11			

DF = degree of freedom SS = Sum of square MS = Mean square

** = Highly Significant ns = non-significant, A probability level of 5% was kept for the construction of ANOVA. LSD value for Cultivars = 2.0669 LSD value for sowing methods =2.2053 Means sharing contrasting letters symbolize statistical significance at P ≤ 0.05.

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Vol: 67 Issue 11 | 2024
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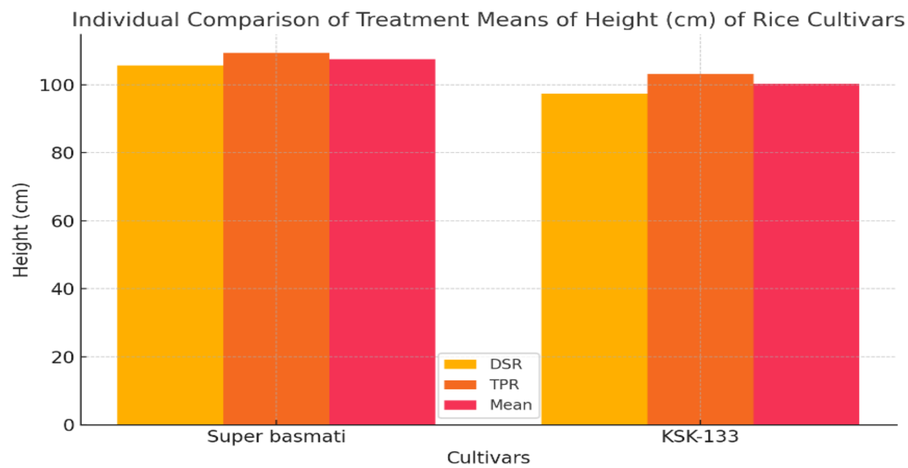

Figure 3.11: Individual Comparison of Treatment Means of Height (cm) of Rice Cultivars as Affected by Varying Planting Methods for Coarse and Fine Rice

3.3.2 No. of Tillers (m^{-2})

Table 3.11 shows that different rice establishment methods and rice cultivars had a substantial impact on the total number of tillers per square meter. Using the KSK 133 cultivar, the largest number of tillers—460 tillers per square meter—was seen in direct seeding. By contrast, the super basmati cultivar produced 439 tillers per square meter when grown utilizing the puddled rice method in all crop growth phases. With 449 tillers per square meter observed vs 414 tillers per square meter for the super basmati cultivar, cultivar KSK-133 performed better than the latter. At a 5% probability level, these cultivar differences were statistically significant. The present findings align with the research conducted, who observed that direct dry-seeded rice (DDSR) had more tillers than transplanted rice (TPR). Figure 3.11 displays the average values of the number of tillers for the studied rice varieties, which were impacted by the sowing techniques used at various growth stages.

Table 3.11 Analysis of Variance No. of Tillers (m^{-2}) of Rice Cultivars as Affected by Varying Planting Methods for Coarse and Fine Rice

Source	DF	SS	MS	F
Rep	2	9.6	4.8	
Sowing	1	400.67	400.67	58.44
Error Rep*Sowing	2	13.71	6.86	
Cultivars	1	3691.82	3691.82	474.9
Sowing*Cultivars	1	179.41	179.41	23.08
Error Rep*Sowing*Cultivar	4	31.1	7.77	
Total	11	4326.31		

DF = degree of freedom SS = Sum of square MS = Mean square

** = Highly Significant A probability level of 5% was kept for the construction of ANOVA. LSD value for cultivars * sowing methods = 2.9989

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Vol: 67 Issue 11 | 2024
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Means sharing contrasting letters symbolize statistical significance at $P \leq 0.05$.

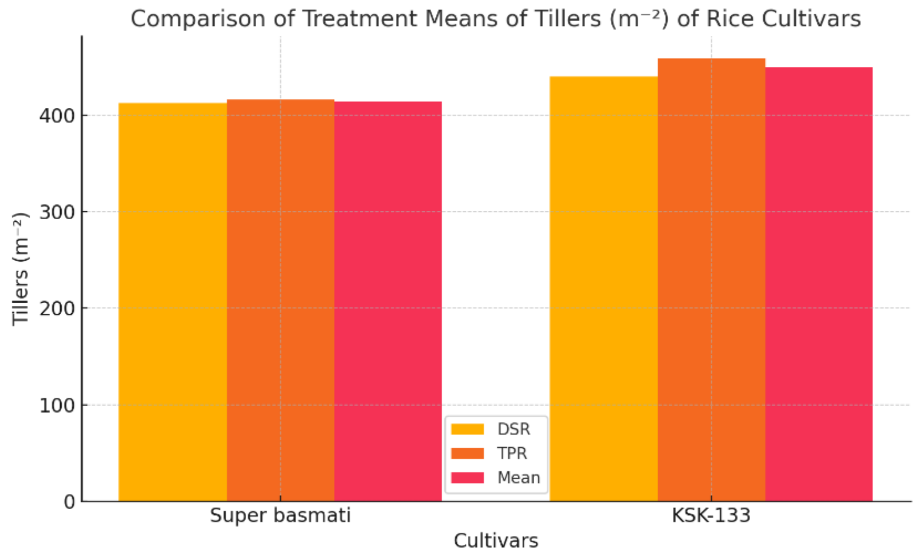

Figure 3.12: Comparison of Treatment Means of Tillers (m^{-2}) of Rice Cultivars as Affected by Varying Planting Methods for Coarse and Fine Rice

3.3.3 Grain Yield (t ha^{-1})

Grain yield is a key metric that is used to evaluate the productivity and economic value of crop plants. The total number of panicles, the number of grains per panicle, and the grain weight all contribute to rice grain output.

Table 3.12 shows that rice cultivars and planting techniques had a highly significant ($p < 0.05$) impact on grain yield. Using the KSK 133 cultivar and puddled transplanted paddy, the highest grain production of 6.14 t ha-1 was obtained among the various combinations. In contrast, the super basmati cultivar used in direct seeded paddy produced the lowest yield, 4.59 t ha-1.

These results are in line with those of Birhane et al. (2013), who found that over the course of a two-year study period, TPR (transplanted paddy rice) produced a greater grain yield than DDSR (direct dry-seeded rice). Similar findings were made by Poudel et al. (2020), who found that transplanted plots had greater grain yields than WDSR (wet direct-seeded rice) plots. The super basmati cultivar was surpassed by the cultivar KSK-133, which yielded a grain yield of 4.61 t ha-1 and 5.88 t ha-1, respectively.

At a 5% likelihood level, there was a statistically significant difference between these two cultivars. This is consistent with the results of Virk et al. (2018), who found that basmati rice had the lowest yield and KSK-515 the highest grain yield. Figure 3.13 summarizes the mean grain yield values of the studied rice types under various sowing techniques at different growth stages.

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ISSN: 1673-064X
E-Publication: Online Open Access
Vol: 67 Issue 11 | 2024
DOI: 10.5281/zenodo.14219950

Table 3.12: Analysis of Variance Variations in Planting Techniques for Coarse and Fine Rice Affect the Grain Production (t ha-1) of Different Rice Varieties

Source	DF	SS	MS	F
Rep	2	0.11762	0.05881	
Sowing	1	0.05467	0.05467	23.52
Error Rep*Sowing	2	0.00465	0.00232	
Cultivars	1	3.77441	3.77441	102.33
Sowing*Cultivars	1	0.15641	0.51641	4.24
Error Rep*Sowing*Cultivar	4	0.14753	0.03688	
Total	11	4.25529		

DF = degree of freedom SS = Sum of square MS = Mean square

** = Highly Significant Probability level of 5% was kept for the construction of ANOVA.

LSD value for cultivars * sowing methods = 0.1524, Means sharing contrasting letters symbolize statistical significance at P ≤ 0.05.

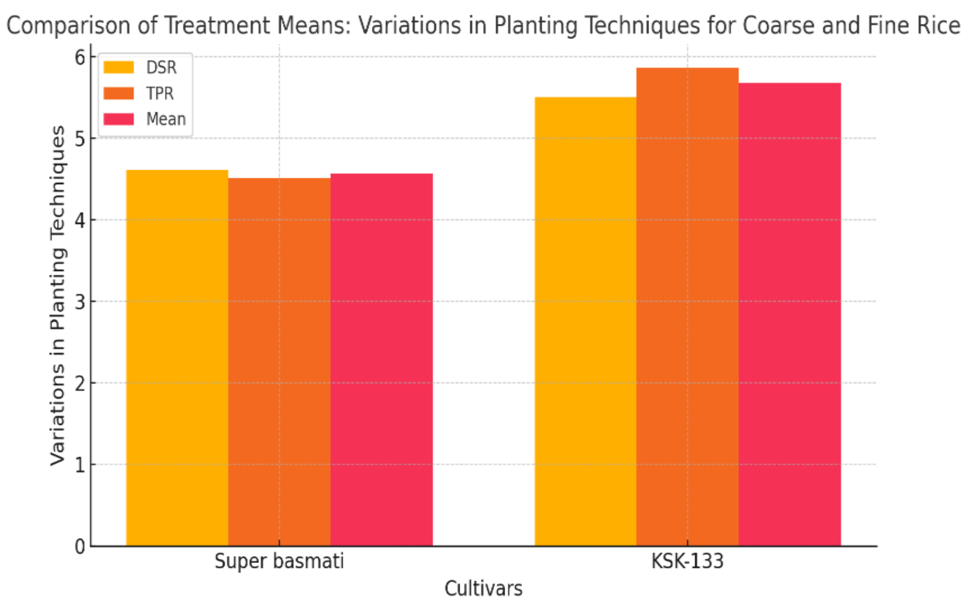

Figure 3.13 Comparison of Treatment Means Variations in Planting Techniques for Coarse and Fine Rice Affect the Grain Production (t ha-1) Of Different Rice Varieties

3.3.4 Biological Yield (t ha^{-1})

The total biomass that a plant produces during the course of its growth and development is referred to as biological yield. Biological yield in the context of paddy rice refers to all plant parts above ground, such as leaves, stems, panicles, and husks. Table 3.13 shows that rice cultivars and different rice establishment techniques had a highly significant impact on biological yield. The KSK 133 cultivar produced the highest biological yield of

Xi'an Shiyou Daxue Xuebao (Ziran Kexue Ban)/
Journal of Xi'an Shiyou University, Natural Sciences Edition
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E-Publication: Online Open Access
Vol: 67 Issue 11 | 2024
DOI: 10.5281/zenodo.14219950

15.14 t ha-1 in puddled transplanted paddy, whereas the super basmati cultivar produced the lowest biological yield of 14.22 t ha-1 in direct seeded paddy. With a biological yield of 15.13 t ha-1, cultivar KSK-133 outperformed the super basmati cultivar, which had a yield of 14.22 t ha-1. At a 5% probability level, these cultivar differences were statistically significant. These results are consistent with those of Jamil et al. (2000), who found that transplanted paddy rice (TPR) produced more biological yield than direct-seeded rice (DSR). Figure 3.14 displays the average grain yield of the tested rice types, taking into account the effects of seeding techniques at various growth stages.

Table 3.13: Analysis of Variance of Rice Cultivars' Biological Yield (T Ha-1) As A Function Of Planting Techniques for Coarse and Fine Rice

Source	DF	SS	MS	F
Rep	2	0.15207	0.07603	
Sowing	1	0.12608	0.12608	0.42
Error Rep*Sowing	2	0.6054	0.3027	
Cultivars	1	1.07401	1.07401	9.73
Sowing*Cultivars	1	0.20541	0.20541	1.86
Error Rep*Sowing*Cultivar	4	0.44173	0.11043	
Total	11	2.60469		

DF = degree of freedom SS = Sum of square MS = Mean square

** = Highly Significant Probability level of 5% was kept for the construction of ANOVA.

LSD value for cultivars * sowing methods = 0.2223 Means sharing contrasting letters symbolize statistical significance at $P \leq 0.05$.

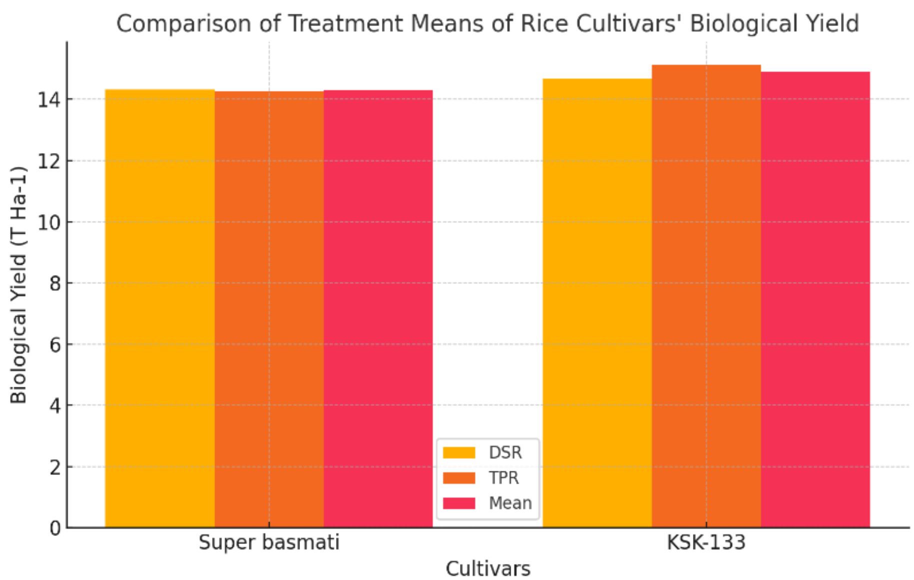

Figure 3.14 Comparison of Treatment Means of Rice Cultivars' Biological Yield (T Ha-1) As A Function of Planting Techniques for Coarse and Fine Rice

ISSN: 1673-064X
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DOI: 10.5281/zenodo.14219950

3.3.5 Harvest Index (%)

The percentage that is derived by dividing the grain yield by the total biological yield (grain yield + straw yield) is known as the harvest index for paddy rice. A higher harvest index means that more photosynthates are being directed towards the grain as opposed to unharvested plant portions.

As shown in Table 3.14, the harvest index was significantly impacted at a 5% probability level by various rice establishment techniques and rice cultivars. The KSK 133 cultivar had the highest harvest index of 40.55% in puddled transplanted paddy, whereas the super basmati cultivar produced the lowest harvest index of 32.30% in direct seeded paddy.

With a harvest index of 38.84%, cultivar KSK-133 outperformed the super basmati cultivar, which had a harvest index of 32.41%. At a 5% probability level, these cultivar differences were statistically significant. These results are in line with those of Ehsanullah et al. (2000), who conducted a two-year study and found that transplanted paddy rice (TPR) produced a maximum harvest index when compared to direct dry-seeded rice (DDSR).

Figure 3.15 displays the average harvest index value for the tested rice varieties, considering the effects of different seeding techniques at different growth stages.

Table 3.14 Analysis of Variance Different Planting Techniques for Coarse And Fine Rice Affect The Harvest Index (%) Of Different Rice Cultivars

Source	DF	SS	MS	F
Rep	2	1.217	0.609	
Sowing	1	8.069	8.069	301.92
Error Rep*Sowing	2	0.053	0.027	
Cultivars	1	124.292	124.292	268.97
Sowing*Cultivars	1	11.96	11.96	25.88
Error Rep*Sowing*Cultivar	4	1.848	0.462	
Total	11	147.44		

DF = degree of freedom SS = Sum of square MS = Mean square

** = Highly Significant A probability level of 5% was kept for the construction of ANOVA. LSD value for cultivars * sowing methods = 0.7760

Means sharing contrasting letters symbolize statistical significance at $P \leq 0.05$.

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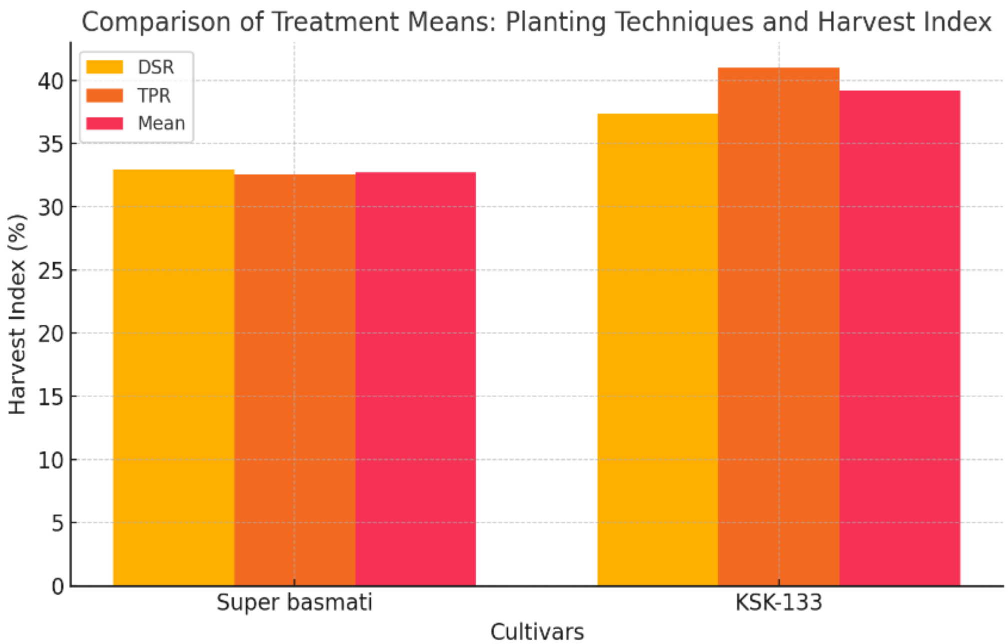

Figure 3.15 Comparison of Treatment Means Different Planting Techniques for Coarse and Fine Rice Affect the Harvest Index (%) Of Different Rice Cultivars

3.3.6 Thousand Grain Weight (g)

One important agronomic metric that sheds light on prospective grain production is the weight of thousand grain, or 1000 grain weight. It is a commonly used and reliable method of calculating output results, weighing one thousand grains.

As shown in Table 3.15, the experiment revealed that there was no discernible variation in thousand grain weight (g) between the investigated rice types affected by the sowing techniques. This implies that the chosen planting techniques had little effect on the mean values of thousand grain weight (g).

The thousand grain weight (g) of the rice varied significantly throughout the cultivars, with KSK-313 exhibiting the highest weight of 27.35 g and super basmati displaying the lowest weight of 20.80 g. The thousand grain weight (g) was shown to be significantly impacted by the planting procedures as well. The transplanted approach yielded a maximum weight of 25.78 g, whereas the direct seeded method produced a weight of 22.37 g.

The results of Sorour et al. (2016), who found that transplanting rice produced the maximum 1000-grain weight when compared to direct seeding, are in line with our findings. The investigated rice varieties' mean effective tiller values, which were impacted by the seeding techniques used at various growth stages, are displayed in Figure 3.16.

Xi'an Shiyou Daxue Xuebao (Ziran Kexue Ban)/
Journal of Xi'an Shiyou University, Natural Sciences Edition
ISSN: 1673-064X
E-Publication: Online Open Access
Vol: 67 Issue 11 | 2024
DOI: 10.5281/zenodo.14219950

Table 3.15: Analysis of Variance Influence of Different Planting Methods on the Thousand Grain Weight (G) of Coarse and Fine Rice Cultivars

Source	DF	SS	MS	F
Rep	2	0.9163	0.4581	
Sowing	1	11.7612	11.761	15.50 *
Varieties	1	72.9147	72.9147	64.40 **
Sowing*Varieties	1	1.748	1.748	1.54 ^{ns}
Error R*S*V	4	4.5287	1.1322	
Total	11	93.3865		

DF = degree of freedom SS = Sum of square MS = Mean square

** = Highly Significant ns = non-significant, LSD value for Cultivars * sowing methods = 2.6905 Means sharing contrasting letters symbolize statistical significance at P ≤ 0.05.

The probability level of 5% was kept for the construction of ANOVA.

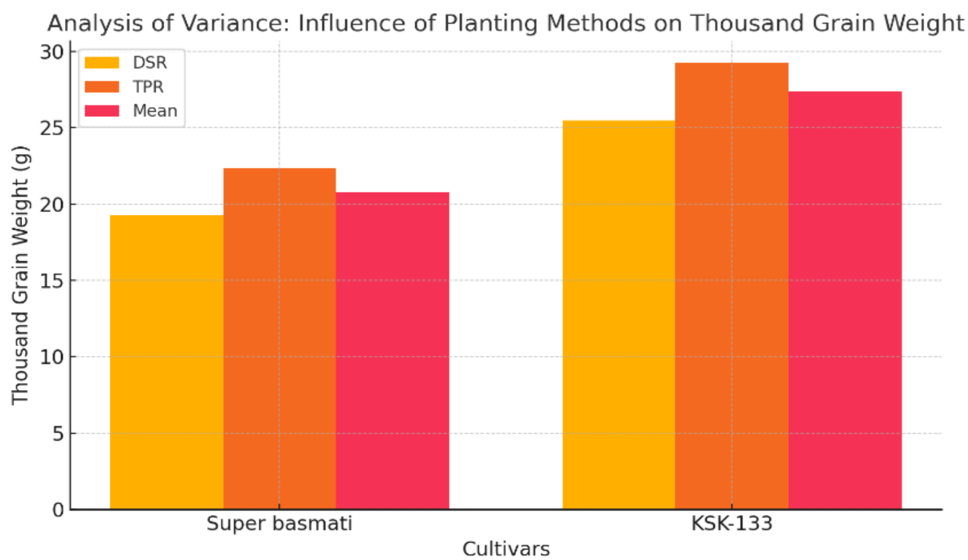

Figure 3.16 Comparison of Different Planting Methods on the Thousand Grain Weight (G) of Coarse and Fine Rice Cultivars

3.4 Crop Growth Modeling

3.4.1 Calibration of Model

To reduce the differences between simulated and actual results, the model's parameters pertaining to the growth, phenology, and yield of rice cultivars were optimized. Below are the calibration results for several characteristics, including grain yield, total biomass, days to anthesis, Leaf Area Index (LAI), and days to maturity.

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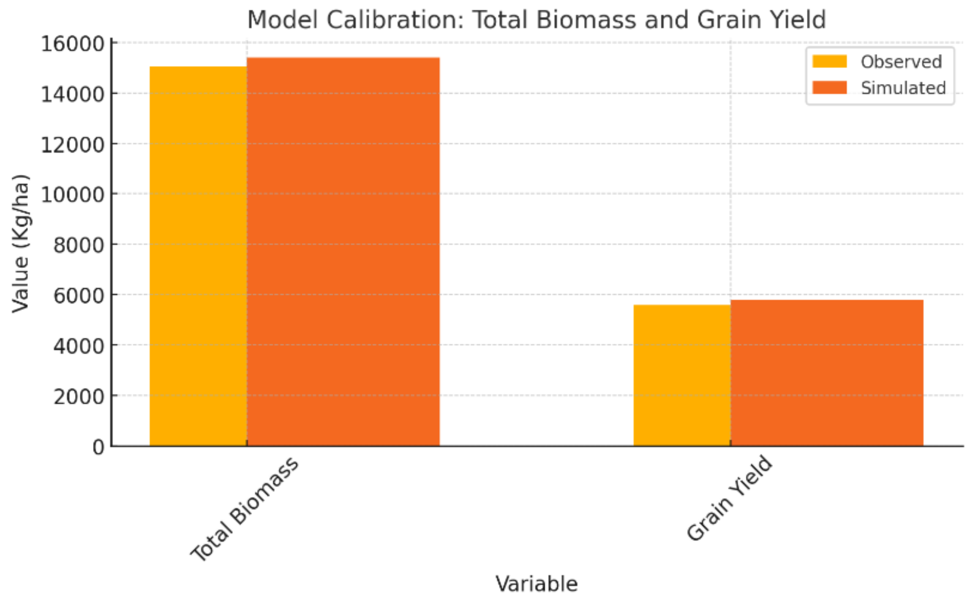

Figure 3.17 Observed and Simulated Values with Model Calibration for Transplanted Method Rice Cultivars

Table 3.16 Model Calibration for Transplanted Method Rice Cultivars

Variable	Unit	Observed	Simulated.	Mean Ratio	Mean Difference
Anthesis Days	Days	94	92	0.984	-2
Total Biomass	Kg/ha	15050	15406	1.024	356
Grain Yield	Kg/ha	5595	5787	1.038	192
LAI	_	4.4	4.32	0.988	-0.38
Maturity Days	Days	143	143	1	0

3.4.2 Model Evaluation

The study tested the accuracy of rice cultivars' growth, phenology, and yield model using the most effective treatments identified in the experiment. Key metrics such as anthesis days, maturity days, leaf area index (LAI), biological yield, and grain yield were analyzed. The results showed that the observed and simulated values for anthesis days, maturity days, LAI, biological yield, and grain yield were close, with minimal mean differences. Biological yield simulations also showed close approximation to observed data. During calibration, five parameters were fine-tuned to determine the most effective treatments. Adjustments were made to cultivar coefficients P1, G2, and G3 (related to tillering and grain weight), and PHINT (phyllochron interval). KSK-133 required higher P1 and PHINT values than Chenab Basmati, and higher G2 and G3 values compared to Super Basmati, indicating greater potential for tillering and grain weight. These findings validate the DSSAT model's ability to simulate crop growth and yield based on soil, weather, and crop management data. As with other DSSAT models, genetic coefficients for local cultivars require separate calibration for accurate results, as supported by previous studies (Liu et al., 2011).

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4. CONCLUSIONS AND RECOMMENDATIONS

The study examines the growth, yield, and components of Super Basmati and KSK 133 rice cultivars under two different sowing techniques: direct-seeded rice (DSR) and traditional puddled transplanted rice (TPR). The results show that the choice of cultivar and sowing technique significantly impacts key parameters like total dry matter, grain yield, straw yield, biological yield, and harvest index. The KSK 133 cultivar under the TPR method consistently achieved the highest results, indicating its suitability for maximizing yield in conventional systems. DSR offers benefits like earlier flowering, increased panicle length, and more tillers, but requires effective management of weed control and crop establishment. DSR has economic and environmental potential, reducing labor, conserving water, and lowering cultivation costs, making it a viable alternative in water-scarce and labor-constrained regions. The study highlights the need to enhance rice yield in Pakistan to improve food security and productivity.

The study suggested promoting the adoption of Sustainable Rice Production (SSR) through improved management practices, focusing on labor and water savings. It recommends selective cultivation of high-yielding varieties, such as KSK 133, for areas with maximum yield and resource efficiency. An integrated approach to rice production, combining suitable varieties, advanced agronomic practices, and optimized inputs, can enhance productivity and sustainability. Further research on DSR's viability is needed to address challenges like crop establishment and weed management. Policymakers should consider incentives for farmers to adopt water- and labor-saving practices, such as DSR, to ensure sustainable rice production and contribute to food security in Pakistan. This approach can help secure stable rice production amidst environmental challenges, ultimately supporting Pakistan's goal of food security and economic resilience.

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Availability of data and material: All data included in this study are available upon request by contacting the corresponding author.

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