Article

Response of Rice (*Oryza sativa* L.) Cultivars to Variable Rate of Nitrogen under Wet Direct Seeding in Temperate Ecology

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Abstract: Transplanting rice appears to pose many problems, including depletion of freshwater reservoirs and competition for labor. Conversely, direct seeding allows us to overcome shortcomings associated with conventional transplanting. Nitrogen is a crucial nutrient needed for plant growth and yield. Therefore, this study was executed to analyze the influence of nitrogen on the performance of rice genotypes grown by direct seeding in wet soil. The experiment comprised various rice cultivars, i.e., Shalimar Rice-1, Shalimar Rice-3, Shalimar Rice-4, and Jhelum, and nitrogen (N) levels, i.e., 0, 90, 120, and 150 kg/ha. Shalimar Rice-4 produced a maximum grain yield (6.39 t/ha), followed by Shalimar Rice-3 and Jhelum. The application of 150 kg N/ha showed maximum values for growth parameters, yield attributing traits, and grain yield (6.68 t/ha); however, it remained at par with 120 kg N/ha. Crop water productivity was highest in Shalimar Rice-4 (0.49 kg/m³), and the same showed a consistent increase with increasing N levels from 0–150 kg/ha, with a comparable value of 0.49 to 0.51 recorded at 120 and 150 kg N/ha. Moreover, the Shalimar Rice-1 variety required the maximum in growing degree days (GDD) and helio-thermal units (HTU) to attain different phenological stages till physiological maturity (131 days). However, the cultivar Shalimar rice-4 (SR-4) performed better by registering significantly higher heat use efficiency (HUE) (4.44 kg/ha °C/day). Additionally, the highest net return and the benefit-cost ratio were registered by Shalimar Rice-4. B:C ratio of 1.75 was realized from application of 150 kg N/ha, which remained very close to that achieved with 120 kg N/ha. In conclusion, the rice cultivar Shalimar Rice-4 with the application of 120 kg N/ha could boost rice production under DSR in water-scarce regions of temperate northern India.

Keywords: direct seeded rice; nitrogen; rice; water productivity; temperate ecology; yield

1. Introduction

Rice (*Oryza sativa* L.) is the staple food crop for more than half of the world population, including Africa, Central America, South America, the southern United States, Australia,
and many countries in Asia, including China, Japan, the Philippines, and India [1]. Rice production is mainly Asia-centric, with that region contributing to more than 90% of world supply. In the Kashmir division of UT-Jammu and Kashmir, located in the northern part of the Indian subcontinent in the vicinity of the Karakoram and Westernmost Himalayan mountain ranges, rice is a major crop and is grown in all districts over an area of 0.159 M ha. Rice in Kashmir and other parts of India is cultivated mainly through transplanting, in which 25–45 day-old rice seedlings from the wet nursery are used [2,3]. However, rice transplanting is labor- and energy-intensive; furthermore, a considerable amount of irrigation water is required to bring the field to a cultivable condition [4]. In the coming years, both the availability of labor and freshwater rice will face a tough challenge on account of the growing industrial sector and escalating labor wages. This twin problem of increased water requirement, which is expected to increase by 55% by 2050 globally [5], and the decreasing labor share in agriculture, which is declining at the rate of 0.2% per year in Asia [6], are expected to impact agriculture in general and rice in particular. In Jammu and Kashmir, canal irrigation is the primary source of fresh water for rice cultivation. The rice crop requires about 100–500 mm water for puddling operations in conventional transplanted rice [7], leading to overexploitation of freshwater resources. Though the puddling operation is a prerequisite in rice cultivation owing to its advantages of arresting leaching losses of nutrients and weed control at the same time, it results in destroying the soil structure [8]. This damage in soil structure is engendered in the form of a hard pan, thereby increasing the soil strength, decreasing permeability, and restricting seed germination and root growth [9,10], and is even more undesirable for successive crops. Therefore, there is a dire need to develop a technically viable and economically feasible alternative for sustainable rice production in Kashmir and other water-scarce rice-growing regions in India [11]. Rice production by the direct-seeding technique (DSR) may offer an ideal alternate water-efficient rice production system [12,13]. Direct seeding of rice uses well-drained, un-puddled, and non-saturated soils for rice production and thus reduces the amount of water needed for irrigation [14]. The higher grain yield and lower water use in direct seeding of rice compared to transplanting have been reported in several previous studies conducted in India, China, the USA, and Japan [15–19].

Nitrogen plays an imperative role in crop production and substantially impacts income and agricultural productivity [20]. It is the most expansively used nutrient in rice crops and is required in greater amounts than other major nutrients [21]. However, the application of N poses severe problems, including loss of N and soil and water pollution [22]. Thus, exploring the appropriate N application is mandatory to reduce these problems. Nitrogen is an essential nutrient for plant growth, yield, quality, and biomass production of rice crops [23].

Moreover, N is also an essential component of proteins, amino acids, and chlorophyll in plants [22]. Many studies have been conducted to determine the impact of N on rice crops, and most of the studies reflected that rice yields increase with increasing N level up to a particular range. However, decreases in the yield at higher rates of nitrogen application have also been witnessed in many studies [20].

During the present investigation, four high-yielding rice varieties, recently released by the University, SKUAST-K, were evaluated under wet DSR conditions with varying nitrogen levels. Identifying a suitable cultivar for DSR is one of the agronomic objectives under a particular management system for realizing higher yields. Additionally, N management differs in DSR as the period of N retention in the main field is extended by almost 1 month, coupled with higher N losses due to aerobic-like situations. Similarly to any other crop establishment method, nitrogen is vital for improving photosynthetic efficiency and grain production in irrigated DSR. Thus, it becomes imperative to quantify the optimum nitrogen requirement to synchronize the N demand for new cultivars under DSR.
2. Materials and Methods

2.1. Experimental Site

The field experiment was conducted during the summer seasons of 2017 and 2018 at the Mountain Research Centre for Field Crops, Sher-e Kashmir University of Sciences and Technology of Kashmir (SKUAST-K), Shalimar, Srinagar, Kashmir, J&K, India (34.08° N, 74.79° E). The annual rainfall at the study site during the experimental years of 2017 and 2018 was 296.6 and 349.7 mm, respectively, most of which was received from June to July. Data on daily observations of maximum and minimum temperature, rainfall, and sunshine hours for cropping season are depicted in Figure 1. The experimental site was previously used for sowing rapeseed. Soil samples were collected at the start of the experiment and were subjected to physicochemical analysis. The texture of the soil sample was determined by the international pipette method [24] and soil reaction by 1:2 soil–water suspension with Beckman’s glass electrode pH meter [25]. Estimations of the available N, P, and K in kg/ha were analyzed by the alkaline potassium permanganate method [26], 0.1 N sodium bicarbonate method [27] and ammonium acetate method [25]. The soil of the experimental plot was silty clay loam in texture, low in N (230 kg/ha) and P (11.5 kg/ha), and medium in K (230 kg/ha), and neutral in acidity (pH 6.9).

![Figure 1. Weather data prevailing during the cropping period of 2017 and 2018.](image)

2.2. Treatments, Experimental Design, and Crop Management

Four varieties—Shalimar Rice-1, Shalimar Rice-3, Shalimar Rice-4, and Jhelum—were evaluated with four nitrogen levels (0, 90, 120, 150 kg/ha) in a randomized block design with three replicates. The fertilizers were applied in the form of urea, DAP, and MOP. The full doses of phosphorus and potassium were used as basal at recommended rates of 60 (P$_2$O$_5$) and 30 (K$_2$O) kg/ha, respectively, and nitrogen was applied as per the treatments. One-third of nitrogen was involved as basal, and the remaining nitrogen was top-dressed in two equal splits each at tillering and panicle initiation stage. Sprouted seeds were sown in lines 20 cm apart, using a seed rate of 80 kg/ha in the last week of May during both years of study, followed by thinning at 25 DAS. Penoxulam @ 22.5 g/ha was applied as pre-emergence herbicide 4 days after sowing for weed control. Irrigation of 5 cm depth was applied 2 days after the disappearance of ponded water (2 DAPW), with no application on rainy days, and was withheld 15 days before harvesting the crop. The growth and yield attributes were recorded as per the standard procedures.
2.3. Phenological Observations

The crop was frequently inspected at 2-day intervals to record the attainment of phenological stages such as days to maximum tillering, days to flowering, and days to maturity. Chlorophyll content in leaves was measured using Soil Plant Analyzer Development (SPAD—502 plus) which is a portable chlorophyll meter, and photosynthetic active radiation (PAR) using Quantum meter (MQ-200) at the flowering stage.

2.4. Meteorological Indices

2.4.1. Growing Degree Days (GDD)

Cumulative growing degree days were determined by summing the daily mean temperature above a base temperature, expressed in degree day. This was determined by using the following formula [28].

\[
\text{GDD} = \frac{T_{\text{max}} + T_{\text{min}}}{2} - T_{\text{base}}
\]

Base temperature of rice = 10 °C

2.4.2. Heliothermal Units (HTU)

The heliothermal units for a day represent the product of GDD and the hours of bright sunshine for that day. The sum of HTU for particular phenophases of interest was computed according to the equation:

\[
\text{HTU} = \sum \{\text{GDD} \times \text{BSS (n)}\}
\]

where,

\( \text{GDD} = \text{growing degree days} \),
\( \text{BSS (n)} = \text{bright sunshine hours (h)} \).

2.4.3. Heat Use Efficiency (HUE)

Heat use efficiency indicates the amount of dry matter produced per unit of growing degree days or thermal time. This was computed by using the following formula [29].

\[
\text{HUE} = \frac{\text{Grain yield}}{\text{GDD}}
\]

Economic yield of rice was converted to carbohydrate equivalent value (t/ha) based on carbohydrate content per 100 g of rice [30].

2.5. Relative Economics

The cost of production incurred in each treatment was worked out by considering the prevailing market price of inputs used and the produce obtained (grain and straw). The net income was calculated by subtracting the cost of cultivation from the gross monetary return.

2.6. Statistical Analysis

The data recorded on different observations were tabulated and analyzed statistically by using the techniques of analysis of variance (ANOVA) as suggested by Cochran [31]. The critical difference at 0.05 probability level was compared to the treatments when the F test was significant. Duncan’s multiple range test was used at \( p \leq 0.05 \) to test the difference between treatment means, and the differences were considered non-significant when \( p \leq 0.05 \).

3. Results

3.1. Growth and Yield Attributes

Different varieties and N levels significantly affected rice crop growth and yield attributing parameters under DSR. Particularly taller plants (122.15 cm) were recorded in Shalimar rice-4 (SR-4), followed by Shalimar rice-3 (SR-3) (115.2 cm), which remained at
par with other varieties. Similarly, SR-4 registered a significantly higher number of tillers per unit area (353.4 m²) though remained at par with SR-3 but significantly superior to other varieties. SR-4 also recorded higher panicles/m², panicle weight, 1000-grain weight, and filled grains/panicle, followed by SR-3. Sterility was highest in SR-1 compared to other cultivars (Table 1). Growth and yield attributes increased significantly with the increase in nitrogen level from 0 to 150 kg N/ha. Maximum values of plant height (120.1 cm), tillers/m² (354), panicles/m² (303), panicle weight (3.0 g), and 1000 seed weight (29.4 g) were registered at 150 kg N/ha, though at par with 120 kg N/ha. However, the significantly highest number of filled grains (158.3) was recorded with 150 kg N/ha, with superiority of 5.1%, 13.5%, and 22.01% over 120, 90, and 0 kg N/ha, respectively. A significantly higher sterility percentage (13.7%) was noticed at a higher nitrogen levels than at lower levels of nitrogen.

| Treatment | Plant Height (cm) | No. of Tillers/m² | Panicles/m² | PAR% | SPAD | Panicle wt. (gm) | 1000-Grain wt. (gm) | Filled Grains/Panicle | Sterility (%) |
|-----------|------------------|-----------------|-------------|-------|------|-----------------|---------------------|----------------------|--------------|
| SR 1      | 112.9 b          | 322.3 b         | 281.15 bc   | 91.5 b | 30.3 | 2.5 bc          | 27.9 a              | 135.6 c             | 11.6 a       |
| SR 3      | 115.2 b          | 336.2 ab        | 294.65 ab   | 93.5 ab | 31.0 | 2.7 ab          | 28.0 ab             | 146.8 b             | 10.3 ab      |
| SR 4      | 122.2 b          | 353.4 a         | 308.85 a    | 94.1 a | 32.1 | 2.8 a          | 29.1 a              | 156.4 a             | 10.2 b       |
| Jhelum    | 111.5 b          | 274.15 c        | 237.45 b    | 80.0 c | 29.9 | 2.4 c          | 27.1 b              | 132.1 d             | 9.8 b        |
| SEm ±     | 1.4              | 7.45            | 6.55        | 0.7   | 0.08 | 0.4           | 1.0                 | 0.3                  |              |
| CD (P = 0.05) | 4.0        | 21.5            | 19          | 2.0   | NS  | 0.24           | 1.1                 | 2.8                  | 0.8          |

Small-case letters indicate statistical significance within the same column at p ≤ 0.05. In a column, means followed by the same letter are not significantly different at p ≤ 0.05. SEm ±: standard error of mean. NS: on-significant at p ≤ 0.05.

3.2. Physiological Parameters

One of the most important micro-climatic factors influencing rice yield is the canopy’s ability to intercept photosynthetically active radiation (PAR). In this study, the interception of photosynthetically active radiation (PAR) by the canopy varied significantly among different cultivars, and SR-4 registered substantially higher PAR interception values (Table 1). Similarly, the highest SPAD values were also recorded with SR-4, followed by SR-3, and the lowest in Jhelum (Table 1). Increasing N levels, of up to 120 kg N/ha, increased PAR and SPAD values significantly (Table 1).

3.3. Phenology

The days taken to reach different phenophases, viz., maximum tillering, flowering, and maturity, were significantly influenced by cultivars and nitrogen levels. The variety SR-1 took the highest number of days to reach maximum tillering (53 days), flowering (90 days), and maturity (131 days), followed by SR-3, SR-4, and Jhelum (Figure 2).

With the increase in nitrogen level from 0 kg to 150 kg N/ha, the days to reach different phenophases increased consistently. Application of the highest level of N @ 150 kg/ha enhanced crop duration required to attain different phenophases and was significantly longer than with lower levels of nitrogen (Figure 2).

3.4. Agro-Meteorological Indices

Growing degree days (GDD) and heliothermal units (HTU) accumulated were found to differ significantly among varieties and nitrogen levels at different phenophases (Table 2). Accumulated GDD and HTU increased at each growth stage commencing towards maturity irrespective of the cultivars. Among the different varieties, SR-1 required more GDD and
HTU to attain flowering and maturity, followed by SR-3, SR-4, and Jhelum. However, at maximal tillering stage, Jhelum accumulated more GDD compared to SR-4.

SR-1 took the highest number of days to reach maximum tillering (53 days), flowering (90 days), and maturity (131 days), followed by SR-3, SR-4, and Jhelum (Figure 2).

With the increase in nitrogen level from 0 kg to 150 kg N/ha, the days to reach different phenophases increased consistently. Application of the highest level of N @ 150 kg/ha enhanced crop duration required to attain different phenophases and was significantly longer than with lower levels of nitrogen (Figure 2).

**Figure 2.** Effects of varieties and nitrogen levels on rice phenology under wet-direct seeded conditions (pooled data for 2 years).

**Table 2.** Effects of varieties and nitrogen levels on agro-climatic indices at different phenophases in direct-seeded rice (pooled data for 2 years).

| Treatments | GDD (°C day) Tillering | HTU (°C day h) Tillering | GDD (°C day) Flowering | HTU (°C day h) Flowering | GDD Maturity | HTU (°C day h) Maturity | HUE (kg/ha °C/day) |
|------------|------------------------|--------------------------|------------------------|--------------------------|---------------|--------------------------|------------------|
| SR-1       | 516 a                  | 4377 a                   | 996.5 a                | 7985 a                   | 1488 a        | 11,089 a                 | 3.86 b           |
| SR-3       | 499.5 b                | 4263 b                   | 979 b                  | 7885 b                   | 1471.5 b      | 11,009 b                 | 4.12 b           |
| SR-4       | 476.0 c                | 4104 c                   | 931 b                  | 7557 c                   | 1439.5 c      | 10,807 c                 | 4.44 c           |
| Jhelum     | 493.5 b                | 3970 d                   | 866.5 c                | 7026 d                   | 1382.5 d      | 10,496 d                 | 3.80 b           |
| SEm±       | 4.335                  | 42.55                    | 3.46                   | 26.35                    | 2.825         | 44.9                     | 0.12             |
| CD (P = 0.05) | 12.53               | 64.15                    | 10.01                  | 76.15                    | 8.17          | 15.5                     | 0.35             |
| N0         | 466.5 c                | 4050 d                   | 915.5 d                | 7423 c                   | 1424 d        | 10,731 d                 | 3.31 c           |
| N90        | 482.0 b                | 4158 e                   | 936.0 c                | 7686 e                   | 1440 c        | 10,822 c                 | 4.02 b           |
| N120       | 491.5 b                | 4202 f                   | 953.5 b                | 7654 b                   | 1449.5 b      | 10,877 b                 | 4.33 ab          |
| N150       | 504.5 a                | 4304 g                   | 967.5 b                | 7443 e                   | 1467.5 e      | 10,974 a                 | 4.55 c           |
| SEm±       | 4.335                  | 42.55                    | 3.46                   | 26.35                    | 2.825         | 44.9                     | 0.12             |
| CD (P = 0.05) | 12.53               | 64.15                    | 10.01                  | 76.15                    | 8.17          | 15.5                     | 0.35             |

Small-case letters indicate statistical significance within the same column at p ≤ 0.05. In a column, means followed by the same letter are not significantly different at p ≤ 0.05. SEm ±: standard error of mean.
Concerning nitrogen application rates, GDD and HTU accumulation were significantly influenced by nitrogen. Application of N @ 150 kg/ha to rice crop accumulated maximum GDD and HTU at each phenophase. Heat use efficiency (HUE), which directly measures the accumulated heat units to contribute to the final yield, was significantly influenced by varieties and nitrogen levels (Table 2). SR-4 recorded the significantly highest HUE followed by SR-3. Among the nitrogen levels, the highest HUE was observed at 150 kg N/ha, which was statistically at par with 120 kg N/ha. The highest HUE resulted from a higher grain yield at 150 kg N/ha.

3.5. Yield

The rice variety SR-4 performed better in grain yield, straw yield, and carbohydrate equivalent than the other varieties (Table 3). SR-4 registered a grain yield superiority of 5.44%, 11.32%, and 21.48% over SR-3, SR-1, and Jhelum, respectively, and similar trends were observed for straw yield with gains of 7.12%, 9.78%, and 20.23% over SR-3, SR-1, and Jhelum, respectively.

| Treatments | Grain Yield (t/ha) | Straw Yield (t/ha) | Carbohydrate Equivalent (t/ha) | Water Productivity (kg/m³) | B:C Ratio |
|------------|-------------------|--------------------|--------------------------------|--------------------------|-----------|
| **Varieties** |                  |                    |                                |                          |           |
| SR 1       | 5.74 ab           | 6.44 ab            | 4.48                           | 0.44 ab                  | 1.43      |
| SR 3       | 6.06 a            | 6.60 ab            | 4.73                           | 0.46 a                   | 1.55      |
| SR 4       | 6.39 a            | 7.07 a             | 4.99                           | 0.49 a                   | 1.68      |
| Jhelum     | 5.26 b            | 5.88 b             | 4.11                           | 0.40 b                   | 1.24      |
| SEm±       | 0.19              | 0.28               | 0.01                           | 0.05                     | -         |
| CD (P = 0.05) | 0.67              | 0.81               | -                              | -                        | -         |
| **Nitrogen levels (kg/ha)** | | | | | |
| N₀         | 4.71 c            | 5.27 c             | 3.68                           | 0.36 c                   | 1.08      |
| N₉₀        | 5.75 b            | 6.25 b             | 4.49                           | 0.44 b                   | 1.44      |
| N₁₂₀       | 6.35 a            | 7.03 a             | 4.96                           | 0.49 ab                  | 1.63      |
| N₁₅₀       | 6.68 a            | 7.43 a             | 5.21                           | 0.51 a                   | 1.75      |
| SEm±       | 0.19              | 0.28               | 0.01                           | 0.05                     | -         |
| CD (P = 0.05) | 0.67              | 0.81               | -                              | -                        | -         |

Small-case letters indicate statistical significance within the same column at \( p \leq 0.05 \). In a column, means followed by the same letter are not significantly different at \( p \leq 0.05 \). SEm ±: standard error of mean.

Among nitrogen levels, the grain and straw yield increased significantly with an increase in nitrogen levels from 0–150 kg N/ha. The highest grain yield (6.39 t/ha) and straw yield (7.07 t/ha) were recorded with 150 kg N/ha, though they remained at par with 120 kg N/ha. The magnitude of increase in grain yield was 41.82%, 16.17%, and 5.19% at 150 kg N/ha over 0, 90, and 120 kg/ha, respectively.

3.6. Water Productivity

The ANOVA model indicated that different cultivars and nitrogen regimes had a significant effect on water productivity (Table 3). Recorded water productivity was significantly the highest with SR-4 but remained at par with SR-3. Water productivity increased consistently with nitrogen levels from 0–150 kg/ha. However, the highest water productivity values of 0.49 and 0.51 kg/m³ at par with each other were registered with N levels applied at 120 and 150 kg/ha.

3.7. Relationship of Physiological Parameters and Grain Yield

Results obtained from correlation analysis (Figure 3) between physiological parameters such as SPAD and PAR and agro-climatic indices such as HUE to grain yield indicated a positive correlation (\( R^2 = 0.80 \)) of SPAD to grain yield. Intercepted PAR and HUE were also
significantly correlated ($R^2 = 0.63$ and $0.85$), respectively, to grain yield. PAR intercepted by the canopy could help augment the process of photosynthesis. These $R^2$ values of 0.8084, 0.6396, and 0.852 for SPAD, PAR, and HUE, respectively, suggest that 80.80%, 63.96%, and 85.20% variation in the mean grain yield can be adequately explained by computed linear regression equations.

\[
y = 0.3149x - 3.8465 \\
R^2 = 0.8084
\]

\[
y = 0.1216x - 5.2859 \\
R^2 = 0.6396
\]

\[
y = 0.9792x + 0.0026 \\
R^2 = 0.852
\]

*Figure 3.* Relationship of rice grain yield with SPAD intercepted PAR and HUE under wet-direct seed condition.
3.8. Economics

The cost of direct-seeded rice cultivation per hectare varied under different treatments. The highest profit of 1.68 rupees per rupee of investment was obtained with variety SR-4, closely followed by variety SR-3; among the nitrogen treatments, a B:C ratio of 1.75 was recorded with 150 kg N/ha (Table 3). Because the increase in grain yield beyond 120 kg/ha was statistically non-significant overall, 120 kg N/ha seems to be a more appropriate dose under wet-direct seeded conditions.

4. Discussion

Our investigation indicated that the overall performance of rice under wet direct seeding measured in terms of yield and economics was significantly influenced by cultivars and variable nitrogen rates. For securing the optimized yield, improvement in the plant architecture is the prerequisite. Rice varieties differed considerably in their growth and yield attributes, which might be due to the variable genetic background of cultivars [32]. Sterility percentage was also found to vary among cultivars. This outcome of our study is in agreement with Li et al. [33] and Souza et al. [34], who attributed this variability in sterility percentage among different cultivars to the genetic makeup of the plant, such as the role of the PTB1 gene, a key modulator of pollen tube growth and seed setting in rice.

Enhancement in the growth and yield attributes with an increase in nitrogen level can be ascribed to increased accessibility of N to plants, triggering its higher uptake and translocation from vegetative to reproductive parts [35]. Higher sterility percentage at higher levels of N can be ascribed to reduced supply of carbohydrates to grain due to the inverse relationship between nitrogen and carbohydrates. These results support the findings of Singh et al. [36] and Li et al. [37]. They reported a higher response of elevated nitrogen to sterility percentage than an optimum level.

Interception of PAR by plant canopy is critical to better crop production [38]. This investigation found that differences in the expression of growth parameters among the cultivars affected the interception of PAR, which was consistent with the genetic makeup of the cultivar. The increased interception of PAR with enhancement in nitrogen levels could be due to an increased number of new meristematic cells, enhanced cell elongation, and increased photosynthetic area and rate due to better nitrogen availability. These results are in agreement with those obtained by Salem et al. [39]. Similarly, higher SPAD values achieved at elevated nitrogen levels can be credited to more greenness of leaves because of higher chlorophyll content due to better availability of nitrogen, which is indirectly reflected in SPAD values.

Variation among the different varieties in reaching different phenophases can be attributed to differences in the genetic background of the varieties. Anas et al. [40] reported that increments in nitrogen level prolong the duration of the crop, as nitrogen leads to prolific vegetative growth and could be the reason for the delay in achieving each phenophase. Differences in the accretion of heat units among cultivars might be due to variation in the duration of these varieties to attainment of maximum tillering [41]. In this study, we observed that the crop accumulated a greater number of GDDs and HTUs at higher levels of nitrogen to reach different phenophases. This more significant accumulation of heat units to reach different phenophases was due to better nitrogen availability, which proved pivotal in prolonging each phenophase, and thus caused the crop to accumulate more GDDs, HTUs, etc., finally requiring a more significant number of days to reach maturity [42].

In this study we observed that the yield (seed and straw) was significantly impacted by cultivars and N level. The seed yield echoed the variability in the range of 5 to 21% among the cultivars and 42% between the N0 and N150 kg/ha nitrogen levels. This difference among the cultivars in yield can be attributed to variability in efficient sink regulation. Furthermore, the superiority of the SR-4 cultivar might be due to better expression of yield attributes (Table 1) and efficient utilization of heat units during the entire growth and developmental period of the crop, which culminated in increased growth and ultimately higher grain yield [43]. These results are in accordance with Kumar et al. [44], who
attributed this variability to the difference in the genetic background of the plant. The possible reasons for increased grain and straw yield at higher N levels might be due to higher biomass formation coupled with the easy translocation of photosynthates to sink, which concomitantly improved the sink size and thereby final yield [35].

Water productivity was significantly affected both by cultivars and nitrogen levels. The lowest water productivity was observed in Jhelum. This lower water productivity in Jhelum is ascribable to its reduced grain yield compared to other cultivars. Similarly, the more outstanding water-saving recorded with 120 and 150 kg N can be credited to higher yield per unit area. Absorption of transmitted light by chloroplast might have led to higher photosynthetic efficiency [45]. This, in turn, increases the capacity of source to export assimilates to sink and could be the reason for showing a positive relationship with grain yield. The improvement in the microclimate of the crop due to an overall enhancement in growth and development fosters interception, which could be the reason for showing the positive correlation between PAR and yield. The amount of radiation intercepted is the primary factor for yield obtained in rice [46,47]. The economic viability of the cultivar SR-4, in conjunction with a higher nitrogen level, can be credited to its higher yield performance.

5. Conclusions

Direct-seeded rice is a feasible and sustainable alternative to transplanted rice based on comparable or even higher yield performance and greater water use efficiency. Among the newly released varieties, SR-4 fertilized with N at 120 kg/ha performed better in yield and water productivity under wet-DSR conditions and was found to be more profitable in terms of net returns and B:C ratio per hectare. Hence under water-scarce conditions in temperate ecology, cultivation of rice var. SR-4 in conjunction with N-120 kg/ha application under wet-DSR offers viable options for farmers.

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