Plant Archives Vol. 26, No. 2, 2026 pp. 2521-2528 e-ISSN:2581-6063 (online), ISSN:0972-5210

Plant Archives

Journal homepage: http://www.plantarchives.org

DOI Url : https://doi.org/10.51470/PLANTARCHIVES.2026.v26.no.2.345

GROWTH AND DEVELOPMENT OF DIRECT-SEEDED RICE AS INFLUENCED BY ESTABLISHMENT METHODS AND WEED MANAGEMENT UNDER TEMPERATE CONDITIONS

Mohammad Rafiq Khan[1], A.A. Saad[1], Tauseef Ahmad Bhat[1], Inayat Mustafa khan[1], Fehim Jeelani Wani[2], Angrej Ali[3], Shabir Ahmad Bhat[1], Aadil Akbar Wani[1]$_1$, Tajalee Gulshan[1], Ashu Sharma[1], Abid Tariq[1] and Mohammad Saleem Bhat[4]

[1]Division of Agronomy, Sher-e-Kashmir University of Agriculture Science & Technology Kashmir, India
[2]Division of Agricultural Economics and Statistics Sher-e-Kashmir University of Agriculture Science & Technology Kashmir, India
[3]Division of Horticulture, Sher-e-Kashmir University of Agriculture Science & Technology Kashmir, India
[4]Division of Entomology Sher-e-Kashmir University of Agriculture Science & Technology Kashmir, India
*Corresponding author E-mail: khanrafeeq60@gmail.com
(Date of Receiving-12-07-2026; Date of Revision-20-09-2026; Date of Acceptance-03-10-2026)

ABSTRACT

A field experiment was conducted during the *Kharif* seasons of 2024 and 2025 at the Faculty of Agriculture, Sher-e-Kashmir University of Agricultural Sciences and Technology of Kashmir (SKUAST-K), Kashmir, to evaluate the effect of establishment methods and weed-management practices on the growth and development of rice (*Oryza sativa* L.) cultivar SR-4. The experiment was laid out in a split-plot design with three replications, comprising two establishment methods in the main plots, viz., dry direct-seeded rice (Dry DSR) and wet direct-seeded rice (Wet DSR), and seven weed-management treatments in the sub-plots. The weed-management treatments consisted of pyrazosulfuron ethyl @ 20 g ha^{-1}, metsulfuron methyl @ 4 g ha^{-1}, chlorimuron ethyl @ 6 g ha^{-1}, ethoxysulfuron @ 100 g ha^{-1}, chlorimuron + metsulfuron premixed (Almix) @ 4 g ha^{-1}, weed-free and weedy check. Plant height, leaf area index (LAI) and dry matter accumulation were recorded at different crop growth stages. Wet DSR resulted in greater plant height, LAI and dry matter accumulation than Dry DSR at all the recorded growth stages in both years. At harvest, plant height under Wet DSR was 102.15 and 103.92 cm during 2024 and 2025, respectively, compared with 98.60 and 98.94 cm under Dry DSR. Similarly, dry matter accumulation at harvest was higher under Wet DSR (1360.26 and 1362.98 g m^{-2}) than Dry DSR (1320.63 and 1322.98 g m^{-2}) during 2024 and 2025, respectively. Among weed-management treatments, the weed-free treatment recorded the highest plant height, LAI and dry matter accumulation, whereas the weedy check recorded the lowest values. The chlorimuron + metsulfuron premixed treatment also performed favourably among the herbicidal treatments. Overall, the results demonstrated that crop establishment method and weed-management practices markedly influenced the growth and biomass accumulation of rice under direct-seeded conditions, with Wet DSR and effective weed management providing superior crop growth compared with Dry DSR and unchecked weed competition.

***Key words*:** direct-seeded rice, dry DSR, wet DSR, weed management, plant height, leaf area index, dry matter accumulation

Introduction

Rice serves as the primary staple food for nearly half of the global population, providing sustenance to over 3.5 billion individuals and representing a critical source of daily caloric intake throughout Asia (Mohidem *et al*., 2022). The cultivation of rice is projected to increase steadily from 510 million tons in 2023 to approximately 550 million tons by 2030 and 590 million tons by 2040, primarily driven by population growth and economic development in developing countries (Yuan *et al*., 2021).

The increasing demand for rice, together with growing constraints on water, labour and other agricultural resources, necessitates the development of production technologies that can maintain crop productivity while improving resource-use efficiency(Mallareddy *et al*., 2023). Rice production in much of Asia has traditionally relied on puddled transplanted rice, in which seedlings are raised in a nursery and subsequently transplanted into puddled and continuously flooded soil (Chaudhary *et al*., 2023). Although puddling facilitates seedling establishment, suppresses some weeds and can reduce percolation losses, repeated puddling has several undesirable consequences, including deterioration of soil physical properties, disruption of soil aggregates, formation of a shallow hardpan and high requirements for water and labour (Kukalm & Aggarwal, 2003). In addition, conventional transplanted rice requires substantial labour during land preparation and transplanting, at a time when agricultural labour availability is increasingly uncertain and wages are rising (Prasad *et al*., 2017). These limitations, coupled with declining water availability and increasing pressure to improve resource-use efficiency, have stimulated interest in alternative rice establishment systems. The challenge of water scarcity is particularly important because rice is a relatively water-intensive crop. Increasing competition for freshwater, declining groundwater resources and greater variability in rainfall associated with climate change are making conventional water-intensive rice production increasingly difficult in many rice-growing regions.

Consequently, water-saving establishment and irrigation practices have become central to the development of more resilient rice production systems. Recent research identifies direct-seeded rice (DSR) as one of the important alternatives capable of addressing the combined challenges of water scarcity, high labour requirements and increasing production costs. Direct-seeded rice refers to the establishment of rice directly from seed in the main field rather than transplanting nursery-raised seedlings (Sandhu *et al*., 2021). By eliminating nursery raising and transplanting, DSR can reduce labour requirements, avoid repeated puddling and reduce water use during crop establishment. The technology can also provide opportunities for earlier crop establishment and maturity and lower greenhouse-gas emissions compared with conventional flooded transplanted systems (Joshi *et al*., 2013). Recent research further emphasizes that DSR is particularly relevant under conditions of increasing water and labour costs, although its wider adoption is constrained by problems related to crop establishment and weed competitiveness (Shekhawat *et al*., 2020).

Direct seeding can broadly be classified into dry, wet and water seeding systems. In dry direct-seeded rice (Dry DSR), dry seed is sown into a prepared dry or relatively moist soil, whereas wet direct-seeded rice (Wet DSR) involves sowing pre-germinated seed on or into a puddled, saturated seedbed. The choice between dry and wet establishment can influence soil moisture conditions, crop emergence, early crop vigour, weed emergence and ultimately crop growth and productivity. Therefore, establishment method is not only an agronomic decision for conserving resources but can also modify the competitive relationship between rice and weeds. Despite the resource-conserving advantages of DSR, weed infestation has emerged as one of its major biological constraints (Singh *et al*., 2024). Unlike transplanted rice, where relatively large seedlings establish a competitive advantage over emerging weeds, rice and weeds in DSR generally emerge simultaneously. This creates intense competition during the early stages of crop establishment for light, water, nutrients and growing space. Recent reviews confirm that weed infestation is one of the principal factors limiting the productivity and wider adoption of direct-seeded rice, particularly under wet direct-seeded conditions. The weed problem in DSR is also becoming increasingly complex because changes in crop establishment and water regimes can alter weed flora and favour species that are well adapted to aerobic or intermittently wet conditions. Important weeds reported in direct-seeded rice include grasses such as *Echinochloa colona*, *Echinochloa crus-galli* and *Leptochloa chinensis*, sedges such as *Cyperus iria* and *Fimbristylis* spp., and several broad-leaved weeds (Hossain *et al*., 2026).

Recent field research in India similarly documented diverse weed complexes in dry-seeded rice, with *Echinochloa crus-galli*, *E. colona* and *L. chinensis* among the dominant grassy weeds. The increasing complexity of the weed flora is accompanied by concerns regarding herbicide resistance and shifts in weed populations. Repeated use of the same herbicide or herbicide mode of action can impose strong selection pressure on weed populations, favouring tolerant or resistant biotypes. Herbicide resistance has already been reported for numerous weed species associated with rice production, and this represents a major threat to the sustainability of chemical weed management in DSR. Consequently, the development of effective and diversified weed-management strategies, including the appropriate selection and rotation of herbicide modes of action, is essential for sustaining the productivity of DSR. Chemical weed management has therefore assumed considerable importance in DSR because of the difficulty

of achieving timely manual weed control over large areas and the simultaneous emergence of rice and weeds. Herbicides can provide rapid and economical weed suppression during the critical period of crop–weed competition. However, no single herbicide is capable of providing reliable control of the diverse weed flora occurring in DSR under all environmental conditions. Recent reviews emphasize that the efficacy of weed-management practices depends on weed spectrum, soil and water conditions, establishment method and timing of application, and that integrated approaches are preferable for sustainable weed management. Among the herbicides used in rice, sulfonylurea herbicides are particularly important because of their high biological activity at relatively low application rates and their activity against a range of grassy, broad-leaved and sedge weeds, depending on the active ingredient. Several sulfonylurea herbicides inhibit acetolactate synthase (ALS), an enzyme involved in the biosynthesis of branched-chain amino acids. Inhibition of ALS disrupts essential metabolic processes and results in rapid suppression of susceptible weed growth. The synopsis underpinning the present study identifies sulfonylurea herbicides as an important group for weed management in direct-seeded rice because of their effectiveness at low doses and broad utility in rice production. Recent research from the temperate agro-ecosystem of Kashmir has demonstrated that crop establishment and weed-management practices can significantly influence crop growth, weed dynamics, productivity and profitability of direct-seeded rice. Thus, locally generated information on the performance of different herbicide options under contrasting establishment methods is necessary for developing suitable weed-management recommendations for the region. Although considerable research has been conducted on weed management in DSR, comparative evaluation of Dry DSR and Wet DSR under a common set of sulfonylurea-based weed-management treatments under temperate conditions remains important. Differences in soil moisture, crop establishment and weed emergence associated with dry and wet seeding may influence herbicide performance and subsequent crop growth. Therefore, understanding the response of rice to different establishment methods in combination with suitable weed-management practices can contribute to the development of more efficient and sustainable DSR production systems.

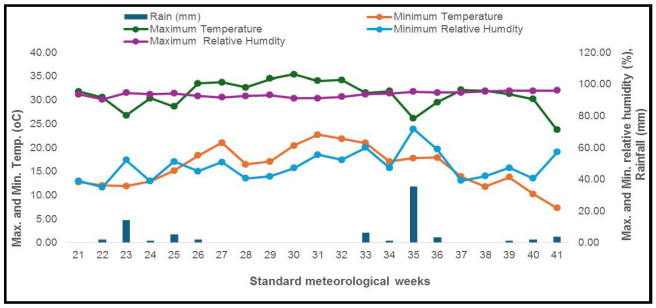


Fig. 1: Weekly mean meteorological parameters, *Kharif*-2024.

Materials and Methods

Experimental site

The field experiment was conducted during the *Kharif* seasons of 2024 and 2025 at the Agronomy Farm, Faculty of Agriculture, Sher-e-Kashmir University of Agricultural Sciences and Technology of Kashmir (SKUAST-K), Wadura, Sopore, Jammu and Kashmir, India. The study was undertaken to evaluate the efficacy of sulfonylurea herbicide-based weed-management programmes under dry and wet direct-seeded rice (DSR) establishment methods under temperate conditions.

Meteorological conditions during the experimental period

The meteorological conditions prevailing during the crop-growing period were recorded on a weekly basis and are presented in Fig. 1 and Fig. 2 for *Kharif* 2024 and 2025, respectively. The observations covered standard meteorological weeks (SMW) 21 to 41, representing the major growth period of rice at the experimental site. During *Kharif* 2024, the experimental period received a total rainfall of 80.0 mm. The minimum temperature varied from 7.31 to 22.73°C, while the maximum temperature ranged from 23.74 to 35.43°C. Rainfall was unevenly distributed during the crop season, with the highest weekly rainfall occurring during SMW 35, followed by rainfall in SMW 23 and 33. Relative humidity also varied across the crop-growing period, with maximum relative humidity remaining comparatively high throughout the season. The relatively low rainfall during the season resulted in comparatively drier conditions during several crop-growth stages. In *Kharif* 2025, rainfall was substantially higher than in 2024, with a total seasonal rainfall of 415.60 mm. The minimum temperature ranged from 5.50 to 20.59°C, whereas the maximum temperature varied from 19.90 to 35.37°C. Rainfall was more frequent and better distributed during 2025, particularly from SMW 28 to 37, with notable rainfall events during SMW 22, 28,

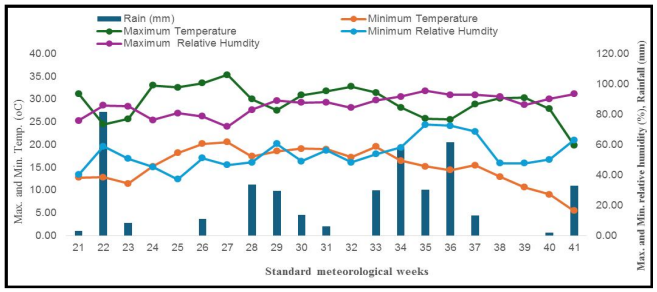


Fig. 2: Weekly mean meteorological parameters, *Kharif*-2025.

29, 33, 34, 35 and 36. Relative humidity also showed considerable week-to-week variation during the crop season, with comparatively higher humidity during the later part of the season.

Experimental design and treatments

The experiment was laid out in a split-plot design with three replications. Establishment methods were assigned to the main plots, while sulfonylurea herbicide treatments were assigned to the sub-plots. Thus, the experiment comprised 2 establishment methods × 7 weed-management treatments × 3 replications, resulting in 14 treatment combinations and 42 experimental plots. Each plot measured 4 m × 3 m (12 m²).

Main-plot treatments: Establishment methods

E_1: Dry direct-seeded rice (Dry DSR)

E_2: Wet direct-seeded rice (Wet DSR)

Sub-plot treatments: Sulfonylurea herbicide programmes

Treatment	Herbicide programme	Dose
T_1	Pyrazosulfuron-ethyl 10% WP (PE)	20 g ha^{-1}
T_2	Pyrazosulfuron-ethyl 10% WP (PE) *fb*. Metsulfuron-methyl 20% WP (PoE)	20 g ha^{-1} fb. 4 g ha^{-1}
T_3	Pyrazosulfuron-ethyl 10% WP (PE) *fb*. Chlorimuron-ethyl 25% WP (PoE)	20 g ha^{-1} fb. 6 g ha^{-1}
T_4	Pyrazosulfuron-ethyl 10% WP (PE) *fb*. Ethoxysulfuron 15% WDG (PoE)	20 g ha^{-1} fb. 100 g ha^{-1}
T_5	Pyrazosulfuron-ethyl 10% WP (PE) *fb*. Chlorimuron 10% + Metsulfuron 10% WP premix (Almix) (PoE)	20 g ha^{-1} fb. 4 g ha^{-1}
T_6	Weed-free	Weed-free at 20-day intervals
T_7	Weedy check	No weed control

Crop and variety

Rice (*Oryza sativa* L.) was used as the test crop. The variety selected for the experiment was Shalimar Rice-4 (SR-4), a variety suited to the temperate conditions of Kashmir

Initial physico-chemical properties of the experimental soil

The initial soil analysis indicated that the experimental field had a pH of 6.53, indicating a nearly neutral soil reaction. The electrical conductivity (EC) was 0.25 dS m^{-1}, indicating normal soluble-salt status. The soil contained 0.78% organic carbon, categorized as medium. The available nutrient status was 388.30 kg N ha^{-1}, 17.13 kg P ha^{-1} and 211.02 kg K ha^{-1}, all falling in the medium category. Based on particle-size distribution, the soil contained 10.50% sand, 54.20% silt and 35.30% clay, and was classified as silty clay loam.

Observations on crop growth

Crop growth observations were recorded at 30-day intervals during the crop growth period. Plant height (cm) was measured at 30, 60, 90 and 120 days after sowing (DAS) and at harvest. Dry matter accumulation (g m^{-2}) was determined at the respective growth stages by collecting representative plant samples, drying them to constant weight and expressing the dry matter on a unit-area basis. Leaf area index (LAI) was recorded at the respective growth stages using a canopy analyser, which provided the leaf area index directly for the crop canopy. These observations were used to assess the effect of establishment methods and weed-management treatments on rice growth during the crop season.

Table 1: Initial physio-chemical properties of soil.

S. No.	Soil parameter	Value	Remark
1	pH (1:2.5)	6.53	Neutral
2	Electrical conductivity (EC), dS m^{-1}	0.25	Normal
3	Organic carbon (%)	0.78	Medium
4	Available N (kg ha^{-1})	388.30	Medium
5	Available P (kg ha^{-1})	17.13	Medium
6	Available K (kg ha^{-1})	211.02	Medium
7	Sand (%)	10.50	Silty Clam loam
8	Silt (%)	54.20	
9	Clay (%)	35.30	

Statistical analysis

The data obtained from the field experiment were statistically analyzed using analysis of variance (ANOVA) appropriate for a split-plot design, with establishment methods as main-plot treatments and weed-management treatments as sub-plot treatments. The statistical analysis was carried out using SPSS Statistics and R statistical software. The significance of treatment effects was tested at the 5% probability level ($P \leq 0.05$). The standard error of mean (SEm±) and critical difference (CD) at 5% probability were calculated for comparison of treatment means wherever the treatment effect was significant.

Results

Plant height

Plant height of rice increased progressively with advancement in crop age, irrespective of establishment method and weed-management treatment. The data presented in Table 2 revealed that the wet direct-seeded rice (Wet DSR) consistently recorded significantly greater plant height than dry direct-seeded rice (Dry DSR) at all the growth stages during both years. At harvest, Wet DSR recorded a plant height of 102.15 and 103.92 cm in 2024 and 2025, respectively, compared with 98.60 and 98.94 cm under Dry DSR, indicating an increase of 3.6 and 5.0%, respectively.

Table 2: Plant height (cm) of rice as influenced by different establishment methods and weed management treatments.

Establishment Methods	30 DAS		60 DAS		90 DAS		120 DAS		Harvest	
	2024	2025	2024	2025	2024	2025	2024	2025	2024	2025
Dry DSR	15.41	17.84	45.23	46.73	89.28	90.28	97.28	98.33	98.60	98.94
Wet DSR	17.32	20.37	48.64	50.64	94.74	96.24	101.90	103.29	102.15	103.92
SEm(±)	0.08	0.41	0.59	0.55	1.11	1.14	0.51	0.91	0.36	0.83
CD (P ≤0.05)	0.34	1.75	2.54	2.35	4.78	4.91	2.17	3.90	1.56	3.58
Weed Management Treatments										
Pyrazosulfuron ethyl (PE) 20 g ha^{-1}	13.28	16.31	43.85	45.60	90.02	91.27	97.02	98.27	97.82	98.89
Metsulfuron methyl (PoE) 4 g ha^{-1}	17.55	20.57	48.12	49.87	93.12	94.37	102.45	103.70	103.30	104.32
Chlorimuron ethyl (PoE) 6 g ha^{-1}	15.82	18.84	46.39	48.14	91.39	92.64	99.89	101.14	100.80	101.76
Ethoxysulfuron (PoE) 100 g ha^{-1}	14.50	17.53	45.07	46.82	90.07	91.32	98.75	99.98	99.55	100.61
Chlorimuron + Metsulfuron Pre-mixed (Almix) (PoE) 4 g ha^{-1}	19.40	21.42	49.97	51.72	98.30	99.55	105.14	106.39	105.95	107.01
weed free	21.60	23.62	52.17	53.92	100.50	101.75	108.05	109.09	108.72	109.71
weedy check	12.42	15.46	42.99	44.74	80.66	81.91	85.84	87.09	86.47	87.71
SEm(±)	0.25	0.99	0.83	0.87	2.21	2.22	1.41	1.39	1.39	1.36
CD (P 0.05)	0.51	2.04	1.70	1.79	4.55	4.56	2.91	2.87	2.88	2.82

Among the weed-management treatments, plant height was significantly influenced by the different treatments at all stages of crop growth. The weed-free treatment (T_6) recorded the highest plant height throughout the crop growth period, registering 21.60, 52.17, 100.50, 108.05 and 108.72 cm at 30, 60, 90, 120 DAS and harvest, respectively, during 2024. A similar trend was observed in 2025, where the corresponding values were 23.62, 53.92, 101.75, 109.09 and 109.71 cm. The chlorimuron + metsulfuron premixed treatment (Almix) (T_5) ranked next, with plant height of 105.95 and 107.01 cm at harvest in 2024 and 2025, respectively. The differences between T_5 and the weed-free treatment were smaller than the respective CD values at harvest, indicating that these treatments were statistically comparable. The weedy check (T_7) recorded the lowest plant height throughout the crop season, with 86.47 and 87.71 cm at harvest in 2024 and 2025, respectively. Thus, at harvest, the weed-free treatment increased plant height by approximately 25.7 and 25.1% over the weedy check in 2024 and 2025, respectively. Among the herbicidal treatments, T_5 maintained comparatively superior plant growth, whereas pyrazosulfuron-ethyl alone (T_1) resulted in relatively lower plant height.

Leaf area index

Leaf area index (LAI) of rice was significantly influenced by the establishment methods and weed-management treatments during both years of experimentation. Under establishment methods, Wet DSR consistently recorded higher LAI than Dry DSR at all the growth stages. At 90 DAS, LAI under Wet DSR was 4.77 and 4.82 in 2024 and 2025, respectively, compared with 4.33 and 4.38 under Dry DSR. The superiority of Wet DSR was also maintained at 120 DAS, where it recorded LAI of 2.52 and 2.60, compared with 2.18 and 2.24 under Dry DSR in 2024 and 2025, respectively. Among the weed-management treatments, the weed-free treatment (T_6) recorded the highest LAI at all the growth stages in both years. In 2024, LAI under T_6 increased from 1.05 at 30 DAS to 5.73 at 90 DAS, followed by a decline to 2.93 at 120 DAS. Similarly, in 2025, LAI increased from 1.15 at 30 DAS to 5.78 at 90 DAS and subsequently declined to 3.00 at 120 DAS. The chlorimuron + metsulfuron premixed (Almix) treatment (T_5) recorded the next highest LAI, with values of 0.84, 3.06, 5.08 and 2.78 at 30, 60, 90 and 120 DAS, respectively, in 2024, and 0.94, 3.18, 5.13 and 2.85, respectively, in 2025. The weedy check (T_7) consistently recorded the lowest LAI throughout the crop growth period, with values of 0.34, 1.32, 2.41 and 1.63 in 2024 and 0.44, 1.57, 2.46 and 1.70 in 2025 at 30, 60, 90 and 120 DAS, respectively. Among the herbicidal treatments, T_5 maintained comparatively higher LAI, whereas pyrazosulfuron-ethyl alone (T_1) recorded relatively lower values. Overall, LAI increased progressively up to 90 DAS, when the maximum canopy development was observed, and subsequently declined at 120 DAS, reflecting crop maturity and senescence. Effective weed management, particularly the weed-free and T_5 treatments, resulted in greater canopy development compared with the weedy check.

Dry matter accumulation

Dry matter accumulation of rice increased progressively with advancement in crop growth and was significantly influenced by both establishment methods and weed-management treatments during 2024 and 2025

Table 3: Leaf area index of rice as influenced by different establishment methods and weed management treatments.

Establishment Methods	30 DAS		60 DAS		90 DAS		120 DAS	
	2024	2025	2024	2025	2024	2025	2024	2025
Dry DSR	0.52	0.62	2.36	2.50	4.33	4.38	2.18	2.24
Wet DSR	0.70	0.80	2.58	2.69	4.77	4.82	2.52	2.60
SEm(±)	0.01	0.01	0.03	0.03	0.09	0.10	0.01	0.01
CD (P ≤ 0.05)	0.04	0.04	0.15	0.15	0.41	0.41	0.04	0.03
Weed Management Treatments								
Pyrazosulfuron ethyl (PE) 20 g ha^{-1}	0.47	0.57	1.66	1.91	4.32	4.37	2.03	2.10
Metsulfuron methyl (PoE) 4 g ha^{-1}	0.54	0.64	2.73	2.78	5.00	5.05	2.59	2.66
Chlorimuron ethyl (PoE) 6 g ha^{-1}	0.53	0.63	2.56	2.69	4.72	4.77	2.34	2.41
Ethoxysulfuron (PoE) 100 g ha^{-1}	0.50	0.60	2.35	2.42	4.56	4.61	2.17	2.24
Chlorimuron + Metsulfuron Premixed (Almix) (PoE) 4 g ha^{-1}	0.84	0.94	3.06	3.18	5.08	5.13	2.78	2.85
weed free	1.05	1.15	3.60	3.63	5.73	5.78	2.93	3.00
weedy check	0.34	0.44	1.32	1.57	2.41	2.46	1.63	1.70
SEm(±)	0.03	0.02	0.10	0.04	0.13	0.13	0.02	0.03
CD (P 0.05)	0.06	0.04	0.20	0.08	0.27	0.28	0.04	0.05

(Table 4). Among the establishment methods, Wet DSR recorded significantly higher dry matter accumulation than Dry DSR at all the growth stages in both years. At harvest, Wet DSR recorded 1360.26 and 1362.98 g m^{-2} in 2024 and 2025, respectively, compared with 1320.63 and 1322.98 g m^{-2} under Dry DSR. This represented an increase of about 3.0% in 2024 and 3.0% in 2025 under Wet DSR. Among the weed-management treatments, weed-free treatment (T_6) recorded the highest dry matter accumulation throughout the crop growth period. At harvest, T_6 recorded 1410.18 g m^{-2} in 2024 and 1412.79 g m^{-2} in 2025, followed by chlorimuron + metsulfuron premixed (Almix) treatment (T_5) with 1388.46 and 1390.07 g m^{-2}, respectively. The difference between T_6 and T_5 at harvest was 21.72 g m^{-2} in 2024 and 22.72 g m^{-2} in 2025, which was smaller than the respective CD values (32.01 and 32.33 g m^{-2}); hence, these treatments were statistically comparable. The weedy check (T_7) recorded the lowest dry matter accumulation at all growth stages, with harvest values of 1266.87 and 1267.45 g m^{-2} during 2024 and 2025, respectively. The weed-free treatment consequently recorded about 11.3% and 11.5% higher dry matter accumulation than the weedy check in 2024 and 2025, respectively. Among the herbicidal treatments, T_5 recorded the highest dry matter accumulation, followed by T_2, T_3 and T_4, while pyrazosulfuron-ethyl alone (T_1) recorded comparatively lower values. Overall, effective weed management enhanced crop dry matter production, whereas unrestricted weed competition substantially reduced dry matter accumulation throughout the crop growth period.

Discussion

Plant height

The progressive increase in plant height with advancement of crop age observed in the present study may be attributed to continuous vegetative growth, internode elongation and accumulation of assimilates during the crop growth period. Wet DSR consistently produced taller plants than Dry DSR during both experimental years. The comparatively greater plant height under Wet DSR may be associated with more favourable moisture conditions during crop establishment and early growth, which would facilitate better root development, nutrient acquisition and subsequent vegetative growth. Similar improvement in crop growth under suitable crop-establishment and weed-management practices has been reported in DSR systems. A recent study on upland rice found that crop establishment method significantly affected plant height, dry matter accumulation and LAI, with line sowing performing better than broadcasting (Soni *et al*., 2025). The marked differences among weed-management treatments indicate the strong influence of weed competition on rice growth. Weed-free conditions produced the maximum plant height, whereas the weedy check recorded the minimum, demonstrating that unrestricted weeds competed strongly with rice for essential growth resources such as nutrients, water, light and space. In DSR, rice and weeds emerge in a relatively similar soil environment, making early weed competition particularly important. Recent research has similarly demonstrated that effective weed management improves crop growth and productivity in DSR, while uncontrolled weed infestation can substantially suppress crop performance (Karthickraja *et al*., 2024). Among the herbicidal programmes, pyrazosulfuron-ethyl followed by chlorimuron + metsulfuron premix (T_5) produced

Table 2: Dry matter accumulation (g m^{-2}) of rice as influenced by different establishment methods and weed management treatments.

Establishment Methods	30 DAS		60 DAS		90 DAS		120 DAS		Harvest	
	2024	2025	2024	2025	2024	2025	2024	2025	2024	2025
Dry DSR	23.85	25.39	213.08	214.58	1137.70	1139.55	1293.54	1294.04	1320.63	1322.98
Wet DSR	35.05	37.30	239.94	242.94	1177.93	1179.65	1329.70	1331.42	1360.26	1362.98
SEm(±)	0.09	0.12	1.31	1.44	1.84	2.01	7.19	7.23	7.20	7.23
CD (P ≤ 0.05)	0.38	0.50	5.67	6.18	7.92	8.63	30.95	31.12	31.01	31.13
Weed Management Treatments										
Pyrazosulfuron ethyl (PE) 20 g ha^{-1}	29.61	31.47	214.35	216.60	1148.25	1151.11	1278.27	1280.88	1303.09	1304.70
Metsulfuron methyl (PoE) 4 g ha^{-1}	30.00	31.94	231.41	233.66	1165.89	1167.50	1336.33	1337.94	1376.65	1377.26
Chlorimuron ethyl (PoE) 6 g ha^{-1}	29.31	31.17	227.94	230.19	1157.25	1158.86	1312.19	1314.80	1347.35	1348.96
Ethoxysulfuron (PoE) 100 g ha^{-1}	28.87	30.73	223.96	226.21	1154.27	1155.88	1307.38	1308.99	1338.38	1339.81
Chlorimuron + Metsulfuron Pre-mixed (Almix) (PoE) 4 g ha^{-1}	30.04	32.05	236.05	238.30	1174.20	1175.81	1340.47	1341.08	1388.46	1390.07
weed free	31.93	33.79	242.94	245.19	1188.25	1189.86	1357.52	1359.13	1410.18	1412.79
weedy check	26.41	28.27	208.93	211.18	1116.58	1118.19	1246.69	1247.86	1266.87	1267.45
SEm(±)	0.29	0.26	1.70	1.78	4.18	4.26	4.33	4.36	7.44	7.51
CD (P 0.05)	0.60	0.54	3.51	3.67	8.64	8.80	18.63	18.76	32.01	32.33

comparatively greater plant height and approached the weed-free treatment. This could be attributed to more effective suppression of the diverse weed flora during the critical period of crop–weed competition, thereby reducing competition and allowing greater availability of resources for rice growth. The superiority of sequential herbicide programmes in improving crop growth has also been reported in recent DSR studies. For example, sequential pre- and post-emergence herbicide programmes have been shown to reduce weed density and biomass while improving plant growth and productivity (Hashim *et al*., 2022; Mir *et al*., 2024).

Leaf area index

Leaf area index (LAI) increased progressively up to 90 DAS and subsequently declined at 120 DAS in both years. The initial increase reflects progressive canopy development, while the decline during the later stage may be attributed to leaf senescence with crop maturity. A two-year study under temperate Kashmir conditions also reported a similar pattern of increasing LAI followed by a decline during the later reproductive phase (Mir *et al*., 2024). Wet DSR recorded significantly higher LAI than Dry DSR at all stages, indicating better canopy development under wet establishment. Greater leaf-area development can enhance radiation interception and support higher crop growth. Similar differences in LAI and other growth indices among crop-establishment methods have been reported in direct-seeded rice (Singh *et al*., 2023). Weed management significantly influenced LAI. The weed-free treatment recorded the highest LAI, whereas the weedy check recorded the lowest, reflecting the adverse effect of prolonged weed competition on crop canopy development. Effective weed control reduces competition for water, nutrients and light, thereby favouring leaf expansion and canopy establishment. Similar improvements in LAI under effective weed-management practices have been reported in DSR. Mir *et al*., (2024). Among herbicide treatments, T_5 (pyrazosulfuron-ethyl followed by chlorimuron-ethyl + metsulfuron-methyl premix) recorded the highest LAI after the weed-free treatment. Its superior performance may be attributed to more effective and sustained suppression of weed competition during crop establishment and canopy development. Recent studies have likewise demonstrated improved crop growth under effective sequential herbicide programmes in DSR (Upadhaya *et al*., 2024).

Dry matter accumulation

Dry matter accumulation increased progressively with crop age under both establishment methods and all weed-management treatments. Wet DSR recorded significantly higher dry matter than Dry DSR at all stages and at harvest, which may be attributed to better crop establishment and canopy development, as also reflected in the higher plant height and LAI. Weed management markedly influenced biomass production(Patel *et al*., 2024). Weed-free treatment recorded the maximum dry matter, whereas the weedy check recorded the minimum, indicating the adverse effect of weed competition on crop growth. Effective weed management reduces competition for water, nutrients and light, thereby favouring biomass production. Similar improvements in crop growth and biomass under effective weed-management practices have been reported in direct-

seeded rice. Among herbicidal treatments, T_5 (pyrazosulfuron-ethyl fb chlorimuron + metsulfuron premix) recorded the highest dry matter, followed by the other sequential herbicide treatments. Its superior performance may be associated with more effective suppression of weeds throughout crop growth, allowing greater utilization of available resources by rice. Recent studies have similarly reported improved crop growth and productivity with effective sequential herbicide programmes in DSR(Choudhary *et al*., 2025).

Conclusion

The study revealed that Wet DSR promoted better crop growth and biomass accumulation than Dry DSR. Effective weed management further enhanced crop performance, with the weed-free treatment recording the highest values, while the weedy check consistently performed poorly. Among herbicidal treatments, T_5 (pyrazosulfuron-ethyl fb chlorimuron + metsulfuron premix) showed the most promising performance. Overall, proper crop establishment coupled with effective weed suppression is essential for achieving vigorous growth and greater biomass production in direct-seeded rice under temperate Kashmir conditions

References

Chaudhary, A., Venkatramanan V., Kumar Mishra A. and Sharma S. (2023). Agronomic and environmental determinants of direct seeded rice in South Asia. *Circular Economy and Sustainability*, **3(1)**, 253-290.

Choudhary, V.K., Sahu M.P., Dubey R.P., Singh R. and Mishra J.S. (2025). Assessment of seed rate and weed management practice on weed control, crop productivity and profitability of dry direct-seeded rice. *Journal of Agriculture and Food Research*, **22**, 102110

Hashim, M., Singh V.K., Singh K.K. and Dhar S. (2022). Herbicidal weed-management options for dry direct-seeded rice (*Oryza sativa*) in North-Eastern Plains of India. *Indian Journal of Agronomy*, **67(4)**, 337–342.

Hossain, A., Islam M.T., Kabir M.P., Harun-Or-Rashid M., Chamara B.S., Awan T.H. and Gathala M.K. (2026). Weed dynamics and management strategies for dry direct-seeded rice in South Asia: a review. *Discover Plants*, **3(1)**, 319.

Joshi, E., Kumar D., Lal B., Nepalia V., Gautam P. and Vyas A.K. (2013). Management of direct seeded rice for enhanced resource-use efficiency. *Plant Knowledge J.*, **2(3)**, 119-134.

Karthickraja, A., Saravanane P., Poonguzhalan R. and Nadaradjan S. (2024). Comparison of UAV and knapsack herbicide application methods on weed spectrum, crop growth and yield in dry direct-seeded rice. *Journal of Applied and Natural Science*, **16(?)**, 307–311. https://doi.org/10.5958/0974-8164.2024.00051.6

Kukal, S.S. and Aggarwal G.C. (2003). Puddling depth and intensity effects in rice–wheat system on a sandy loam soil: II. Water use and crop performance. *Soil and Tillage Research*, **74(1)**, 37–45. https://doi.org/10.1016/S0167-1987(03)00124-7

Mallareddy, M., Thirumalaikumar R., Balasubramanian P., Naseeruddin R., Nithya N., Mariadoss A. and Vijayakumar S. (2023). Maximizing water use efficiency in rice farming: A comprehensive review of innovative irrigation management technologies. *Water*, **15(10)**, 1802.

Mir, M.S., Singh P., Kanth R.H., Shah Z.A., Dar E.A., Bhat J.A., Nazir A., Amin Z., Lone A.H., Nain M.S., Yousuf D., Alie B.A., Ahngar T.A., Abd-ElGawad A.M. and Mattar M.A. (2024). Influence of sowing dates and weed management practices on weed dynamics, productivity and profitability of direct seeded rice. *Scientific Reports*, **14**, 18877. https://doi.org/10.1038/s41598-024-69519-9

Mohidem, N.A., Hashim N., Shamsudin R. and Che Man H. (2022). Rice for food security: Revisiting its production, diversity, rice milling process and nutrient content. *Agriculture*, **12(6)**, 741.

Patel, V.J., Chaudhari D.D., Bhanvadia A.S., Patel H.K., Patel B.D. and Chaudhary N.N. (2024). Efficacy of herbicide mixtures on weed dynamics in direct-dry-seeded rice under irrigated condition. *Indian J. of Weed Sci.*, **56(2)**, 112–116. https://doi.org/10.5958/0974-8164.2024.00019.4

Prasad, R., Shivay Y.S. and Kumar D. (2017). Current status, challenges, and opportunities in rice production. *Rice production worldwide*, 1-32.

Sandhu, N., Yadav S., Kumar Singh V. and Kumar A. (2021). Effective crop management and modern breeding strategies to ensure higher crop productivity under direct seeded rice cultivation system: A review. *Agronomy*, **11(7)**, 1264.

Shekhawat, K., Rathore S.S. and Chauhan B.S. (2020). Weed management in dry direct-seeded rice: A review on challenges and opportunities for sustainable rice production. *Agronomy*, **10(9)**, 1264.

Singh, S.K., Kumar H.J.M., Maurya S., Kumar A., Yadav S. and Sah D. (2024). Direct-seeded rice: potential benefits, constraints and prospective. *Journal of Scientific Research and Reports*, **30(7)**, 272-280.

Singh, S., Ghosh A., Das T.K., Dhar S., Prasad S.M., Tripathy S., Verma G. and Tomar J. (2023). Influence of nitrogen and weed-management practices on crop-growth indices and productivity of dry direct-seeded rice (*Oryza sativa*). *Indian Journal of Agronomy*, **68(1)**, 89–92. https://doi.org/10.59797/ija.v68i1.209

Soni, S., Salam P.K., Thakur A.K., Chandrakar T., Kumar N. and Ramteke V. (2025). Impact of direct seeding methods and weed management strategies on growth and yield of upland rice (*Oryza sativa*). *Indian Journal of Agronomy*, **70(3)**, 353–356. https://doi.org/10.59797/ija.v70.i3.5628

Upadhaya, B., Tiwari R.K., Kishor K., Harsha B.R., Singh S.K., Kumar S. and Kumar S. (2024). Herbicide evaluation in direct seeded rice in the middle Gangetic plains of India. *Weed Biology and Management*, **24(4)**, 135–143. https://doi.org/10.1111/wbm.12296

Yuan, S., Linquist B.A., Wilson L.T., Cassman K.G., Stuart A.M., Pede V., Miro B., Saito K., Agustiani N., Aristya V.E., Krisnadi L.Y., Zanon A., Heinemann A.B., Carracelas G., Subash N., Brahmanand P.S., Li T., Peng S.B. and Grassini P. (2021). Sustainable intensification for a larger global rice bowl. *Nat Commun.*, **12**, 7163.