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Crop growth, biomass accumulation and yield attributes of transplanted rice as influenced by sequential weed-management practices

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ABSTRACT

A field experiment was conducted during kharif 2024 at the Agronomy Main Research Farm, Odisha University of Agriculture and Technology (OUAT), Bhubaneswar, Odisha, to evaluate the influence of sequential herbicide-based weed-management practices on crop growth, growth analysis and yield attributes of transplanted rice. The experiment was conducted in a randomized block design with eight weed-management treatments and three replications using rice cultivar 'Hasanta'. Weed-management treatments significantly influenced plant height, tiller production, leaf area index (LAI), crop dry matter accumulation, crop growth rate (CGR), effective tillers, filled grains and unfilled grains panicle⁻¹. Treatment T₃, consisting of pyrazosulfuron ethyl as pre-emergence followed by florypyrauxifen-benzyl + cyhalofop-butyl as post-emergence, recorded the highest plant height (109.48 cm at 60 DAT and 140.14 cm at harvest), tiller number (534.67 and 486.67 m⁻²), LAI (4.63 and 4.47), and crop dry matter accumulation (1092 and 1874 g m⁻²), respectively. T₃ also recorded the highest CGR during 60–90 DAT (18.86 g m⁻² day⁻¹) and 90 DAT to harvest (10.82 g m⁻² day⁻¹), effective tillers (392.00 m⁻²) and filled grains (163.00 panicle⁻¹). The lowest values for most growth and yield attributes occurred under the partially weedy check (T₈). Unfilled grains were lowest under T₃ (10.56 panicle⁻¹) and highest under T₈ (34.11 panicle⁻¹). In contrast, relative growth rate, panicle length and test weight were not significantly affected. The results indicate that effective sequential weed management improved rice growth and biomass accumulation and favoured productive tiller formation and grain filling under transplanted conditions.

Keywords: Transplanted rice, Sequential herbicide, Weed management, Crop growth, Biomass accumulation, Yield attributes

1. Introduction

Rice (*Oryza sativa* L.) is one of the most important food crops globally and plays a central role in food and nutritional security, particularly in Asia. Weed interference is a major biological constraint to rice productivity because weeds compete with rice for nutrients, water, light and space, especially during early and active crop-growth stages. The magnitude of yield loss depends on weed density, species composition, duration of interference and crop competitiveness (Mahajan *et al.*, 2014; Mamun, 2014; Dass *et al.*, 2017) [2, 3, 1].

Crop establishment and early crop growth influence crop competitiveness, resource utilization and subsequent productivity. Although transplanted rice generally establishes a vigorous stand, weeds emerging after transplanting can compete throughout the season; maintaining adequate crop growth during the critical period of weed–crop competition is therefore important. Establishment practices also influence crop stand, canopy development and yield performance (Parameswari *et al.*, 2014) [4].

Rice fields contain diverse weed communities comprising grasses, sedges and broad-leaved species with different emergence patterns, growth habits and responses to control measures. Consequently, a single intervention may not provide sustained suppression of all weed groups. Jannu *et al.* (2023) [5] emphasized the complexity of weed flora and the importance of timely and integrated approaches in rice. Although their review focused on direct-seeded rice, the underlying principles are relevant to rice production systems more broadly.

Weed competition affects crop growth before its effects become evident in final yield. Competition during vegetative growth can reduce plant height, tillering, leaf area development and dry matter accumulation, thereby limiting canopy development, radiation interception and productive panicle formation (Mahajan *et al.*, 2014; Dass *et al.*, 2017; Mamun, 2014) [2, 1, 3]. Crop growth analysis using LAI, dry matter accumulation, CGR and RGR provides complementary information on canopy development and biomass production. Maintaining effective weed control during the critical period is particularly important for protecting crop growth and yield formation (Knezevic *et al.*, 2015) [6].

Herbicide-based weed management is an important component of modern rice production because manual weeding is often constrained by labour availability, timeliness and cost. However, differences in weed emer

gence and flora can reduce the effectiveness of a single herbicide application. Sequential pre-emergence (PE) followed by post-emergence (PoE) applications can extend weed suppression and target weeds emerging at different stages. Current weed-management approaches increasingly emphasize efficient and integrated strategies for sustainable crop production (Narendar *et al.*, 2026) [7]. Accordingly, weed-management effectiveness should be assessed not only through weed density or mortality but also through crop establishment, canopy development, biomass accumulation and yield formation.

Recent studies have reported improved crop growth and productivity under sequential herbicide programmes in transplanted rice. Choudhary *et al.* (2024) [8] reported improved weed management, crop productivity and profitability with herbicide-based approaches, while Shah *et al.* (2025) [9] observed improved crop growth and productivity under effective sequential herbicide applications. However, individual growth and yield attributes do not necessarily respond uniformly; weed suppression may strongly influence biomass and tiller formation while effects on RGR, panicle length or individual grain weight may be smaller or non-significant.

Despite considerable research on weed-control efficacy, greater emphasis has often been placed on weed density, weed dry matter and final yield, with comparatively less attention to the crop-growth trajectory linking weed management with biomass accumulation and individual yield components. Therefore, the present study evaluated the influence of contrasting weed-management practices on plant height, tillering, LAI, dry matter accumulation, CGR, RGR and yield attributes of transplanted rice, with emphasis on the crop-growth responses underlying differences in productivity.

2. Materials and methods

A field experiment was conducted during the kharif season of 2024 at the Agronomy Main Research Farm, Odisha University of Agriculture and Technology (OUAT), Bhubaneswar, Odisha, India. The experimental soil was sandy loam with pH 5.41, organic carbon 0.62%, and available N, P and K of 275.23, 24.82 and 215.35 kg ha⁻¹, respectively. During the crop season, rainfall was 972.6 mm over 59 rainy days, with mean maximum and minimum temperatures of 32.6 and

24.6 °C, respectively. The experiment was laid out in a randomized block design (RBD) with eight weed-management treatments and three replications. Each plot measured 5.0 × 4.0 m. Rice cultivar 'Hasanta' was transplanted using 25-day-old seedlings at 20 × 10 cm spacing with two seedlings hill⁻¹. The recommended dose of fertilizer (RDF) was 80:40:40 kg N:P₂O₅:K₂O ha⁻¹. PE herbicides were applied at 3 DAT and PoE herbicides at 20 DAT using a knapsack sprayer. The partially weedy check (*T*₈) received no herbicide and one hand weeding at 60 DAT. Treatment details are given in Table 1.

Crop growth observations were recorded at specified stages. Plant height was measured from ground level to the tip of the tallest fully expanded leaf or panicle-bearing portion and expressed in cm. Tillers were counted from a representative area and expressed as tillers m⁻². LAI was determined from sampled leaf area relative to the corresponding ground area. Crop dry matter was determined from representative plant samples dried to constant weight and expressed as g m⁻². CGR and RGR were calculated from dry matter observations at the respective sampling stages. CGR was calculated as $(W_2 - W_1)/(T_2 - T_1)$, where *W*₁ and *W*₂ are crop dry matter (g m⁻²) at times *T*₁ and *T*₂, respectively, and *T*₁ and *T*₂ are sampling dates in days. CGR was expressed as g m⁻² day⁻¹. RGR was calculated as $[\ln(W_2) - \ln(W_1)]/(T_2 - T_1)$ and expressed as mg g⁻¹ day⁻¹ after multiplying g g⁻¹ day⁻¹ values by 1000. At physiological maturity, representative plants were selected for yield-attribute observations. Effective tillers were expressed as m⁻²; panicle length was measured from base to tip in cm; filled and unfilled grains were counted per panicle; and test weight was recorded in g. At maturity, the net plot crop was harvested separately for each treatment, and grain and straw yields were recorded after threshing, cleaning and drying and expressed as t ha⁻¹.

Data were subjected to analysis of variance appropriate for RBD. Treatment means were compared using critical difference (CD) at 5% probability when the *F*-test was significant, and SEm (±) was calculated. Differences among non-significant treatment means were not interpreted as significant. Relationships between selected crop-growth and yield variables were examined using regression analysis based on treatment means. Statistical significance was assessed at *P* ≤ 0.05.

Table 1. Weed-management treatments imposed in transplanted rice

Treatment	Weed-management programme
<i>T</i> ₁	Pendimethalin + pyrazosulfuron ethyl 785 g ha ⁻¹ PE at 3 DAT fb florypyrauxifen-benzyl + cyhalofop-butyl 150 g ha ⁻¹ PoE at 20 DAT
<i>T</i> ₂	Pretilachlor + pyrazosulfuron ethyl 615 g ha ⁻¹ PE at 3 DAT fb florypyrauxifen-benzyl + cyhalofop-butyl 150 g ha ⁻¹ PoE at 20 DAT
<i>T</i> ₃	Pyrazosulfuron ethyl 22.5 g ha ⁻¹ PE at 3 DAT fb florypyrauxifen-benzyl + cyhalofop-butyl 150 g ha ⁻¹ PoE at 20 DAT
<i>T</i> ₄	Pendimethalin + pyrazosulfuron ethyl 785 g ha ⁻¹ PE at 3 DAT fb bispyribac sodium + chlorimuron ethyl + metsulfuron methyl 43 g ha ⁻¹ PoE at 20 DAT
<i>T</i> ₅	Penoxsulam + pendimethalin 625 g ha ⁻¹ PE at 3 DAT fb fenoxaprop-ethyl 67 g ha ⁻¹ + ethoxysulfuron 18 g ha ⁻¹ PoE at 20 DAT
<i>T</i> ₆	Florypyrauxifen-benzyl + cyhalofop-butyl 150 g ha ⁻¹ PoE at 20 DAT
<i>T</i> ₇	Bispyribac sodium + chlorimuron ethyl + metsulfuron methyl 43 g ha ⁻¹ PoE at 20 DAT
<i>T</i> ₈	Partially weedy check; hand weeding at 60 DAT

3. Results and discussion

Plant height

Plant height was significantly influenced by weed-management treatments at 60 DAT and harvest. At 60 DAT, values ranged from 91.13 to 109.48 cm, with the highest under *T*₃ (109.48 cm), followed by *T*₁ (106.54 cm), and the lowest under *T*₈ (91.13 cm); the CD was 7.73 cm. At harvest, plant height ranged from 120.58 to 140.14 cm, with *T*₃ recording the maximum (140.14 cm), followed by *T*₁ (136.29 cm) and *T*₄ (135.61 cm), while *T*₈ recorded 120.58 cm (CD 8.43 cm) (Table 2).

The greater height under effective weed-management treatments indicates reduced competition for nutrients, water, light and space during active crop growth. *T*₃ also maintained comparatively low weed density and dry matter, which corresponded with better crop growth. Similar improvement in plant growth under sequential herbicide programmes was reported by Choudhary *et al.* (2024) [8] and Shah *et al.* (2025) [9]. The results are also consistent with the established effect of weed competition on rice growth and the importance of timely suppression during critical growth periods (Mahajan *et al.*, 2014; Dass *et al.*, 2017) [2, 1]. The response appears to reflect improved growing conditions from weed suppression rather than a direct growth-promoting effect of the herbicides.

Number of tillers

Tiller number m^{-2} was significantly affected at 60 DAT and harvest. At 60 DAT, values ranged from 370.67 to 534.67 m^{-2} , with T_3 highest (534.67 m^{-2}), followed by T_1 (512.67) and T_4 (494.00), and T_8 lowest (370.67; CD 54.42). At harvest, T_3 again recorded the maximum (486.67 m^{-2}), followed by T_1 (466.00) and T_4 (443.33), whereas T_8 had the minimum (326.67; CD 46.95 m^{-2}) (Table.2). Reduced weed interference during vegetative development favoured tiller initiation and retention by reducing competition for nutrients, moisture and radiation. The superiority of T_3 was associated with comparatively lower weed density and dry matter, while persistent competition in T_8 produced fewer tillers. This agrees with the reported sensitivity of rice tillering to early weed competition (Mahajan *et al.*, 2014; Mamun, 2014; Dass *et al.*, 2017) [2, 3, 1] and with improved productive tiller formation under effective weed management in transplanted rice (Choudhary *et al.*, 2024) [8].

Leaf area index

LAI differed significantly at both stages. At 60 DAT, LAI ranged from 3.40 to 4.63, with T_3 highest (4.63), followed by T_4 (4.47) and T_1 (4.42), and T_8 lowest (3.40; CD 0.36). At harvest, LAI ranged from 3.10 to 4.47; T_3 recorded 4.47, followed by T_4 (4.35) and T_1 (4.13), while T_8 recorded 3.10 (CD 0.54) (Table.2). Greater LAI indicates better canopy development under reduced weed competition, permitting greater radiation interception. The well-developed canopy under T_3 was consistent with its lower weed density and dry matter and could also contribute to subsequent weed suppression through shading. Similar crop-growth responses to sequential herbicide programmes were reported by Choudhary *et al.* (2024) [8] and Shah *et al.* (2025) [9].

Crop dry matter accumulation

Dry matter accumulation was significantly influenced at both stages. At 60 DAT, values ranged from 643 to 1092 g m^{-2} , with T_3 highest (1092), followed by T_1 (998) and T_4 (931), and T_8 lowest (643; CD 166 g m^{-2}). At harvest, values ranged from 1062 to 1874 g m^{-2} , with T_3 maximum (1874), followed by T_1 (1723) and T_4 (1681), and T_8 minimum (1062; CD 217 g m^{-2}) (Table.2). Greater height, tiller production and LAI under T_3 provided a larger photosynthetically active canopy and greater biomass accumulation. Conversely, persistent weed pressure in T_8 restricted resource availability. Similar improvement in crop biomass under sequential herbicide treatments was reported by Shah *et al.* (2025) [9] and Choudhary *et al.* (2024) [8].

Crop growth rate

CGR was significantly affected during both growth intervals. During 60–90 DAT, CGR ranged from 9.67 to 18.86 $\text{g m}^{-2} \text{day}^{-1}$; T_3 recorded the highest (18.86), followed by T_4 (17.86) and T_1 (17.61), while T_8 recorded 9.67 (CD 3.14 $\text{g m}^{-2} \text{day}^{-1}$). From 90 DAT to harvest, CGR ranged from 6.42 to 10.82 $\text{g m}^{-2} \text{day}^{-1}$, with T_3 highest (10.82), followed by T_4 (10.72) and T_1 (9.84), and T_8 lowest (6.42; CD 2.00) (Table.3). The consistently greater CGR under T_3 reflects greater absolute biomass accumulation and agrees with its higher height, tillering, LAI and dry matter. Effective weed suppression reduces competition for light, nutrients, water and space, supporting biomass production during critical crop-growth periods (Knezevic *et al.*, 2015; Dass *et al.*, 2017) [6, 1]. Similar responses were reported by Choudhary *et al.* (2024) [8] and Shah *et al.* (2025) [9].

Relative growth rate

RGR did not differ significantly among treatments in either interval. During 60–90 DAT, RGR ranged from 12.59 to 15.09 $\text{mg g}^{-1} \text{day}^{-1}$, with T_4 numerically highest (15.09) and T_8 lowest (12.59). During 90 DAT to harvest, values ranged from 5.82 to 6.89 $\text{mg g}^{-1} \text{day}^{-1}$; T_4 was numerically highest (6.89) and T_7 lowest (5.82) (Table.3). Because these differences were non-significant, they should not be interpreted as treatment effects. The contrast between significant CGR and non-significant RGR suggests that weed management influenced

absolute biomass accumulation more strongly than the proportional rate of growth relative to existing biomass.

Effective tillers

Effective tillers m^{-2} were significantly influenced. T_3 recorded the highest number (392.00 m^{-2}), followed by T_1 (374.67) and T_4 (364.67), while T_8 recorded the lowest (255.33; CD 39.97 m^{-2}). Greater effective tiller formation under T_3 was consistent with its higher tiller population during earlier growth (Table.3). Effective weed suppression during vegetative development can favour tiller initiation and survival, whereas prolonged competition can reduce productive tillers. Balaji *et al.* (2024) [10] similarly reported higher productive tiller numbers under effective sequential PE→PoE herbicide management.

Panicle length

Panicle length was not significantly influenced. T_3 recorded the longest panicles (25.53 cm), followed by T_4 (24.91) and T_1 (24.35), while T_8 recorded the shortest (22.08 cm). Although better crop growth may have contributed to the numerical advantage under T_3 (Table.3), the non-significant response indicates insufficient statistical evidence for a treatment effect. Weed-management effects were more clearly expressed through tiller production, biomass accumulation and grain number.

Filled grains

Filled grains panicle⁻¹ were significantly influenced. T_3 recorded the highest number (163.00), followed by T_1 (152.67) and T_4 (146.00), whereas T_8 recorded the lowest (114.56; CD 20.00). Greater filled-grain number under T_3 can be related to its greater biomass, LAI and productive tiller development under reduced weed competition, providing more favourable conditions for reproductive development and grain filling (Table.3). Similar improvements in yield attributes under sequential weed management were reported by Choudhary *et al.* (2024) [8] and Balaji *et al.* (2024) [10].

Unfilled grains

Unfilled grains panicle⁻¹ were significantly influenced. T_3 recorded the lowest number (10.56), followed by T_4 (13.11) and T_5 (13.33), whereas T_8 recorded the highest (34.11; CD 3.98). The lower number under T_3 indicates better reproductive success under reduced weed competition, consistent with its greater crop biomass, LAI, effective tillers and filled grains (Table.3). Persistent weed interference in T_8 was associated with greater reproductive limitation, consistent with the reported effects of prolonged weed competition on crop resource acquisition and grain formation (Table.3) (Mahajan *et al.*, 2014; Mamun, 2014; Dass *et al.*, 2017) [2, 3, 1].

Test weight

Test weight was not significantly affected. T_3 recorded the highest numerical value (24.52 g), followed by T_1 (24.26 g) and T_4 (24.18 g), while T_8 recorded the lowest (23.26 g). Thus, the treatments did not substantially modify individual grain weight under the experimental conditions. The numerical advantage under T_3 should not be interpreted as a statistically established response; differences in yield formation were more closely associated with crop stand, effective tillers and filled grains (Table.3).

Overall interpretation

The results show a consistent association between weed suppression and crop growth. T_3 , which maintained comparatively low weed density and dry matter, recorded the highest values for plant height, tiller number, LAI, dry matter, CGR, effective tillers and filled grains, together with the fewest unfilled grains. T_8 generally recorded the poorest crop-growth and yield-component values and the greatest number of unfilled grains. These responses support the importance of reducing the intensity and duration of weed-crop interference during critical growth periods (Dass *et al.*, 2017; Knezevic *et al.*, 2015) [1, 6]. They are also consistent with recent evidence that sequential PE→PoE programmes can extend weed suppression and improve rice

growth and productivity (Choudhary *et al.*, 2024; Shah *et al.*, 2025) [8, 9]. Importantly, RGR, panicle length and test weight were non-significant, showing that treatment effects were expressed mainly through vegetative growth, biomass accumulation, CGR, productive tiller formation and grain filling rather than uniformly across all traits.

4. Summary

Weed-management treatments produced clear differences in crop growth and several yield attributes of transplanted rice. Plant height, tiller production, LAI and crop dry matter accumulation were significantly influenced at 60 DAT and harvest, with T_3 consistently recording the highest values and T_8 the lowest. At harvest, T_3 produced 140.14 cm plant height, 486.67 tillers m^{-2} , LAI of 4.47 and 1874 g m^{-2} crop dry matter, compared with 120.58 cm, 326.67 tillers m^{-2} ,

3.10 and 1062 g m^{-2} , respectively, under T_8 . CGR was also significantly higher under T_3 during 60–90 DAT and 90 DAT to harvest (18.86 and 10.82 g $m^{-2} day^{-1}$, respectively), whereas RGR did not differ significantly. Effective tillers and filled grains were highest under T_3 (392.00 m^{-2} and 163.00 panicle $^{-1}$), while T_8 recorded the lowest values (255.33 m^{-2} and 114.56 panicle $^{-1}$). Unfilled grains were lowest under T_3 (10.56 panicle $^{-1}$) and highest under T_8 (34.11 panicle $^{-1}$). Panicle length and test weight were not significantly affected. Overall, better weed suppression was associated with improved vegetative growth, biomass accumulation, productive tiller formation and grain filling. The consistent performance of T_3 across the significantly influenced traits indicates that the sequential programme of pyrazo-sulfuron ethyl followed by florasulfuron-benzyl + cyhalofop-butyl provided favourable conditions for crop growth under the experimental conditions.

Table 2. Effect of weed-management treatments on crop growth attributes of transplanted rice

Treatment	Plant height (cm)	Plant height (cm)	No. of tillers m^{-2}	No. of tillers m^{-2}	Leaf area index (LAI)	Leaf area index (LAI)	Dry matter accumulation (g m^{-2})	Dry matter accumulation (g m^{-2})
	60 DAT	At harvest	60 DAT	At harvest	60 DAT	At harvest	60 DAT	At harvest
T_1	106.54	136.29	512.67	466.00	4.42	4.13	998	1723
T_2	99.65	129.54	468.00	402.33	4.06	3.93	838	1429
T_3	109.48	140.14	534.67	486.67	4.63	4.47	1092	1874
T_4	104.51	135.61	494.00	443.33	4.47	4.35	931	1681
T_5	101.13	132.47	472.67	420.67	4.02	3.87	882	1513
T_6	96.77	125.30	426.00	378.67	3.79	3.32	717	1215
T_7	98.16	127.77	432.00	382.00	3.86	3.67	830	1389
T_8	91.13	120.58	370.67	326.67	3.40	3.10	643	1062
SEm ($\pm$)	2.55	2.78	17.94	15.48	0.12	0.18	55	72
CD($p \leq 0.05$)	7.73	8.43	54.42	46.95	0.36	0.54	166	217

Table 3. Effect of weed-management treatments on growth analysis and yield attributes of transplanted rice

Treatment	Crop growth rate (g $m^{-2} day^{-1}$)		Relative growth rate (mg $g^{-1} day^{-1}$)		Effective tillers m^{-2}	Panicle length (cm)	Filled grains panicle $^{-1}$	Unfilled grains panicle $^{-1}$	Test wt.
Treatment	60-90 DAT	90-At Harvest	60-90 DAT	90-At Harvest					
T_1	17.61	9.84	14.21	6.05	374.67	24.35	152.67	17.67	24.26
T_2	13.89	8.71	13.40	6.51	341.33	23.31	139.22	23.33	23.84
T_3	18.86	10.82	14.01	6.22	392.00	25.53	163.00	10.56	24.52
T_4	17.86	10.72	15.09	6.89	364.67	24.91	146.00	13.11	24.18
T_5	14.68	9.54	13.59	6.76	350.67	23.72	137.11	13.33	23.72
T_6	11.66	7.37	13.24	6.47	298.00	22.70	127.22	26.00	23.45
T_7	13.55	7.63	13.29	5.82	322.00	23.41	133.11	21.52	23.67
T_8	9.67	6.42	12.59	6.46	255.33	22.08	114.56	34.11	23.26
SEm ($\pm$)	1.04	0.66	1.01	1.38	13.18	1.26	6.60	1.31	1.07
CD($p \leq 0.05$)	3.14	2.00	NS	NS	39.97	NS	20.00	3.98	NS

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