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RESEARCH ARTICLE

Weed dynamics and crop productivity in kharif *rice* (*Oryza sativa* L.) under different establishment methods and herbicide treatments

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Abstract

The present study was conducted during the kharif season of 2024 at the Post Graduate Research Farm, M S Swaminathan School of Agriculture, Centurion University of Technology and Management, Paralakhemundi, Odisha. The objective was to evaluate the effect of herbicides on weed dynamics and crop productivity under different establishment methods. The experiment was laid out in a split-plot design with 2 main plots and 10 subplots, replicated thrice. The main plots consisted of 2 establishment methods: transplanted rice (TPR) and dry-seeded rice (DSR). Subplots included 5 weed management treatments: W_1 to W_5, comprising combinations of pre- and post-emergence herbicides, W4: hand weeding (HW) and a weedy check (W_5), using the test variety *RNR-15048*. TPR exhibited superior weed suppression (35 % higher WCE), improved growth, yield attributes and recorded 33 % higher yield over DSR. Among weed control treatments, W_3 (Pretilachlor 600 g ha^{-1} PE *fb* Pyrazosulfuron ethyl 10 % WP 20 g ha^{-1} at 20 DAT/S) was most effective, with 83–93 % weed control efficiency which was only 5–18 % less than HW. Though HW achieved the highest yield, W_3 registered the highest benefit-cost (B:C) ratio of 1.66, outperforming HW due to reduced labour dependency, which resulted in a 41 % lower B:C ratio in HW. Despite higher cultivation costs, TPR showed a 33 % higher B:C ratio than DSR. Thus, W_3 in either TPR or DSR is recommended as a labour-saving and cost-effective weed management strategy, especially vital amidst growing labour scarcity in Indian agriculture.

Keywords: crop productivity; growth study; establishment methods; herbicidal control; weed control efficiency

Introduction

Rice is the major food crop for most of the population, particularly in Asian countries. India is the second-largest producer of rice after China, contributing 26.4 % to the world's total rice production (1). The state of Odisha is one of the leading states in rice both in area (3.94 million hectares) and production (9.14 million tonnes) with a low productivity (2318 kg/ha). Moreover, in the Gajapati district of Odisha, rice is cultivated over 37.55 thousand hectares, producing 71.7 thousand tonnes, with a productivity of 1772 kg/ha, which is lower than the state average (2). The most popular method for growing rice in South and Southeast Asia is still traditional transplantation. However, labour shortages during transplanting seasons and postponed transplanting have led to lower yields and reduced revenues in several rice-growing nations. Rice producers are being forced to look into transplanting as an option due to a lack of irrigation water, a lack of farm workers and the rising cost of conventional transplanting in puddled soil (3). However, as an alternative, direct seeding is practiced successfully with few manipulations, depending on the geographic and agro-climatic conditions. Direct seeded rice (DSR) offers significant benefits over conventional transplanting methods, including reduced labour, time and water requirements (4), 25–30 % less reduction in methane emissions than puddled transplanted rice (5), sometimes comparable yield as well. However, severe weed infestations can lead to yield losses of up to 100 % in DSR (6), whereas transplanted rice (TPR) experiences an estimated yield loss of about 35 % (7). Additionally, it reduces labour and operational costs compared to manual weeding methods, thereby improving overall profitability (8). Among weed control approaches, chemical management is the most effective and economical for suppressing competing weeds (9). However, reliance on chemical weed control becomes more common; sometimes termed herbicidal farming (10). To manage the complex weed pressure, farmers often use pre-emergence (PE) and post-emergence (PoE) herbicides: e.g., PE herbicides like pendimethalin, oxadiargyl, pretilachlor, penoxsulam + pendimethalin; PoE herbicides like bispyribac-sodium, ethoxysulfuron, metsulfuron-methyl, etc (11, 12). Bispyribac-sodium is the major herbicide used under DSR-PSI (pre-sowing irrigation), while both pendimethalin and bispyribac-sodium dominate in DSR-IAS (irrigation after sowing); pretilachlor is common in PTR (puddled transplanted rice). Moreover, the DSR-PSI records fewer weeds than DSR-IAS, leading to lower herbicide dependence and herbicide consumption cost is lowest in PTR, but statistically similar to DSR-PSI and lower than DSR-IAS (13). Increasing weed pressure in DSR has led to heavier herbicide use, raising risks of environmental pollution and groundwater contamination. Studies report harmful impacts on ecosystems and non-target organisms, with global herbicide use rising from 42 % to 55 % in the last decade (14). Additionally, frequent application of a single herbicide can alter the weed population and lead to the development of herbicide resistance in weeds (15, 16). Hence, promoting the DSR-PSI method for reduced herbicide use and monitoring herbicide use in farmers' rice fields is essential to promote awareness and reduce excessive reliance on chemicals (13, 14). Integrating post-emergence herbicides with pre-emergence treatments can enhance overall weed control efficacy, leading to improved crop yields (17). This field study was planned to generate a comprehensive dataset on the efficacy of herbicides for weed control in TPR and DSR.

Materials and Methods

Experimental site and soil characteristics

During the kharif season, from July to November 2024, a field experiment was conducted to examine the effects of crop establishment methods and herbicide applications on weed dynamics and crop productivity of RNR-15048 variety. The experimental location was the Post Graduate Research Farm, M S Swaminathan School of Agriculture, Centurion University of Technology and Management, located at 18°53' N latitude and 84°17' E longitude in Paralakhemundi, Gajapati district, Odisha. The maximum temperature ranged from 34.3 °C to 31.2 °C and the minimum temperature ranged from 26.7 °C to 21.2 °C. A total rainfall of 46.35 mm was received during the rice growth cycle of rice in 2024. At the time of initiation of the experiment, the soil was sandy loam (75 % sand, 10 % silt and 15 % clay) and had 6.89 soil pH, 0.8 dS m^{-1} (EC), 0.49 % organic carbon, 196 kg ha^{-1} available nitrogen, 14 kg ha^{-1} available phosphorus and 125 kg ha^{-1} available potassium.

Experimental design and treatment details

The experiment was carried out in a split plot design with 2 main plots and 5 subplots replicated thrice. Two establishment methods, viz. T_1:TPR and T_2: DSR. Five weed management practices, viz. W_1:Pretilachlor 37 % EW 600 g ha^{-1} PE *fb* Fenoxaprop-p-ethyl 6.7 % EC 50 g ha^{-1} at 20 DAT/S; W_2: Pretilachlor 600 g ha^{-1} PE *fb* Ethoxysulfuron 15 % WDG 15 g ha^{-1} at 20 DAT/S; W_3: Pretilachlor 600 g ha^{-1} PE *fb* Pyrazosulfuron ethyl 10 % WP 20 g ha^{-1} at 20 DAT/S; W_4: Hand weeding at 20, 40 and 60 DAT/S and W_5: Weedy check were allocated to sub plots of split plot design respectively, in kharif rice with plot size 4.8 × 4 m.

Crop management

The semi-tall short duration variety RNR-15048 (Telengana Sona) was sown on July 5, 2024, in plots of DSR and on July 7, 2024, in the nursery bed for TPR. After 30 days seedlings were transplanted into the experimental field for TPR on August 7, 2024, using 2–3 seedlings per hill at a spacing of 20 × 15 cm. The applied fertilizer consisted of 100 kg ha^{-1} of nitrogen (N), 60 kg ha^{-1} of phosphorus (P) and 40 kg ha^{-1} potassium (K). This fertilizer regimen was employed, with an initial application of half of the N and full dose of P and K. The remaining portion of N was split into equal portions and applied at 30 and 45 DAT/S. Irrigation was applied at 27 DAS, 28 DAT and 67 DAT/S as required and herbicides were applied using a battery-operated knapsack sprayer. The weedy check plots were left untreated for weed control throughout the entire growth period. The DSR and TPR were harvested on November 7, 2024.

Observations and calculations

Data on weed density and dry weight were gathered at 2 different intervals, namely, 30 and 60 DAT/S. In each plot, a 0.25 m^2 quadrat was randomly employed for this purpose and the weeds within it were categorized into 3 groups: grasses, sedges and broadleaf weeds. The total weed population and the population within each group were quantified in terms of individuals per square meter (m^2). The weed samples were divided into categories and placed in paper bags. The samples were then dried, first in the shade, then in an oven at 65 °C for 24 hr. Next, the weeds' dry weight was calculated and presented as g m^{-2}. At various observation periods 30, 60 and 90 DAT/S as well as at the time of harvest, crop growth parameters, such as plant height, the number of tillers m^{-2}, dry matter accumulation (g m^{-2}) and leaf area index (LAI) were assessed. The number of panicles m^{-2}, the number of total spikelets per panicle, the number of filled spikelets per panicle and the test weight (1000-grain weight) were all yield-related measurements that were kept. Following crop harvest, grain, straw and biological yield were recorded to determine productivity, harvest index (HI) was computed using the formula specified in Eqn. 1

$$\text{Harvestindex (HI)} = \frac{\text{Economic yield}}{\text{Biological yield}} \times 100\ (\%) \quad \text{(Eqn. 1)}$$

Under economic parameters, cost of cultivation, gross return, net return and B:C ratio were calculated taking into consideration the prevailing costs of the region and minimum support price of 2024.

Statistical analysis

The collected data was statistically analyzed using the analysis of variance method 18 and the F value was calculated at a 5 % level of probability. The software used for statistical analysis was the OPSTAT statistical package for primary data interpretation and Python was utilized for advanced statistical analysis.

Results and Discussion

Weed density and weed dry weight

The major weed flora was *Echinochloa colona, Dactyloctenium aegyptium* and *Leptochloa chinensis* among grasses; *Cyperus difformis*, *Cyperus iria* and *Fimbristylis miliacea* among sedges; and *Eclipta prostrata*, *Physalis minima* and *Ludwigia parviflora* among broadleaf weeds. The data pertaining to weed density were presented in Table 1 and weed dry weight in Table 2. The results showed a significant difference between the effects of main plot treatments i.e., TPR and DSR on weed density at 30 DAT/S and dry matter at 60 DAT/S. In regards to total weed

Table 1. Effect of weed management on weed density under different establishment methods in kharif rice, 2024

Treatments	Weed density (no. m^{-2}) at 30 DAT/S			
	Grasses	Sedges	broadleaf	Total
Methods of establishment (E)				
TPR	2.12 (3.99)	1.66 (2.24)	1.87 (3.00)	3.12 (9.23)
DSR	3.88 (14.55)	2.77 (7.17)	3.26 (10.13)	5.69 (31.88)
S.Em.±	0.07	0.13	0.10	0.12
CD (P=5 %)	0.45	0.80	0.58	0.75
Weed management (W)				
Pretilachlor PE *fb* FPE	1.59 (2.03)	3.05 (8.8)	3.18 (9.61)	4.58 (20.48)
Pretilachlor PE *fb* ES	2.84 (7.57)	1.89 (3.07)	1.30 (1.19)	3.51 (11.82)
Pretilachlor PE *fb* PZS	2.63 (6.42)	1.58 (2.00)	1.51 (1.78)	3.27 (10.19)
HW at 20,40 and 60 DAT/S	1.38 (1.4)	1.60 (2.06)	1.89 (3.07)	2.90 (7.91)
Weedy check	6.55 (42.4)	3.69 (13.12)	5.77 (32.79)	9.42 (88.24)
S.Em.±	0.18	0.26	0.15	0.24
CD (P=5 %)	0.54	0.77	0.45	0.72
Interaction (E×W)				
S.Em.±	0.26	0.36	0.25	0.34
CD (P=5 %)	NS	NS	0.76	NS

*DAT: Days after transplanting; DAS: Days after sowing; FPE: Fenoxaprop-p-ethyl; ES: Ethoxysulfuron; PZS: Pyrazosulfuron-ethyl; HW: Hand

Table 2. Effect of weed management on weed dry weight under different establishment methods in kharif rice, 2024

Treatments	Weed dry weight (g m^{-2}) at 60 DAT/S			
	Grasses	Sedges	Broadleaf	Total
Establishment method (E)				
TPR	3.68 (13.02)	2.85 (7.63)	3.61 (12.55)	5.80 (33.2)
DSR	5.84 (33.55)	4.19 (17.08)	5.65 (31.40)	9.08 (82.04)
S.Em.±	0.12	0.10	0.12	0.34
CD (P=5 %)	0.74	0.60	0.75	2.09
Weed management (W)				
Pretilachlor PE *fb* FPE	2.97 (8.35)	4.93 (23.76)	6.56 (42.56)	8.67 (74.67)
Pretilachlor PE *fb* ES	5.17 (26.18)	3.76 (13.66)	2.66 (6.57)	6.85 (46.41)
Pretilachlor PE *fb* PZS	4.37 (18.63)	2.60 (6.28)	3.51 (11.83)	6.10 (36.73)
Hand weeding at 20,40 and 60 DAT/S	1.22 (0.98)	0.93 (0.37)	1.23 (1.00)	1.69 (2.36)
Weedy check	10.05 (100)	5.39 (28.5)	9.19 (84.01)	14.61 (213)
S.Em.±	0.26	0.22	0.19	0.37
CD (P=5 %)	0.79	0.67	0.58	1.10
Interaction (E×W)				
S.Em.±	0.37	0.32	0.27	0.52
CD (P=5 %)	1.12	NS	0.82	1.56

*DAT: Days after transplanting; DAS: Days after sowing; FPE: Fenoxaprop-p-ethyl; ES: Ethoxysulfuron; PZS: Pyrazosulfuron-ethyl; HW: Hand weeding

density, the treatment HW at 20, 40 and 60 DAT/S (7.91 m^{-2}) was statistically at par with pretilachlor 600 g ha^{-1} PE *fb* pyrazosulfuron ethyl 10 % WP 20 g ha^{-1} at 20 DAT/S (10.19 m^{-2}) and pretilachlor 600 g ha PE *fb* ethoxysulfuron 15 % WDG 15 g ha^{-1} at 20 DAT/S (11.82 m^{-2}) treatments. The weedy check recorded the highest total weed density (88.24 m^{-2}).

The treatment HW at 20, 40 and 60 DAT/S administered significantly lowest total weed dry weight (2.36 g m^{-2}). However, statistically comparable weed dry weight was registered in treatments pretilachlor 37 % EW 600 g ha^{-1} PE *fb* pyrazosulfuron ethyl 10 % WP 20 g ha^{-1} at 20 DAT/S (36.73 g m^{-2}) and pretilachlor 37 % EW 600 g ha^{-1} PE *fb* ethoxysulfuron 15 % WDG 15 g ha^{-1}at 20 DAT/S (46.41 g m^{-2}) treatments.

Among all herbicidal treatments, pretilachlor 37 % EW at 600 g ha^{-1} PE *fb* fenoxaprop-p-ethyl 6.7 % EC at 50 g ha^{-1} applied at 20 DAT/S recorded the lowest density of grasses (8.00 m^{-2}). Pretilachlor 37 % EW 600 g ha^{-1}PE *fb* pyrazosulfuron-ethyl 10 % WP at 20 g ha^{-1} applied at 20 DAT/S was the most effective in reducing the density of sedges (6.01 m^{-2}). This treatment was statistically at par with pretilachlor 600 g ha^{-1} 37 % EW PE *fb* ethoxysulfuron 15 % WDG at 15 g ha^{-1} (9.67 m^{-2}) and pretilachlor 37 % EW 600 g ha^{-1} PE *fb* fenoxaprop-p-ethyl 50 g ha^{-1} (22.82 m^{-2}). For broadleaf weeds, the lowest density (5.54 m^{-2}) was recorded with pretilachlor 37 % EW 600 g ha^{-1} PE *fb* ethoxysulfuron 15 % WDG at 15 g ha^{-1}applied at 20 DAT/S. Similar trend was followed in weed dry weight.

The sequential application of pretilachlor (pre-emergence) followed by fenoxaprop-p-ethyl (post-emergence) effectively controlled grasses because pretilachlor inhibits cell division during early weed germination, while fenoxaprop-p-ethyl targets acetyl-CoA carboxylase (ACCase) in emerged grassy weeds, ensuring season-long control (19, 20). The application of pretilachlor (pre-emergence) followed by pyrazosulfuron-ethyl (post-emergence) effectively controls sedges because Pretilachlor suppresses early weed emergence, including some sedges, by disrupting mitosis, while pyrazosulfuron-ethyl, a sulfonylurea herbicide, specifically inhibits acetolactate synthase (ALS), an enzyme crucial for sedge growth and development (21). The sequential application of pretilachlor (pre-emergence) followed by ethoxysulfuron (post-emergence) effectively controls broadleaf weeds because pretilachlor inhibits early weed germination, while ethoxysulfuron, an ALS-inhibitor, specifically targets broadleaf and sedge species by blocking essential amino acid synthesis (22).

Plant growth parameters

Data pertaining to growth parameters like number of tillers m^{-2}, dry matter accumulation and LAI as affected by the application of herbicides under different establishment methods were presented in Table 3.

The highest number of tillers was observed for TPR, which was significantly superior to dry seeded rice. In the TPR method, puddling increased the number of tillers by fostering a favourable environment for root growth and nutrient uptake. In contrast, DSR that does not puddle produced fewer tillers because of inadequate water retention and nutrient leaching. Moreover, nutrients like nitrogen and the availability of water, particularly during the tillering stage, were important factors in tiller production. This explains why, in contrast to the dry seeding method, the TPR method showed the greatest number of tillers m^{-2}. Among the weed management options, the highest number of tillers m^{-2} was recorded under hand weeding at 20, 40 and 60 DAT/S, producing 333 and 283 tillers m^{-2} at 60 and 90 DAT/S respectively. This treatment was statistically at par with pretilachlor 600 g ha^{-1} PE followed by pyrazosulfuron-ethyl 10 % WP at 20 g ha^{-1} applied at 20 DAT/S, which resulted in 301 and 270 tillers m^{-2} at 60 and 90 DAT/S, respectively. It was also comparable to pretilachlor 600 g ha^{-1} PE followed by ethoxysulfuron 15 % WDG at 15 g ha^{-1} applied at 20 DAT/S, which produced 264 tillers m^{-2} at 90 DAT/S only. Among all herbicidal treatments, the highest number of tillers was found under pretilachlor 600 g ha^{-1} PE *fb* pyrazosulfuron ethyl 10 % WP 20 g ha^{-1} at 20 DAT/S, which was statistically at par with the other 2 herbicidal treatments across all observation periods. The highest number of tillers m^{-2} was found in HW at 20, 40 and 60 DAT/S at all observation periods. Due to less weed competition, which allowed the crops to absorb the necessary amount of nutrients, water and sunlight for its growth and tillering, there were more tillers in the pretilachlor 600 g ha^{-1} PE *fb* pyrazosulfuron ethyl 10 % WP 20 g ha^{-1} at 20 DAT/S treatment among all herbicidal treatments. This treatment resulted in a comparable number of tillers m^{-2} to the hand weeding treatment. This is in agreement with the findings of previous study (23).

Significant differences between main plot treatments (TPR and DSR) were observed at all observation periods. In case of dry matter accumulation, results showed that the highest dry matter accumulation was observed under HW at 20, 40 and 60 DAT/S (709 $m^{-2}$and 939 m^{-2}at 60 and 90 DAT/S respectively), which was statistically at par with pretilachlor 600 g ha^{-1} PE *fb* pyrazosulfuron ethyl 10 % WP 20 g ha^{-1} at 20 DAT/S (676 g $m^{-2}$and 900 g m^{-2}respectively). Among all herbicidal treatments, the treatment with the highest dry matter accumulation, pretilachlor 600 g ha^{-1} PE *fb* pyrazosulfuron ethyl 10 % WP 20 g ha^{-1} at 20 DAT/S, was statistically at par with the other 2 herbicidal treatments in the TPR method only, which may be due to efficacy of herbicides pronounced similar effect in TPR only rather than dry DSR.

LAI is higher in the TPR method because the rice plants were grown under a well-spaced environment due to lower weed population, hence resulting in healthier establishment quickly, allowing for better leaf expansion. This resulted in more leaf surface area per unit ground area compared to the DSR method. Among weed management options results showed that the highest LAI value was observed from the HW at 20, 40 and 60 DAT/S (4.34 and 3.53, respectively at 60 and 90 DAT/S). Moreover, it was statistically at par with pretilachlor 37 % EW 600 g ha^{-1} PE *fb* pyrazosulfuron ethyl 10 % WP 20 g ha^{-1} at 20 DAT/S (4.20, 3.40, at 60 and 90 DAT/S respectively) and with pretilachlor 600 g ha^{-1} PE *fb* ethoxysulfuron 15 %WDG 15 g ha^{-1} at 20 DAT/S (4.11 at 90 DAT/S only). The treatment weedy check recorded the lowest LAI value (3.88 and 2.91, at 60 and 90 DAT/S respectively). Pretilachlor 37 % EW 600 g ha^{-1} PE *fb*

Table 3. Effect of weed management on dry matter accumulation and LAI under different establishment methods in kharif rice, 2024

Treatments	Number of tillers (m^{-2})		Dry matter accumulation (g m^{-2})		LAI	
	60 DAT/S	90 DAT/S	60 DAT/S	90 DAT/S	60 DAT/S	90 DAT/S
Methods of establishment (E)						
TPR	321	286	675	907	4.74	3.41
DSR	264	240	535	721	3.45	3.04
S.Em.±	6	7	15	21	0.12	0.06
CD (P=5 %)	34	43	89	128	0.73	0.38
Weed management (W)						
Pretilachlor PE *fb* FPE	285	261	623	836	3.97	3.04
Pretilachlor PE *fb* ES	294	264	628	845	4.11	3.24
Pretilachlor PE *fb* PZS	301	270	676	900	4.20	3.40
HW at 20,40 and 60 DAT/S	333	283	709	939	4.34	3.53
Weedy check	250	236	390	551	3.88	2.91
S.Em.±	9	8	15	21	0.10	0.08
CD (P=5 %)	26	24	44	63	0.29	0.25
Interaction (E×W)						
S.Em.±	12	11	21	30	0.14	0.12
CD (P=5 %)	37	NS	62	NS	NS	0.35

*DAT: Days after transplanting; DAS: Days after sowing; FPE: Fenoxaprop-p-ethyl; ES: Ethoxysulfuron; PZS: Pyrazosulfuron-ethyl; HW: Hand weeding

pyrazosulfuron ethyl 10 % WP 20 g ha^{-1} at 20 DAT/S treatment, grown up with a comparable LAI with HW and weeding treatment due to the production of a higher number of leaves, which increased total photosynthetic surface with an increase in the form of leaf area and secondly due to increased availability of nitrogen, which resulted in larger leaves due to lower weed competition for nutrients (24). All of the sequential herbicide applications employed in the experiment demonstrated a considerable reduction in weed density and weed growth when compared to the weedy check. Biomass, exhibited superior broad-spectrum weed management. Dry matter accumulation, comprising plant height, tiller number and LAI, contributed to photosynthesis and crop development. These growth processes are influenced by the availability of essential resources including space, water and nutrients, among others (25, 26). Crop-weed competition for growth resources during the critical period decreased as a result of the decline in the weed population.

Yield attributes and yield

There is a significance difference between the crop yield parameters for main plot treatments i.e. TPR and DSR. The data pertaining to yield attributes and yield are presented in Table 4. The maximum number per panicle was observed from HW at 20, 40 and 60 DAT/S (228) which was statistically at par with pretilachlor 600 g ha^{-1} PE *fb* pyrazosulfuron ethyl 10 % WP 20 g ha^{-1} at 20 DAT/S (214). The treatment weedy check recorded the lowest number of panicles m^{-2} (171). The interaction between establishment methods and weed management was found to be significant with respect to the number of panicles m^{-1} at harvest. In TPR the highest number of panicles m^{-2}was found in pretilachlor 600 g ha^{-1}PE *fb* pyrazosulfuron ethyl 10 % WP 20 g ha^{-1}at 20 DAT/S (236), which was statistically at par with pretilachlor 600 g ha^{-1}PE *fb* ethoxysulfuron 15 % WDG 15 g ha^{-1}at 20 DAT/S (236), pretilachlor 37 % EW 600 g ha^{-1}PE *fb* fenoxaprop-p-ethyl 6.7 % EC 50 g ha^{-1} at 20 DAT/S (231) and HW at 20, 40 and 60 DAT/S (231). For DSR, HW at 20, 40 and 60 DAT/S had the maximum number of panicles m^{-2} (225) and among all herbicidal treatments, the highest number of panicles m^{-2} was found under pretilachlor 600 g ha^{-1} PE *fb* pyrazosulfuron ethyl 10 % WP 20 g ha^{-1}at 20 DAT/S (191), which was statistically at par with pretilachlor 37 % EW 600 g ha^{-1}PE *fb* fenoxaprop-p-ethyl 6.7 % EC 50 g ha^{-1}at 20 DAT/S (187) and pretilachlor 600 g ha^{-1}PE *fb* ethoxysulfuron 15 % WDG 15 g ha^{-1}at 20 DAT/S (177). In case of test weight, the highest test weight was observed from pretilachlor 37 % EW 600 g ha^{-1} PE *fb* fenoxaprop-p-ethyl 6.7 % EC 50 g ha^{-1}at 20 DAT/S (17.4 g) and lowest was recorded from pretilachlor 600 g ha^{-1} PE *fb* pyrazosulfuron ethyl 10 % WP 20 g ha^{-1} at 20 DAT/S (16.9 g).

In case of grain yield, there is a significant difference between the crop yield for main plot treatments i.e., TPR and DSR. The maximum grain yield was obtained for HW at 20, 40 and 60 DAT/S which was statistically at par with pretilachlor 600 g ha^{-1} PE *fb* pyrazosulfuron ethyl 10 % WP 20 g ha^{-1} at 20 DAT/S (4.69 t ha^{-1}). The treatment weedy check recorded the lowest grain yield (2.53 t ha^{-1}). Due to uncontrolled weed growth and highest crop-weed competition, the lowest grain yield was observed from pretilachlor 37 % EW 600 g ha^{-1}PE *fb* fenoxaprop-p-ethyl 6.7 % EC 50 g ha^{-1}at 20 DAT/S among all the herbicidal treatments and grain yield was 13 %, 9 % and 4 % lower in comparison to HW at 20, 40 and 60 DAT/S, pretilachlor 600 g ha^{-1}PE *fb* pyrazosulfuron ethyl 10 % WP 20 g ha^{-1} at 20 DAT/S and pretilachlor 600 g ha^{-1}PE *fb* ethoxysulfuron 15 % WDG 15 g ha^{-1} at 20 DAT/S respectively. In the interaction effect, the highest grain yield was recorded under HW at 20, 40 and 60 DAT/S in both establishment methods, in TPR (5.22 t ha^{-1}) and in DSR (4.15 t ha^{-1}). In the TPR method, it was statistically at par with the rest of the herbicidal treatments. However, in the DSR method, only the treatment of pretilachlor 600 g ha^{-1}PE *fb* pyrazosulfuron ethyl 10 % WP 20 g ha^{-1}at 20 DAT/S (3.87 t ha^{-1}) showed comparable grain yield with the same HW at 20, 40 and 60 DAT/S. In the DSR method, among all herbicidal treatments, pretilachlor 600 g ha^{-1}PE *fb* pyrazosulfuron ethyl 10 % WP 20 g ha^{-1}at 20 DAT/S (3.87 t ha^{-1}) was not statistically at par with pretilachlor 37 % EW 600 g ha^{-1}PE *fb* fenoxaprop-p-ethyl 6.7 % EC 50 g ha^{-1} at 20 DAT/S (3.26 t ha^{-1}). Among all herbicidal treatments, the highest HI value was found in pretilachlor 600 g ha^{-1}PE *fb* ethoxysulfuron 15 % WDG 15 g ha^{-1}at 20 DAT/S (43.17 %) and pretilachlor 600 g ha^{-1}PE *fb* pyrazosulfuron ethyl 10 % WP 20 g ha^{-1}at 20 DAT/S had the lowest HI value (42.94 %).

The strong weed control, which lowered the crucial crop-weed competition, may be the cause of the treatments exhibiting high crop growth characteristics. Conversely, due to intense crop weed competition, development was severely impeded in weedy check, leading to the lowest yield (27). Because there was no competition, the weed-free check had the highest growth, grain yield and HI.

Table 4. Effect of weed management on yield attributes and yield under different establishment methods in kharif rice, 2024

Treatments	Panicles m^{-2}	Test weight (g)	Grain yield (t ha^{-1})	HI (%)
Method of establishments (E)				
Transplanted rice	225	17.5	4.59	43.33
Dry seeded rice	186	17.0	3.44	42.32
S.Em.±	6	3.7	0.11	-
CD (P=5 %)	36	NS	0.69	-
Weed management (W)				
Pretilachlor PE *fb* FPE	209	17.4	4.06	43.01
Pretilachlor PE *fb* ES	206	17.3	4.32	43.17
Pretilachlor PE *fb* PZS	214	16.9	4.46	42.94
HW at 20, 40 and 60 DAT/S	228	17.2	4.69	43.45
Weedy check	171	17.4	2.53	41.19
S.Em.±	5	0.8	0.12	-
CD (P=5 %)	16	NS	0.37	-
Interaction (E×W)				
S.Em.±	7	1.2	0.17	-
CD (P=5 %)	22	NS	0.52	-

*DAT: Days after transplanting; DAS: Days after sowing; FPE: Fenoxaprop-p-ethyl; ES: Ethoxysulfuron; PZS: Pyrazosulfuron-ethyl; HW: Hand weeding

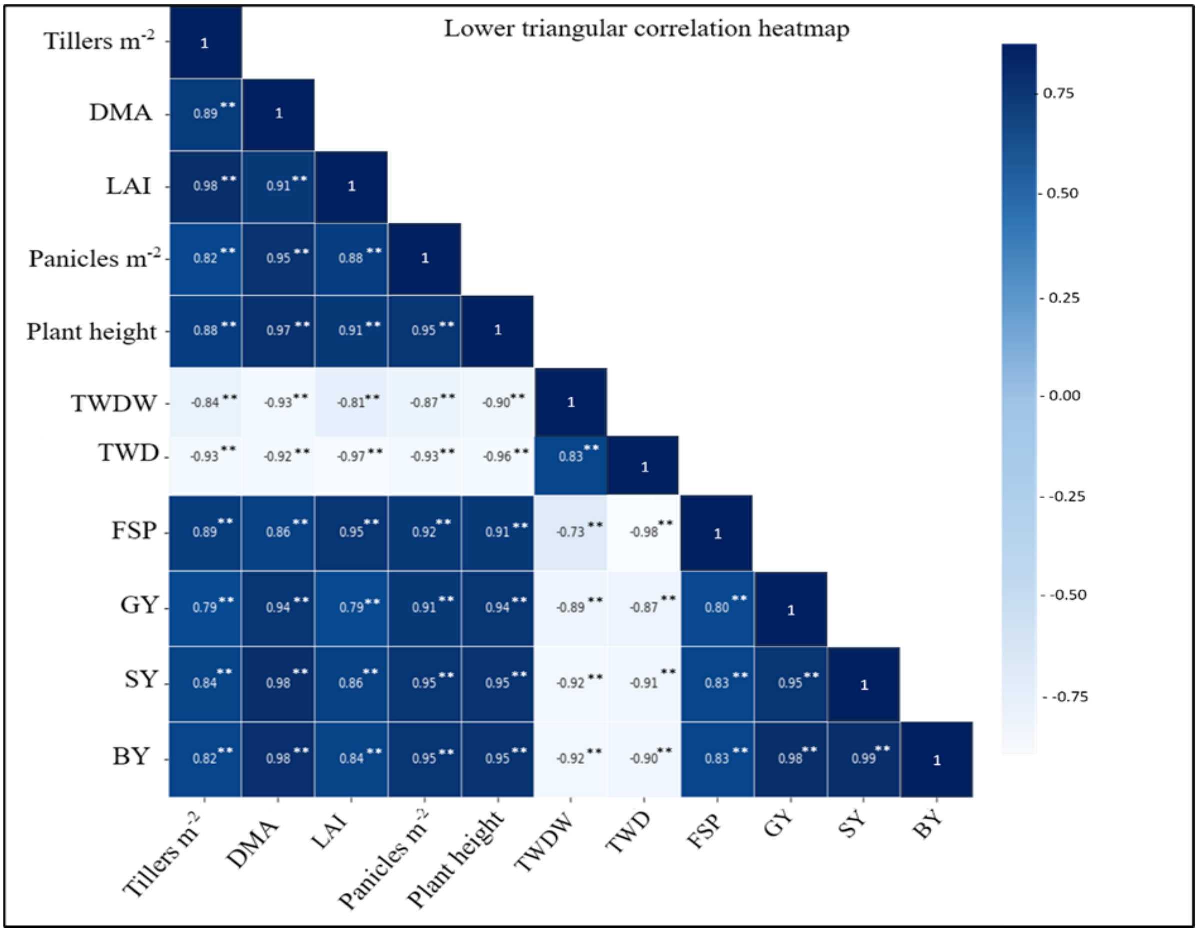

Fig. 1. Lower triangular correlation heatmap depicting the pairwise Pearson correlation coefficients between various agronomic traits and yield-related components.

Statistical interpretation

Correlation analysis of agronomic traits and their relationship with yield components

A correlation matrix (Fig. 1) was generated to understand the degree and direction of linear relationships among key agronomic traits i.e., tillers m^{-2}, dry matter accumulation (g m^{-2}), LAI, plant height, total weed dry weight (g m^{-2}), total weed density (no. m^{-2}), panicles m^{-2}, filled spikelets per panicle and their influence on yield (in terms of grain, straw and biological yield) in kharif rice grown under transplanted and dry direct-seeded conditions.

The correlation matrix explicated the findings in 3 dimensions as follows:

⇒ **Strong positive correlation with yield:**

Dry matter accumulation (r = 0.94), panicles m^{-2} (r = 0.91), plant height (r = 0.94) and filled spikelets per panicle (r = 0.91) all show strong positive correlations with grain yield. These results indicate that increases in these traits are typically associated with increased yield, making them critical components of crop productivity under both rice establishment methods.

⇒ **Weed dynamics show negative correlations:**

As weeds act as pests to crop, it shows negative correlations with crop productivity. Total weed dry weight is negatively correlated with yield (r = -0.89) while total weed density is strongly negatively correlated with key agronomic traits such as LAI (r = -0.97), plant height (r = -0.93) and filled spikelets (r = -0.98).Similarly, these findings emphasize that higher weed pressure significantly reduces plant growth and reproductive efficiency, ultimately lowering yield.

⇒ **Highly interrelated productivity traits:**

Many traits, including dry matter accumulation, LAI, plant height and straw yield, are strongly positively correlated with each other (r > 0.90 in most cases), indicating a tight physiological linkage among vegetative growth parameters. Biological yield is almost perfectly correlated with straw yield (r = 0.99) and grain yield (r = 0.95), suggesting that treatments with robust biomass also contribute to higher grain production.

⇒ **Critical trait for yield selection:**

Among all traits, filled spikelets per panicle (r = 0.91) and dry matter accumulation (r = 0.94) emerged as significant direct contributors to grain yield, while total weed dry weight and density emerged as the detrimental factors.

The correlation heatmap highlights the multivariate interdependence among yield-related traits, revealing that dry matter accumulation, LAI, tillering ability and reproductive traits such as filled spikelets per panicle are positively associated with grain yield. On the contrary, weed dynamics negatively influenced yield. These insights underlined the necessity for integrated weed management and trait-focused selection to enhance productivity under both transplanted and dry direct-seeded rice systems.

Regression analysis of agronomic traits and their relationship with grain yield

i) Total weed dry weight vs grain yield

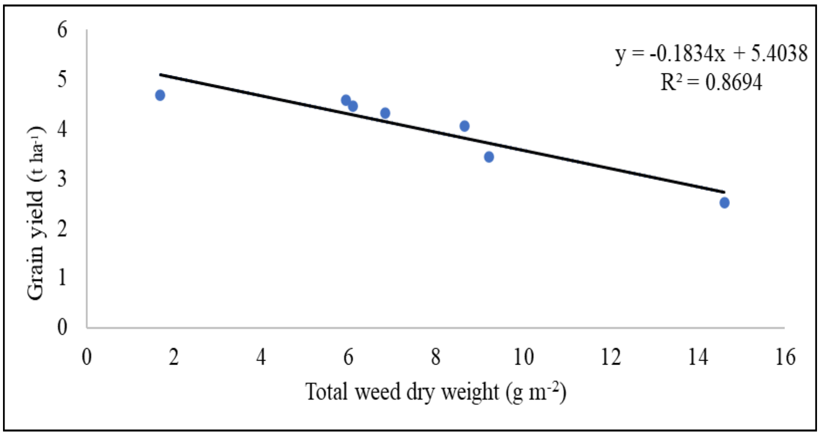

Fig. 2. Linear regression describing the relationship between total weed dry weight (g m^{-2}) and grain yield (t ha^{-1}).

A significant negative linear relationship was observed between weed dry weight and grain yield (Fig. 2), with a coefficient of determination (R^2) of 0.869, indicating that approximately 87 % of the variation in yield can be explained by weed biomass. The regression equation (y = -0.183x + 5.403) suggests that for every 1 g m^{-2} increase in weed dry weight, grain yield decreases by 0.183 t ha^{-1}.

ii) Total weed density vs LAI

Fig. 3 demonstrates a strong negative linear relationship between total weed density and LAI. As weed density increases, the LAI decreases significantly, indicating a competitive suppression effect of weeds on crop canopy development. Weed density accounts for 93.25 % of the variation in LAI of the crop. The steep negative slope (–4.3998) and high R^2 indicates a strong inhibitory effect of weed density on LAI.

iii) Panicles m^{-2} vs grain yield

The graph (Fig. 4) depicts a strong positive linear relationship between panicle density (panicles m^{-2}) and grain yield. The regression equation with positive slope (0.0311) and high R^2 value (0.8306) indicates a strong positive influence of panicle density on yield, such that an increase in 1 panicle m^{-2}, grain yield of 0.03 t ha^{-1} will be increased, explaining approximately 83 % of the variation in grain yield.

Multiple linear regression analysis (using original variables)

A multiple linear regression model was developed to assess the direct relationships of 8 independent variables with the dependent variable, grain yield. The model explains 99.75 % of variability in grain yield. Dry matter accumulation (t = 4.10), LAI (t = -5.16) and filled spikelets per panicle (t = 2.99) had relatively high t-stats, showing stronger effects. However, due to a very high *p* value, it is statistically non-significant. Moreover, many predictors have high standard errors and wide confidence intervals indicating multicollinearity. Thus, although the regression model using the original independent variables showed a high R^2, the coefficients were unstable and inflated due to multicollinearity. To reduce dimensionality and avoid multicollinearity, principal component analysis (PCA) was subsequently performed.

PCA for independent variables

PCA has been performed using the 8 independent variables showing PCA loadings (Table 5) and eigenvalues of all principal components (PCs) (Table 6).

The above analysis has been depicted in graphs representing PCA biplot and scree plot.

PCA biplot

PCA was performed to reduce the dimensionality of the dataset and to identify the most influential variables contributing to yield variability by adopting weed management options under different establishment methods in kharif rice. As PC1 explained 91.55 % of the variance which leads to a strong reduction in dimensionality and as PC2 explained 4.5 % of it, together explained around 96 % of variance, a biplot (Fig. 5) between PC1

Table 5. PCA loadings for selection of eight independent variables

	PC1	PC2	PC3	PC4	PC5	PC6	PC7	PC8
tillers	-0.35	0.21	0.63	-0.02	0.01	-0.03	0.66	-0.08
Tillers m^{-2}	-0.36	-0.31	-0.04	-0.18	0.69	-0.12	-0.02	0.50
Dry matter accumulation	-0.36	0.32	0.31	-0.29	0.16	0.22	-0.63	-0.34
LAI	-0.35	-0.15	-0.53	-0.54	-0.12	-0.06	0.29	-0.42
Plant height	-0.36	-0.14	-0.22	0.71	0.24	0.32	0.05	-0.36
Total weed dry weight	0.33	0.66	-0.28	-0.02	0.55	-0.10	0.20	-0.15
Total weed density	0.36	-0.24	0.10	-0.28	0.18	0.81	0.19	-0.03
Filled spikelets per pani-	-0.35	0.47	-0.30	0.01	-0.31	0.42	0.05	0.54
Panicle m^{-2}								

Table 6. Eigenvalues and explained variance ratio

	PC	Explained variance ratio	Eigen values
0	PC1	0.92	8.14
1	PC2	0.04	0.40
2	PC3	0.03	0.25
3	PC4	0.01	0.05
4	PC5	0.00	0.04
5	PC6	0.00	0.01
6	PC7	0.00	0.00
7	PC8	0.00	0.00

Table 7. Multiple linear regression model

SUMMARY OUTPUT (Grain Yield)				
Regression Statistics				
Multiple R	0.999			
R square	0.998			
Adjusted R square	0.978			
Standard error	0.155			
Observations	10.000			
	Coefficients	*Standard Error*	*t Stat*	*P-value*
Intercept	20.68	10.61	1.95	0.30
Tillers m^{-2}	0.07	0.03	2.07	0.29
Dry matter accumulation	0.02	0.01	4.10	0.15
LAI	-13.58	2.63	-5.17	0.12
Plant height	-0.13	0.05	-2.83	0.22
Total weed dry weight	-0.07	0.09	-0.76	0.58
Total weed density	-0.49	0.31	-1.61	0.35
Filled spikelets per panicle	0.17	0.06	2.99	0.21
Panicle m^{-2}	-0.07	0.03	-2.15	0.28

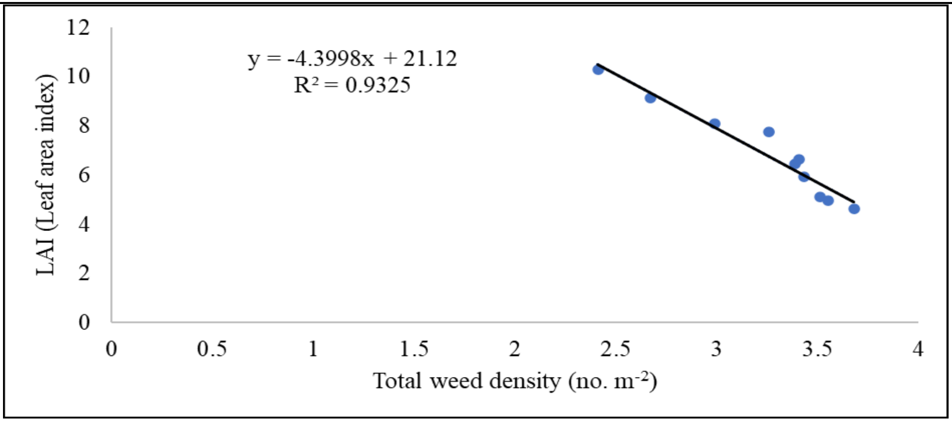

Fig. 3. Linear regression between total weed density (no. m^{-2}) and LAI of crop.

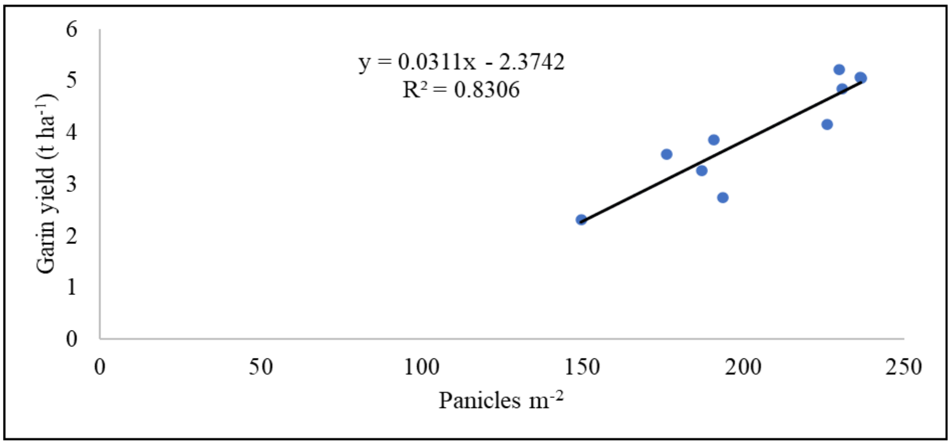

Fig. 4. Linear regression between panicles m^{-2} and grain yield (t ha^{-1}).

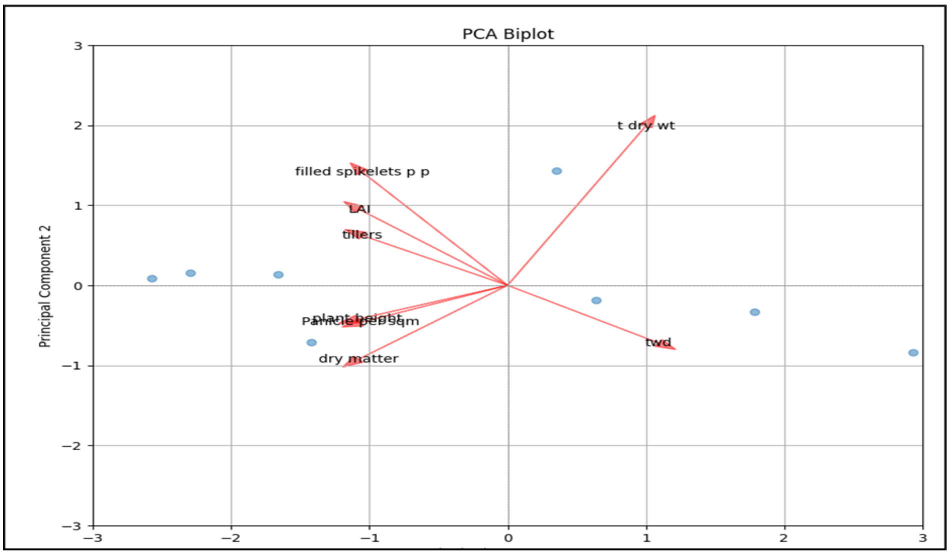

Fig. 5. PCA Biplot between principal component 1 (PC1) and principal component 1 (PC2) for agronomic and yield-attributes variables.

and PC2 was generated. The biplot visually represents the relationship between the variables and the PCs, as well as the distribution of treatments/samples in the reduced PCA space and this PCA biplot highlights the primary agronomic and weed-related traits driving variability under transplanted and dry direct -seeded rice systems (Table 7). The findings suggest that variables such as total dry weight (t dry wt.) and total weed density (TWD) show the strongest influence on the PCA space, indicated by the longer arrows, reflecting a high contribution to the overall variability among treatments. LAI, tillers m^{-2} and filled spikelets per panicle show moderate contributions, aligning closely with PC2 and partially with PC1. Variables like dry matter accumulation, panicles per sqm (panicles m^{-2}) and plant height contribute more subtly and cluster together, indicating positive correlations among them. TWD is oriented opposite to grain yield -related traits (like filled spikelets), suggesting a negative correlation between weed biomass and yield components. The separation of treatments in the PCA space (blue dots) implies variation in performance based on herbicide efficacy and establishment methods, supporting the multivariate structure of the dataset.

PCA: Scree plot

PCA was employed to identify patterns in the multivariate dataset and to reduce dimensionality while retaining the most significant information. A scree plot was generated to visualize the proportion of variance explained by each PC, as shown in Fig. 6. The first PC (PC1) accounts for the majority of the variance in the dataset, approximately 90 %, with a steep drop-off in variance explained by subsequent components.

The dominance of PC1 in explaining the variance implies that a single latent factor, most likely related to the combined effect of agronomic traits and weed competition which drives the major differences among treatments or genotypes. The limited contribution of PC2 and other components suggests that the remaining variability is relatively minor and may represent noise or less critical variations. Therefore, PC1 represents a general size/biomass component combining all variables. Using PC1 as a predictor, regression analysis was performed for grain yield.

PCA regression (using PC1 as predictor)

Given that PC1 captures over 80 % of the total variance (as supported by the regression output showing a high R^2 value of 0.8186 between PC1 and grain yield) (Table 8), it can be considered a composite index summarizing the key traits influencing grain yield performance under different establishment conditions. F = 36.11 (p = 0.00032) i.e., highly significant, PC1 is a strong predictor of grain yield.

As original multiple regression showed high R^2 but unstable, inflated coefficients due to multicollinearity, PCA helped compress the 8 independent variables into 1 PC (PC1) that retains > 91 % of the variance and PCA regression using PC1 significantly predicted grain yield with high explanatory power of 82 % and stable coefficients.

The graph (Fig. 7) illustrates a significant negative linear relationship between the first PC (PC1) and grain yield. The negative slope (–0.3284) suggests an inverse relationship, with PC1 explaining approximately 81.9 % (R^2 = 0.8192) of the variation in grain yield.

Economics

The data showing the effect of crop establishment and weed management options on harvest index are presented in Table 9. The lowest total cost of cultivation was observed from DSR (₹45402 ha^{-1}) and TPR had the highest cost of cultivation (₹52802 ha^{-1}), gross return (₹108491 ha^{-1}), net return (₹55689 ha^{-1}) and B:C ratio (1.05).

Among weed management options, the lowest total cost of cultivation was observed in the weedy check treatment (₹35802 ha^{-1}), while the highest gross return was recorded in HW at 20, 40 and 60 DAT/S (₹110831 ha^{-1}), which is 46 % more than the weedy check treatment. Among all herbicide treatments, pretilachlor 600 g ha^{-1} PE *fb* pyrazosulfuron ethyl 10 % WP 20 g ha^{-1} at 20 DAT/S had the highest net return (₹65926 ha^{-1}) and B:C ratio (1.66). Though the weed-free treatment yielded the highest in both the crop establishment methods, it incurred a high cost of cultivation due to the high labour requirement in hand

Table 8. PCA regression model

Summary output				
Regression Statistics				
Multiple R	0.90			
R square	0.82			
Adjusted R square	0.80			
Standard error	0.47			
Observations	10.00			
	Coefficients	Standard error	t Stat	P-value
Intercept	4.01	0.15	27.18	0.000000004
PC1	-0.33	0.05	-6.01	0.000320000

Table 9. Effect of weed management on economics under different establishment methods in kharif rice, 2024

Treatments	Economics			
	Total cost of cultivation (₹ ha^{-1})	Gross return (₹ ha^{-1})	Net return (₹ ha^{-1})	Benefit-cost ratio(B:C)
Methods of establishment (E)				
TPR	52802	108491	55689	1.05
DSR	45402	81389	35987	0.79
Weed Management (W)				
Pretilachlor PE *fb* FPE	40692	95982	55290	1.36
Pretilachlor PE *fb* ES	39533	102327	62794	1.59
Pretilachlor PE *fb* PZS	39635	105561	65926	1.66
HW at 20,40 and 60 DAT/S	50802	110831	60029	1.18
Weedy check	35802	59999	24197	0.68

*DAT: Days after transplanting; DAS: Days after sowing; FPE: Fenoxaprop-p-ethyl; ES: Ethoxysulfuron; PZS: Pyrazosulfuron-ethyl; HW: Hand weeding

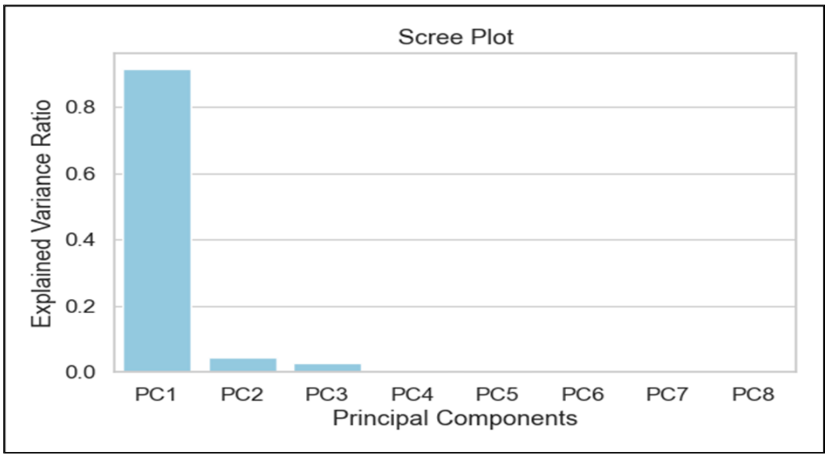

Fig. 6. Scree plot for (PC and explained variance ratio.

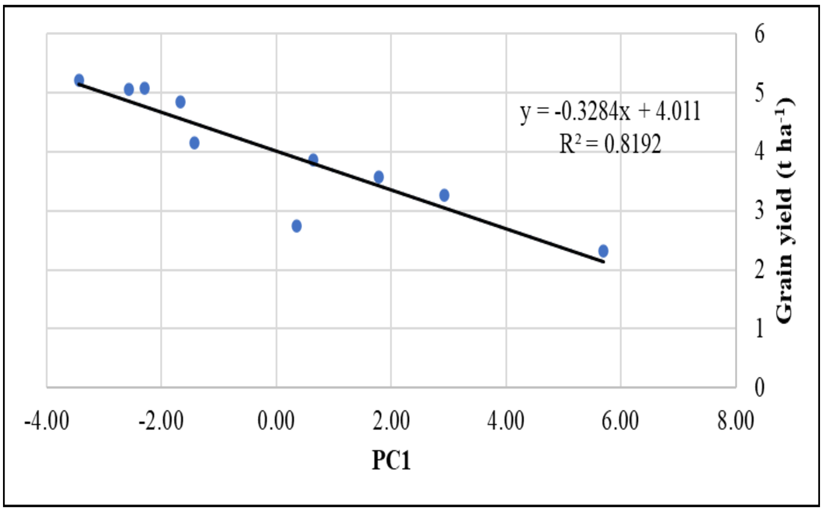

Fig. 7. Linear regression between PC1 and grain yield (t ha^{-1}).

weeding. Similarly, among the crop establishment methods, the high cost of cultivation was in TPR due to nursery raising. So, the herbicidal treatment pretilachlor 600 g ha^{-1} PE *fb* pyrazosulfuron ethyl 10 % WP 20 g ha^{-1} at 20 DAT/S in the DSR method showed almost the same result with HW at 20, 40 and 60 DAT/S in yield as well as most of the parameters taken for study.

Conclusion

TPR in the main plot performed better than DSR in terms of weed dynamics, growth parameters, yield and yield attributes. Among herbicidal treatments. pretilachlor 600 g ha^{-1} PE *fb* pyrazosulfuron ethyl 10 % WP 20 g ha^{-1} at 20 DAT/S was found to perform better than the remaining treatments in regard to weed dynamics, growth parameters, yield and yield attributes. Vital growth parameters such as dry matter accumulation and LAI contribute to yield, therefore the crop should be supervised with optimum and adequate agronomic management. Additionally, effective weed management through suitable herbicides is the need of the hour. Hence, the herbicidal treatment pretilachlor 600 g ha^{-1} PE *fb* pyrazosulfuron ethyl 10 % WP 20 g ha^{-1} at 20 DAT/S can be recommended for the benefit of the farming community. Although TPR had a higher cost of cultivation, the benefit-cost (B:C) ratio indicated that the returns justified the investment, making it a viable approach. Meanwhile, the herbicidal treatment with pretilachlor *fb* pyrazosulfuron-ethyl achieved the highest B:C ratio among all treatments, making it a practical and efficient alternative, especially considering labour shortages in Indian agriculture. Hence, adoption of pretilachlor 600 g ha^{-1} PE *fb* pyrazosulfuron ethyl 10 % WP 20 g ha^{-1} at 20 DAT/S in TPR or DSR will be more impactful for gaining more agricultural produce for meeting food security demands.

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Authors' contributions

NB carried out the field research work and laboratory analysis, drafting of manuscript. The experiment was conceptualised, designed and supervised by SM and the interpretation of data and critically revision of the article was carried out as well. The statistical analysis and designing of figures were carried out by BG. Review of data was carried out by BSB and NT. Revision of the final article was performed by MM and PP. All authors read and approved the final manuscript.

Compliance with ethical standards

Conflict of interest: Authors do not have any conflict of interest to declare.

Ethical issues: None

References

1. Food and Agriculture Organization. FAOSTAT: Crops and livestock products. Rome: Food and Agriculture Organization of the United Nations; 2023.
2. Government of Odisha. Directorate of Agriculture and Food Production. Department of Agriculture and Farmers' Empowerment, Government of Odisha. 2025.
3. Kumar P, Singh PD, Singh T, Singh A, Pal RK, Singh G. Yield, nutrient uptake, quality and economics of rice (*Oryza sativa* L.) as affected by various crop establishment methods and nitrogen levels. J Pharmacogn Phytochem. 2019;8(5):2009–12.
4. Ahmed S, Humphreys E, Salim M, Chauhan BS, Kumar V, Zaman AU, et al. Dry direct-seeded and broadcast rice: a profitable and climate-smart alternative to puddled transplanted aus rice in Bangladesh. Field Crops Res. 2025;322:109739. https://doi.org/10.1016/j.fcr.2025.109739
5. Joshi E, Dinesh K, Lal B, Nepalia V, Gautam P, Vyas AK. Management of direct-seeded rice for enhanced resource use efficiency. Plant Knowl J. 2013;2:119–34.
6. Rao A, Johnson D, Sivaprasad B, Ladha J, Mortimer A. Weed management in direct-seeded rice. Adv Agron. 2007;93:153–255. https://doi.org/10.1016/S0065-2113(06)93004-1
7. Oerke EC, Dehne HW. Safeguarding production: losses in major crops and the role of crop protection. Crop Prot. 2004;23:275–85. https://doi.org/10.1016/j.cropro.2003.10.001
8. Sekhawat K, Rathore SS, Chauhan BS. Weed management in dry direct-seeded rice: a review on challenges and opportunities for sustainable rice production. Agronomy. 2020;10(9):1264. https://doi.org/10.3390/agronomy10091264
9. Mirza H, Kamrun N, Karim MR. Effectiveness of different weed control methods on the performance of transplanted rice. Pak J Weed Sci Res. 2007;13:17–25.
10. Kumar S, Shivani M, Mishra JS, Kumar S, Kumar U, Bharati RC. Efficacy of pre- and post-emergence herbicides on complex weed flora in direct-seeded rice (*Oryza sativa*). Indian J Agric Sci. 2018;88:387–92. https://doi.org/10.56093/ijas.v88i3.78502
11. Chaudhary A, Venkatramanan V, Kumar MA, Sharma S. Agronomic and environmental determinants of direct seeded rice in South Asia. Circ Econ Sustain. 2023;3(1):253–90. https://doi.org/10.1007/s43615-022-00173-x
12. Kaur T, Kaur S, Singh G, Singh M, Singh J, Kaur P, et al. Weed control in direct-seeded rice with ready mix of penoxsulam + pendimethalin. Indian J Weed Sci. 2025;57(2):155–9. https://doi.org/10.5958/0974-8164.2025.00026.6
13. Brar NS, Sandhu PS, Kumar A, Singh P, Kaur S. Economic assessment of herbicide use in rice under different establishment methods in Northwest India. Agrochemicals. 2025;4(2):7. https://doi.org/10.3390/agrochemicals4020007
14. Bamal D, Duhan A, Pal A, Beniwal RK, Kumawat P, Dhanda S, et al. Herbicide risks to non-target species and the environment: a review. Environ Chem Lett. 2024;22:2977–3032. https://doi.org/10.1007/s10311-024-01773-9
15. Rao AN, Singh RG, Mahajan G, Wani SP. Weed research issues, challenges and opportunities in India. Crop Prot. 2020;134:104451. https://doi.org/10.1016/j.cropro.2018.02.003
16. Monteiro A, Santos S. Sustainable approach to weed management: the role of precision weed management. Agronomy. 2022;12:118. https://doi.org/10.3390/agronomy12010118
17. Mitra B, Patra K, Bhattacharya PM, Ghosh A, Chowdhury AK, Dhar T, et al. Efficacy of pre- and post-emergence herbicide combinations on weed control in no-till mechanically transplanted rice. Cogent Food Agric. 2022;8(1):2139794. https://doi.org/10.1080/23311932.2022.2139794
18. Gomez KA, Gomez AA. Statistical procedures for agricultural research. 2nd ed. New York: John Wiley & Sons; 1984. 680 p.
19. Rao VS. Principles of weed science. New Delhi: Oxford & IBH Publishing; 2000. p. 145–62. https://doi.org/10.1201/9781482279603
20. Yadav DB, Yadav A, Punia SS. Evaluation of herbicides for weed control in transplanted rice. Indian J Weed Sci. 2011;43(1–2):61–4.
21. Chauhan BS, Abugho SB. Growth of four weed species in response to rice cultivar and density. PLoS One. 2012;7(2):e29413.
22. Mahajan G, Chauhan BS. Integrated weed management in rice: advances and future directions. Adv Agron. 2013;120:315–66.
23. Suryakala P, Murugan G, Saravanaperumal M, Suseendran K, Stalin P. Effect of weed management practices with new generation herbicides in transplanted rice. J Pharmacogn Phytochem. 2019;8(3):3913–5.
24. Dey RK, Sana M, Pal S, Mondal R, Pal S. Effect of post emergence herbicides on weed management in transplanted kharif rice (*Oryza sativa* L.) and their residuality on soil microorganisms. Curr J Appl Sci Technol. 2020;39(27):88–95. https://doi.org/10.9734/CJAST/2020/v39i2730923
25. Chauhan BS, Johnson DE. The role of seed ecology in improving weed management strategies in the tropics. Adv Agron. 2010;105:221–62. https://doi.org/10.1016/S0065-2113(10)05006-6
26. Rao VS. Principles of weed science. 2nd ed. New Delhi: Oxford & IBH Publishing; 2015.
27. Kumar V, Yadav S, Singh S. Effect of weed management practices on growth and yield of rice under system of rice intensification. Indian J Weed Sci. 2014;46(1):50–3.

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