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RESEARCH ARTICLE

Eco-friendly weed management strategies on weed dynamics, growth and yield of transplanted rice

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Abstract

A field experiment was conducted during the kharif seasons of 2024–2025 at the Experimental farm, Department of Agronomy, Annamalai University to evaluate eco-friendly weed management strategies on weed dynamics, growth and yield of transplanted rice (*Oryza sativa* L.). The experiment was laid out in a split plot design with 3 replications. Treatments combinations comprised of 3 stale seed bed (SSB) practices in the main plots: normal seed bed, stale seed bed for 7 days and stale seed bed for 14 days and 4 weed management practices in the sub plots: hand weeding twice at 15 and 35 days after transplanting (DAT), cono-weeding twice at 15 and 35 DAT, application of azolla 250 kg ha^{-1} on 3 DAT followed by cono-weeding on 35 DAT and a weedy check. Both stale seedbed methods and weed management practices exerted a significant influence on crop growth and yield of transplanted rice. Among the SSB methods, the stale seedbed technique with 14 days of weed flush prior to planting recorded the highest weed control efficiency (WCE), enhanced crop growth and resulted in superior grain yield. Among the weed management practices, hand weeding twice at 15 and 35 DAT achieved the maximum WCE and yield, which was followed by application of azolla 250 kg ha^{-1} on 3 DAT followed by cono-weeding on 35 DAT.

Keywords: azolla; cono weeding; rice yield; stale seedbed

Introduction

Weeds remain one of the most persistent biotic constraints in rice cultivation, causing considerable yield reductions ranging from 30–80 % and posing a serious threat to the long-term viability of rice-based production systems through intense competition for nutrients, water and light, increased yield instability and higher production costs. Traditionally, chemical herbicides such as thiobencarb, penoxsulam and benzobicyclon + halosulfuron have been extensively used in rice farming to achieve effective weed control, reduce labour dependency and enhance crop productivity. Nevertheless, the continuous and indiscriminate use of herbicides has raised significant environmental, economic and human health concerns, including the growth of weed populations resistant to herbicides, deterioration of soil health specifically biological indices and pollution of surface and groundwater resources. In addition, escalating prices of synthetic herbicides have raised questions regarding their long-term economic feasibility for farmers (1). In view of these challenges, several studies have highlighted the importance of integrating non-chemical weed management approaches such as manual and mechanical weeding, biological interventions using azolla and cultural practices like stale seedbed techniques for effective weed suppression and improved crop performance (2, 3). These eco-friendly strategies not only reduce reliance on chemical herbicides but also enhance soil fertility, optimize water use efficiency and enhance farm profitability, thereby promoting sustainable rice production systems (4). Consequently, the adoption of sustainable weed management practices has become imperative to sustain rice productivity while minimizing ecological risks and safeguarding environmental health. In this context, the present study aimed to assess eco-friendly weed management strategies and their influence on weed dynamics, growth and yield of transplanted rice.

Materials and Methods

Experimental site

Experiments were conducted at the Department of Agronomy, Annamalai University, Chidambaram, Tamil Nadu, India, during kharif seasons of 2024 and 2025. The experimental site is located at 11°24' N latitude, 79°44' E longitude, at an altitude of approximately 5.79 m above mean sea level. The experimental soil was clay loam with low levels of organic carbon (0.46 %) and available nitrogen (232 kg ha^{-1}), medium in available phosphorus (17.91 kg ha^{-1}) and high levels of available potassium (357 kg ha^{-1}).

Climatic conditions

In the first year (2024), the weekly mean maximum and minimum temperatures ranged between 32.6–37.7 °C (mean 35.96 °C) and 20.6–23.7 °C (mean 21.68 °C), respectively. In the second year (2025), ranged between 32.2–37.8 °C (mean 34.97 °C) and 18.8–21.5 °C (mean 20.02 °C), respectively. Relative humidity ranged from 64–77 % with an average of 68.67 % and 68.39 % in the first and second years, respectively. During its growing period crop received the total amount of rainfall of 189.70 and 369.6 mm, respectively in 2024 and 2025.

Experimental treatment and design

The experiment was laid out in a split plot design (SPD) with 3 replications. The levels of stale seed bed (SSB) were placed under main plots, whereas sub plots were occupied with 4 levels of weed management practices.

Main plot treatments (SSB practices)

M_1: Normal seed bed (control)

M_2: Stale seed bed for 7 days

M_3: Stale seed bed for 14 days

Sub plot treatments (Weed management practices)

S_1: Control

S_2: Hand weeding twice on 15 and 35 DAT

S_3: Cono-weeding twice on 15 and 35 DAT

S_4: Azolla 250 kg ha^{-1} on 3 DAT + Cono-weeding on 35 DAT

Crop details

ADT 43 a slender grain, short duration rice cultivar of 110 days was used for the present study. Twenty-one-day-old seedling were transplanted in main field at a spacing of 20 × 10 cm with consideration of cono weeding and fresh weight of azolla was applied at 3 DAT to facilitate biological weed suppression.

Data collection and observations

Weed density, weed dry matter production and grain yield were used to determine weed control efficiency (WCE) and weed index (WI) (5). Observations on crop growth and yield parameters were systematically recorded during both 2024 and 2025 cropping seasons. Observations were taken from a net plot size of 4.20 × 3.60 m.

Statistical analysis

Analysis of variance (ANOVA) was carried out for the split-plot design using statistical methods outlined earlier and treatment effects were tested for significance at the 5 % probability level (6).

Results and Discussion

Effect on weed and growth attributes

Stale seedbed duration significantly influenced WCE and WI during both the experimental years (2024 and 2025). Stale seedbed for 14 days recorded the highest WCE (70.38 and 71.08 %) and the lowest WI (14.36 and 14.52 %), which was superior to stale seedbed for 7 days and the normal seedbed (Table 1). The progressive improvement in weed suppression with increasing stale seedbed duration may be attributed to enhanced germination of weed seeds followed by their elimination prior to crop establishment, resulting in depletion of the active weed seed bank. Similar reductions in weed pressure under extended stale seedbed periods have been reported in transplanted rice (7, 8).

Weed management practices exerted a pronounced effect on weed control parameters during both experimental years (2024 and 2025). Hand weeding twice at 15 and 35 DAT consistently registered the highest WCE (89.48 and 90.25 %) and the lowest WI (1.96 and 2.21 %) during 2024 and 2025, respectively and this was followed by azolla at 250 kg ha^{-1} at 3 DAT + cono-weeding at 35 DAT (Table 1). The superior performance of hand weeding may be due to the effective removal of weeds during the critical period of crop-weed competition, whereas azolla suppressed weeds through surface shading and physical obstruction, thereby limiting weed emergence. Comparable findings on the effectiveness of manual and integrated non-chemical weed management practices have been documented (9). Earlier reports indicated that cono weeding was not comparable with hand weeding due to the ineffective control of weeds in the intra rows and our findings also falls in line with these reports (10).

Crop growth parameters such as plant height, leaf area index (LAI) and dry matter production (DMP) were significantly affected by stale seedbed techniques as well as weed management practices. Stale seedbed for 14 days resulted in the tallest plants, highest LAI and greatest DMP. The lowest plant height, LAI and DMP were recorded with normal seedbed (Table 1).

Table 1. Effect of different stale seedbed and weed management treatments on weed indices and growth of transplanted rice

Treatments	WCE (%)		Weed index		Plant height (cm)		LAI		DMP (kg ha^{-1})	
	2024	2025	2024	2025	2024	2025	2024	2025	2024	2025
Stale seed bed										
Normal seed bed (control)	61.06	61.67	20.92	20.84	92.76	94.64	3.85	4.34	9514	9368
Stale seed bed for 7 days	65.87	66.67	16.72	16.65	95.18	97.08	4.54	4.96	9959	9829
Stale seed bed for 14 days	70.38	71.08	14.36	14.52	100.89	101.92	5.26	5.15	10543	10337
SEd.					1.02	0.95	0.14	0.14	59	56
CD					4.69	4.37	0.62	0.64	272	259
Weed management										
Hand weeding twice (15 & 35 DAT)	89.48	90.25	1.96	2.21	100.91	102.93	5.22	5.50	11366	11213
Cono weeding twice (15 & 35 DAT)	84.69	85.44	7.58	7.49	98.48	99.84	4.71	4.86	10702	10513
Azolla at 250 kg ha^{-1} on 3 DAT + cono-weeding on 35 DAT	77.98	78.83	3.90	3.75	99.18	100.76	5.04	5.26	10962	10806
Weedy check	10.92	11.37	55.90	55.89	86.53	87.99	3.25	3.66	6991	6846
SEd.					0.59	0.48	0.13	0.11	70	75
CD					1.70	1.37	0.37	0.31	202	215
Interaction effect										
M × S					5.21	4.72	NS	NS	397	404
S × M					2.94	2.37	NS	NS	349	372

DAT: days after transplanting; WCE: weed control efficiency; LAI: leaf area index; DMP: dry matter production.

Reduced weed competition under extended stale seedbed conditions likely enhanced the availability of nutrients, light and moisture, thereby promoting better crop growth. Similar improvements in rice growth attributes due to effective weed suppression have been reported (11). Among weed management practices, hand weeding twice recorded the highest plant height, LAI and DMP during 2024 and 2025 which is on par with application of azolla at 250 kg ha^{-1} at 3 DAT + cono-weeding at 35 DAT and significant over cono-weeding twice on 15 and 35 DAT. This may be due to a weed-free environment during early crop growth stages, leading to better photosynthetic efficiency and biomass accumulation. In contrast, the weedy check recorded the lowest growth parameters due to severe competition for growth resources, which restricted crop development (12, 13). The interaction between stale seedbed methods and weed management practices was significant for plant height and DMP, indicating that the effectiveness of weed management practices was enhanced when combined with longer stale seedbed duration as evidenced from effective weed control and enhanced crop growth with treatment stale seedbed for 14 days along with hand weeding twice on 15 and 35 DAT (14).

Effect on yield attributes and yield

Stale seedbed duration significantly influenced yield attributes and yield of transplanted rice during both the years (2024 and 2025). Among the treatments, stale seedbed for 14 days recorded significantly higher number of productive tillers per square meter (345.58 and 337.58) and filled grains per panicle (113.60 and 112.52) whereas stale seedbed for 7 days ranked second (Table 2). The improvement in yield attributes under longer stale seedbed duration could be explained by effective depletion of the weed seed bank prior to transplanting, resulting in reduced crop-weed competition and better utilization of growth resources by the crop. Similar findings were earlier reported in transplanted rice systems (15, 16).

Grain and straw yields trended similarly as that of yield attributes, with stale seedbed for 14 days producing significantly higher grain yield (5616 and 5662 kg ha^{-1}) and straw yield (7745 and 7717 kg ha^{-1}) during 2024 and 2025, respectively. In contrast, the normal seedbed recorded the lowest yield, primarily due to higher weed interference leading to poor crop stand and reduced sink development. Test weight was not significantly influenced by stale seedbed treatments. Weed management techniques exerted a marked influence on yield attributes and rice yield (17). Hand weeding twice at 15 and 35 DAT resulted in the highest number of productive tillers per square meter (377.78 and 371.78) and filled grains per panicle (118.80 and 117.47), which ultimately translated into the maximum grain yield (6430 and 6477 kg ha^{-1}) during 2024 and 2025, respectively (Table 2) and may be attributed to efficient removal of weeds during the critical period of crop-weed competition, which enhanced assimilate partitioning towards reproductive structures (18). This was followed by azolla at 250 kg ha^{-1} applied at 3 DAT + cono-weeding at 35 DAT, possibly due to the effectiveness of azolla in suppressing weeds through surface shading, coupled with mechanical disturbance by cono-weeding, likely created a favourable microenvironment for crop growth. Similar benefits of azolla-based non-chemical weed management have been documented (19, 20).

The weedy check consistently recorded the lowest values for productive tillers, filled grains per panicle, grain yield and straw yield during 2024 and 2025 due to intense competition for nutrients, moisture and light, which restricted tiller formation and grain filling. Test weight remained unaffected by different weed management practices, suggesting that weed competition mainly influenced sink number rather than grain size (21). The interaction between stale seedbed duration and weed management practices was significant for productive tillers, filled grains per panicle, grain yield and straw yield, indicating that the beneficial effects of weed management practices were enhanced under longer stale seedbed duration (22). However, the interaction effect was non-significant for test weight, further confirming its stability across treatments. The combination of stale seedbed for 14 days with effective non-chemical weed management practices proved superior in improving yield attributes and productivity of transplanted rice (23).

The regression analysis clearly showed strong negative linear association between rice grain yield and weed dry weight during both 2024 and 2025 (Fig. 1). The high coefficients of determination (R^2 = 0.9686 in 2024 and 0.9597 in 2025) indicate that more than 95 % of the variation in grain yield was governed by weed dry matter accumulation, emphasizing the decisive role of weed competition in limiting rice productivity. The nearly identical regression slopes across years further confirm the consistency of yield loss per unit increase in weed biomass, irrespective of seasonal variability (24).

Table 2. Effect of different stale seedbed and weed management treatments on yield parameter and yield of transplanted rice

Treatments	No. of productive tillers m^{-2}		Number of filled grains $panicle^{-1}$		Test weight (g)		Grain yield (kg ha^{-1})		Straw yield (kg ha^{-1})	
	2024	2025	2024	2025	2024	2025	2024	2025	2024	2025
Stale seed bed										
Normal seed bed (control)	303.67	299.42	102.28	100.93	15.41	15.27	5186	5244	7288	7304
Stale seed bed for 7 days	326.17	321.25	108.18	106.93	15.45	15.32	5461	5521	7587	7602
Stale seed bed for 14 days	345.58	337.58	113.60	112.52	15.48	15.36	5616	5662	7745	7717
SEd.	1.37	1.67	0.82	0.56	0.01	0.01	28	31	48	53
CD	6.32	7.68	3.80	2.58	NS	NS	128	144	220	244
Weed management										
Hand weeding twice (15 & 35 DAT)	377.78	371.78	118.80	117.47	15.49	15.37	6430	6477	5882	8550
Cono weeding twice (15 & 35 DAT)	356.89	351.44	110.94	109.18	15.46	15.33	6060	6127	8155	8173
Azolla at 250 Kg ha^{-1} on 3 DAT + cono-weeding on 35 DAT	369.89	364.11	114.78	113.33	15.47	15.34	6302	6376	8431	8450
Weedy check	196.00	190.33	87.56	86.44	15.36	15.23	2892	2922	4992	4993
SEd.	1.52	1.35	0.50	0.46	0.01	0.01	37	41	66	59
CD	4.37	3.90	1.43	1.32	NS	NS	115	126	196	179
Interaction effect										
M × S	8.88	9.39	4.26	3.17	NS	NS	193	185	353	343
S × M	7.57	6.75	2.48	2.29	NS	NS	174	144	330	292

DAT: days after transplanting.

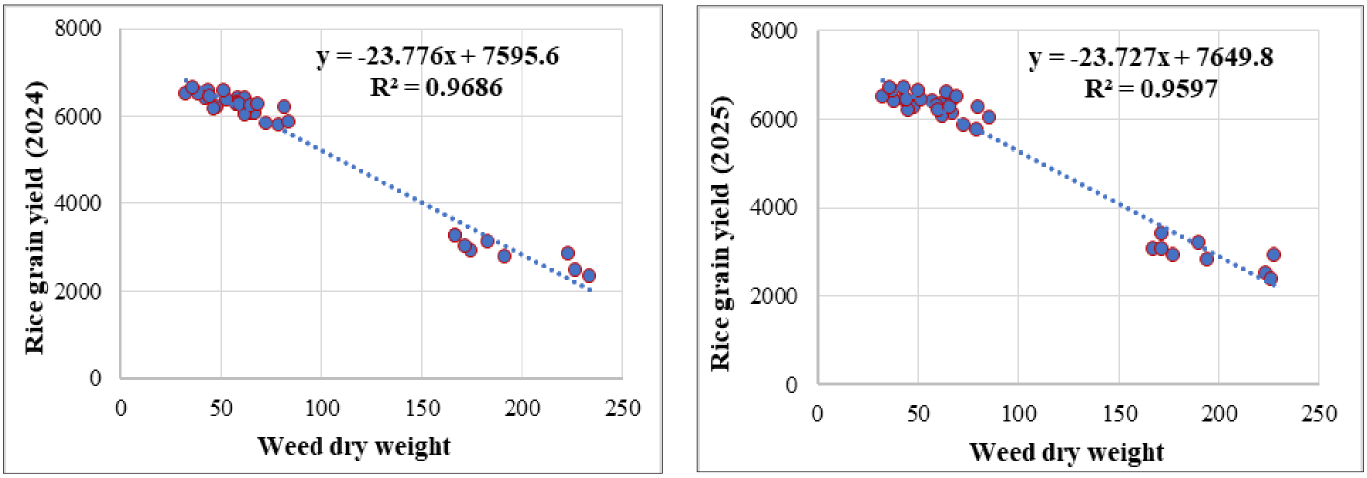

Fig. 1. The relationship between grain yield and total weed dry weight at harvest during 2024 and 2025.

Conclusion

The combined method of using a stale seed bed for 14 days and hand weeding twice at 15 and 35 DAT was found to be the most effective in suppressing diverse weed flora, resulting in the highest rice grain yield and emerging as a technically sound and financially feasible weed management strategy for transplanted rice.

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Authors' contributions

KP conceived and formulated the research concept, designing and executing the field trials, compiling and analysing the data and drafting the initial manuscript. PA offered overall supervision along with intellectual input on the experimental framework and interpretation of the findings. SN and AS supported the planning of the experiments, assisted in data evaluation and contributed to reviewing the manuscript. KS provided technical expertise, carried out critical revisions and edited the manuscript. All authors have reviewed and approved the final manuscript.

Compliance with ethical standards

Conflict of interest: All authors do not have conflict of interest to declare.

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Declaration of generative AI and AI-assisted technologies in the writing process

During the preparation of this article, the authors used Grammarly and QuillBot to improve language readability. The authors carefully reviewed and edited the content as required and take full responsibility for the content of the publication.

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