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RESEARCH ARTICLE

Sowing methods and weed management for yield maximization in wet direct-seeded rice (*Oryza sativa* L.) cultivation in Tamil Nadu

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Abstract

Wet direct-seeded rice has emerged as a viable alternative to traditional transplanted rice, overcoming labour and water scarcity challenges while mitigating rising cultivation costs. However, effective weed management practices are required to prevent severe yield losses due to heavy weed infestation. A field experiment was conducted during the *Kharif* seasons of 2020, 2021 and 2022 at the Department of Rice, Tamil Nadu Agricultural University in Coimbatore. The objective was to investigate various sowing methods and weed management practices to maximize yield in wet direct-seeded rice, utilizing a split-plot design with 3 replications. The results indicated that the paddy drum seeding method resulted in lower weed density, reduced weed dry weight, a higher number of productive tillers/m^2 and a higher grain yield than other sowing methods. Among the weed management practices, the sequential use of pre-emergence (PE) Pretilachlor, followed by the early post-emergence (EPOE) herbicide bispyribac sodium for the first and second weed flushes at 25 and 45 days after sowing (DAS), effectively reduced both weed density and dry weight, while producing the highest number of productive tillers/m^2 and resulted in a significantly higher grain yield of 5277 kg/ha compared to other sowing methods. Thus, the paddy drum seeded method, combined with the sequential application of PE herbicide pretilachlor at 0.75 kg/ha at 8 DAS *fb* EPoE herbicide Bispyribac sodium at 25 g/ha for the 1st and 2nd weed flushes at 25 and 45 DAS, effectively enhances productivity and weed control in wet direct-seeded rice.

Keywords

early post emergence herbicide; pre-emergence herbicide; rice; sowing methods; weed management; wet direct-seeded

Introduction

Rice (*Oryza sativa* L.) is one of the most important global food grain crops and a staple for more than half the global population. During 2022-23, rice in India was cultivated on 46.38 million ha, with a production of 130.29 million tonnes and a productivity of 2.80 t/ha (1). In India, the predominant method of establishing rice involves manually transplanting seedlings into puddled soil. This conventional practice, which necessitates repeated field puddling, is characterized by heavy water usage and significant labour requirements. However, it is associated with several challenges, including the

depletion of water tables, labour shortages during peak agricultural periods and degradation of soil health (2).

To tackle these challenges, an alternative approach is a direct-seeded rice (DSR) method, which includes 2 methods: dry direct-seeded rice (dry-DSR) and wet direct-seeded rice (wet-DSR). These methods use less water and labour, decrease methane emissions and enhance soil quality (3). Moreover, they achieve yields comparable to traditional methods (4). Wet tillage-based direct-seeded rice has been identified as beneficial, leading to increased economic returns and reduced water usage and costs (5).

Direct-seeded rice (DSR), regarded as one of the earliest crop establishment techniques, is becoming more popular because of its minimal input needs. This method provides numerous benefits, including reduced labour, lower water consumption, less physical effort, quicker crop maturity, decreased production costs, enhanced soil conditions for future crops, lower methane emissions and the ability to adapt well to different cropping systems (6). DSR has proven effective in enhancing rice productivity and resilience, particularly under adverse climatic conditions, exhibiting higher yields and more successful crop establishment than mechanically transplanted rice (7).

The wet direct seeding method is increasingly popular in India, including Tamil Nadu, due to its efficiency in saving labour and water (8, 9). This approach eliminates the need for nursery preparation and transplanting, reducing labour demands by 25% (8). Additionally, it facilitates quicker planting and enhances water usage efficiency. However, wet seeding can increase weed growth and lodging, requiring specific genotypes and management practices (9).

In this method, pre-germinated seeds are sown on the surface of puddled soil, significantly reducing labour and water usage and yielding higher crop productivity than conventional methods (10). Wet-DSR presents a promising alternative to traditional transplanting techniques, potentially enhancing productivity and profitability (11). The advantages of wet-DSR include decreased water and labour needs, reduced methane emissions and improved soil physical characteristics (5,7). These benefits can result in a higher benefit-cost ratio compared to traditional puddled transplanted rice (12).

Historically, wet direct seeding has received less emphasis than transplanting in rice farming. In tropical regions, rice farmers typically practice wet seeding by either broadcasting or line seeding to place germinated seeds directly onto puddled soil. Broadcasting in DSR is advantageous for cost and labour savings, but it poses difficulties in maintaining optimal plant density (13). This method may lead to suboptimal plant populations and reduced poor grain quality, characterized by lower amylose/amylopectin levels and increased chalkiness (14).

Using a drum seeder for direct wet seeding of rice provides several benefits, including quicker and easier planting, significantly reduced labour requirements (only 1-2 labourers per ha), maintenance of optimal plant density, accelerated crop growth, improved water efficiency and earlier maturation. This approach has led to a 25% reduction (equivalent to 250-300 man-hr) in the overall human labour needed for rice cultivation, enhancing the profitability of rice farming (15). Selecting the suitable sowing method is critical in wet direct-seeded rice cultivation, as employing methods like drum seeding and dry-converted wet rice line sowing can improve yield characteristics, grain production and economic returns (16). These findings highlight the importance of selecting an appropriate sowing technique to enhance productivity and profitability in wet DSR cultivation.

This study evaluated different sowing methods, including broadcasting, line sowing and paddy drum seeder method. Cultivating rice using the drum seeding method is not only simple to use but also has been found effective in maintaining optimal plant populations, essential for sustaining rice production (13). Whether dry or wet, direct seeding of rice is a critical technique for establishing crops, especially in lowland rice farming, however, it faces considerable challenges from weeds, especially those in the Poaceae family (17). Effective weed control is crucial for successful wet DSR, underscoring the importance of integrated weed management strategies (18).

In direct-seeded rice systems, weed control is commonly achieved through a combination of manual, mechanical and chemical methods, with integrated herbicide and cultural practices proving to be effective for optimal weed management (19). In this approach, the sequential application of a pre-emergence herbicide followed by an early post-emergence herbicide has been practical in managing weeds in wet-DSR through chemical control methods (20). Early post-emergent herbicides and efficient cultivation practices can significantly enhance grain yield and profitability in wet-DSR systems (11). Integrated weed management strategies, incorporating cultural practices and chemical herbicides, are essential for effective weed control (21). These strategies have been shown to significantly reduce weed density and biomass, resulting in higher grain yields and improved nutrient uptake (22).

In particular, cultural practices, such as the choice of sowing methods, should be carefully combined with chemical weed control techniques to achieve improved outcomes in weed management (23). In this context, the present investigation was carried out to evaluate suitable sowing methods and efficient weed management practices for wet direct-seeded rice cultivation in Tamil Nadu.

Materials and Methods

A field experiment was conducted during the *Kharif* seasons of 2020, 2021 and 2022 at the Department of Rice, Tamil Nadu Agricultural University, Coimbatore. This was to evaluate different sowing methods and weed management practices for maximizing yield in a wet direct-seeded rice eco-system. The experimental field's soil was clayey with a pH of 8.21, organic carbon content (0.47%), low available nitrogen (217 kg/ha), medium available phosphorus (23 kg/ha) and high available potassium (472 kg/ha). The experiment was laid out in split plot design with 3 rep-

lications.

Different sowing methods were tested in the main plot: M_1 - Broadcasting method, M_2 - Line sowing (manual) method and M_3 - Paddy drum seeding method. The broadcasting method involved evenly spreading the seeds, while line sowing used a 20 cm spacing between seeds. For the drum seeder method, a paddy drum seeder was used to maintain row spacing at 20 cm and plant spacing at 10 cm.

The sub plot treatment includes various weed management practices:

- S_1, manual weeding was done on three times at 20, 40 and 60 DAS.
- S_2, PE herbicide application of pretilachlor at 0.75 kg/ha on 8 DAS followed by EPoE herbicide application of bispyribac sodium at 25 g/ha on 25 DAS at 2-3 leaf of weed emergence stage.
- S_3, PE herbicide application of pretilachlor at 0.75 kg/ha was applied on 8 DAS followed by manual weeding twice on 25 and 45 DAS.
- S_4, PE herbicide application of pretilachlor at 0.75 kg/ha on 8 DAS followed by EPoE herbicide bispyribac sodium at 25 g/ha on 25 DAS for first flush of weed stage (2-3 leaf stage) and 45 DAS for second flush of weed stage.

The rice variety CO 52 was chosen for the study. Recommended fertilizer doses of N:P:K at 150:50:50 kg/ha were applied using urea, single superphosphate and muriate of potash. Nitrogen and potassium were applied in 4 equal doses at 21 days after sowing (DAS) and during the active tillering, panicle initiation and heading stages. The total dose of phosphorus was applied as a basal treatment before sowing. During sowing, a thin layer of water was maintained, followed by alternating irrigation and drainage over the next 8-10 days to support germination and seedling establishment. Thereafter, irrigation was provided to a depth of 5 cm using the alternate wetting and drying method as needed. Plant protection measures were implemented as required for wet direct-seeded rice cultivation.

Sampling techniques for growth and yield parameters followed standard procedures. Total weed density and dry weight were measured at the active tillering stage using a 1 m^2 quadrat in each plot. Weeds within the quadrat were uprooted, identified, counted and recorded as weeds/m^2. To determine dry weight, the collected weeds were first washed, sun-dried for 48 hr and then oven-dried at 65 °C until a constant weight was achieved. The final weight was recorded in g/m^2. Productive tillers were recorded using a quadrat in each experimental plot and the results were averaged and expressed as the number/m^2. Seed yield was obtained from the undisturbed central area of each plot and expressed in kilograms per hectare (kg/ha).

The significance of variations was analyzed using Fisher Snedecor's "F" test with the error mean square approach at a 0.05 probability level. To normalize the distribution, data showing high variation and zero values in weed density and biomass, a square root transformation (SQRT) ($\sqrt{(x + 0.5)}$) was applied before statistical analysis (24).

Results and Discussion

Weed parameters

Total weed density

Among the different sowing methods, the paddy drum seeding method recorded the lowest weed density (7.47 numbers/m^2) at the active tillering stage compared to other sowing methods (Table 1). This is due to its uniform seed placement and optimal spacing, which reduces light availability for weeds and promotes faster crop establishment, allowing rice plants to outcompete weeds (25). The paddy drum seeder maintains consistent row-to-row and plant-to-plant spacing compared to other methods. This resulted in optimal plant stand and vigorous growth, suppressing weeds more effectively.

In the subplot, among the weed management practices, the sequential application of pre-emergence pretilachlor at 0.75 kg/ha on 8 DAS, followed by early post-emergence application of bispyribac sodium at 25 g / ha

Table 1. Evaluation of treatment impacts on total weed density during the active tillering phase in wet direct-seeded rice (Pooled data over 3 years)

Treatments (Main plot / Subplot)	Broadcasting method (M_1)	Line sowing method (M_2)	Paddy drum seeding method (M_3)	Mean
S_1 - Manual weeding (3 times)	8.23(2.95)	8.20(2.95)	7.13(2.76)	7.85
S_2 - PE herbicide (Pretilachlor) + EPoE herbicide (Bispyribac sodium)	11.27(3.43)	10.67(3.34)	9.47(3.15)	10.47
S_3 - PE herbicide (Pretilachlor) + manual weeding (2 times)	8.60(3.02)	8.27(2.96)	7.27(2.79)	8.05
S_4 - PE herbicide (Pretilachlor) + EPoE herbicide (Bispyribac sodium) for first and second flush - 25 and 45 DAS	7.13(2.76)	6.77(2.70)	6.00(2.55)	6.63
Mean	8.81	8.48	7.47	
	S.Ed		**CD(0.05)**	
M	0.03		0.07	
S	0.02		0.07	
M at S	0.07		NS	
S at M	0.05		NS	

PE - Pre emergence; **EPoE** - Early post-emergence; **DAS** -Days after sowing

herbicide 2 times at 25 and 45 DAS (S_4), recorded the lowest weed density (6.63 numbers/m^2), followed by manual weeding thrice at 20, 40 and 60 DAS (S_3) (7. 85 numbers/m^2). This effectiveness is attributed to the combination of preventive and corrective measures.

Pre-emergence herbicide pretilachlor controls germinating weeds, significantly reducing their initial population, while the timely applications of bispyribac sodium target any weeds that may have emerged, ensuring thorough management during critical growth stages. This strategic timing and combination of herbicides disrupt the weed life cycle, reduce resource competition and promote healthier crop growth (26).

Pretilachlor is a selective herbicide used in rice farming that disrupts amino acid production in susceptible plants by inhibiting acetolactate synthase (ALS) (27). Its effectiveness in rice fields is due to its rapid breakdown and elimination from plants (28). The pre-emergence use of pretilachlor at 0.75 kg a.i/ha, followed by post-emergence use of bispyribac sodium at 20 g a.i. /ha at the 2-3 leaf stage of weed emergence effectively reduces weed populations and increases weed control efficiency (29). The recommended dosage for enhancing weed control efficiency in direct-sown, drum-seeded rice is to apply pre-emergence followed by early post-emergence herbicide application (30). In wet-DSR, pretilachlor applied at 0.30 to 0.75 kg/ha significantly reduces weed density (31). Additionally, the early post-emergence herbicide bispyribac-sodium is more effective in broad-spectrum weed control than other herbicides, achieving a 75% reduction in weed density in direct-seeded rice systems (32).

Weed dry weight

Sowing with a paddy drum seeder resulted in lower weed dry weight (1.77 g m^{-2}) at the active tillering stage (Fig. 1) compared to other sowing methods. This reduction is attributed to the drum seeder's precise sowing technique, which promotes an optimal crop stand and strong establishment, enhancing the crop's competitiveness against weeds. By optimizing resource use, such as light, nutrients and moisture, the drum seeder method reduces the resources available for weed growth (33). Among weed management techniques, the sequential application of PE herbicide pretilachlor on 8 DAS, followed by 2 applications of EPoE herbicide bispyribac sodium at 25 and 45 DAS (S_4), recorded the lowest weed dry weight (1.77 g m^{-2}), followed by PE herbicide pretilachlor and manual weeding at 25 and 45 DAS (S_3). This sequential approach is effective as the pre-emergence application inhibits weed germination, drastically reducing initial weed biomass. In contrast, subsequent post-emergence applications target emerging weeds at critical growth stages, minimizing their competition with the crop. This combined approach enhances healthy crop establishment, reducing overall weed dry weight (29, 30, 32).

The interaction effect between sowing methods and weed management practices was significant. The combination of paddy drum seeder sowing with pretilachlor application followed by bispyribac sodium at 25 and 45 DAS (M_3S_4) achieved the lowest weed dry weight (1.35 g/m^2) compared to other treatments. Rice sown using the drum seeder exhibited reduced weed dry matter compared to other sowing techniques, particularly at the active tillering stage (34, 35). Applying pretilachlor as a pre-emergence herbicide, followed by bispyribac sodium as a post-emergence treatment, significantly decreased weed dry weight and achieved yields comparable to those in weed-free plots (36). Bispyribac-sodium has demonstrated superior weed control effectiveness compared to other herbicides, reducing weed dry weight by up to 80% in direct-seeded rice systems (32). Additionally, increasing the application rates of pretilachlor substantially decreased weed biomass from 293.1 to 31.3 g/m^2 and improved the effectiveness of the herbicide from 12% to 90% (37).

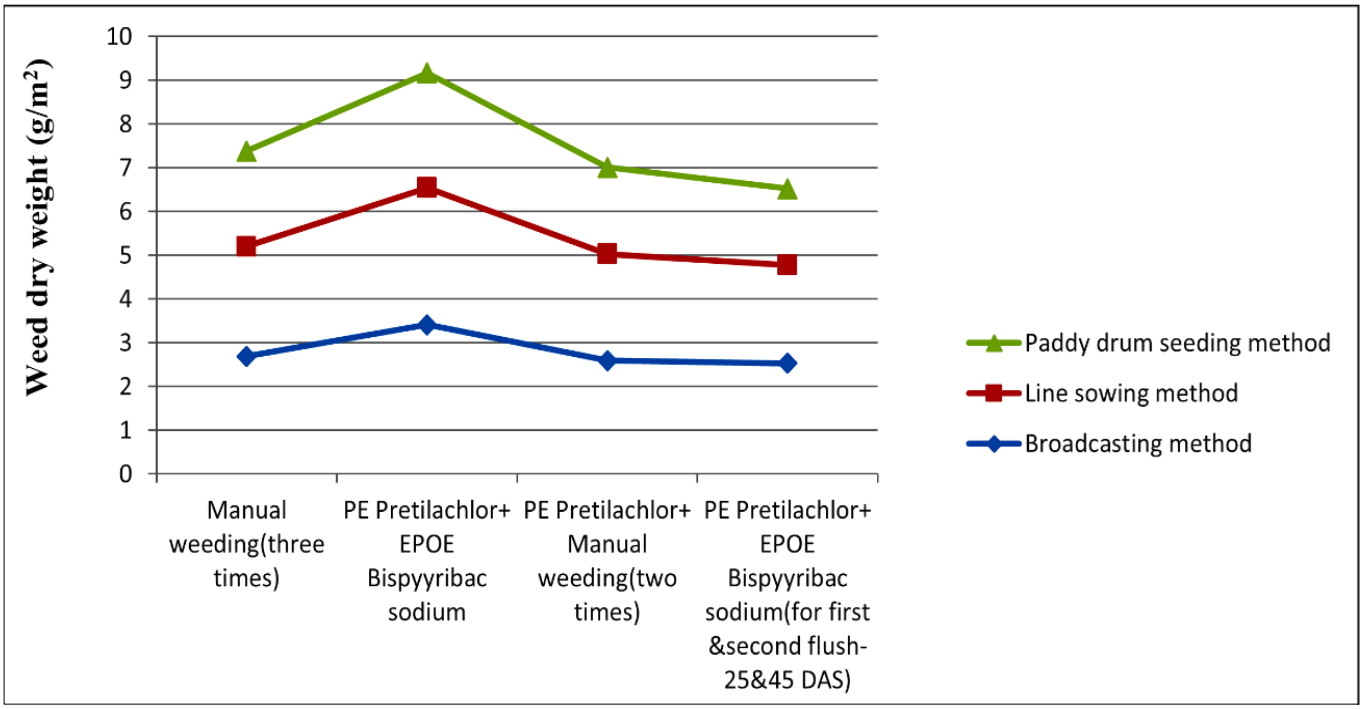

Fig. 1. Analysis of treatment effects on weed dry weight (g/m^2) during active tillering in wet direct-seeded rice (Pooled analysis of 3 years of data)

Yield parameters

Number of productive tillers/m²

The paddy drum seeder method of sowing resulted in a higher number of productive tiller/m² than other methods (Fig. 2). This method provides uniform seed placement, ensuring optimal spacing and depth, promoting better tiller development (38-40). This resulted in an optimal plant stand and increased tiller production at the active tillering stage, ultimately leading to more productive tillers/m². The paddy drum seeder method (M_3) produced the highest number of productive tillers/m² (320 numbers/m²), followed by the line sowing method (M_2) with 302 tillers/m². Among the weed management practices, the sequential application of the pre-emergence application of pretilachlor on 8 DAS, followed by early post-emergence application of bispyribac sodium at 25 and 45 DAS (S_4), recorded a higher number of productive tillers/m² (294 numbers/m²), followed closely by manual weeding thrice (S_1). The interaction effect between sowing methods and weed management practices was significant. The combination of paddy drum seeder sowing with PE pretilachlor followed by EPoE bispyribac sodium herbicide two times at 25 and 45 DAS (M_3S_4) resulted the highest number of productive tillers/m² (327 numbers/m²) compared to other treatments.

Direct sowing using a drum seeder resulted in a 7.1% increase in the number of tillers/m² and a 7.6% increase in the number of panicles/m² compared to traditional farming practices (38). Under direct-seeded technology using a drum seeder, the number of tillers (395) and panicles (370)/m² was higher compared to the broadcasting method, which produced fewer tillers (365) and panicles (346)/m² (39). Improved yield parameters were achieved through the drum seeder establishment method and herbicide application (41).

Grain yield (kg/ha)

The paddy drum seeder method of sowing achieved a higher grain yield than other methods. This method resulted in an optimal plant stand and a higher number of productive tillers, ultimately contributing to increased grain yield (38, 39). Among the crop establishment methods, the paddy drum seeder (M_3) yielded the highest grain yield (5277 kg/ha), followed by the line sowing method (M_2) with a grain yield of 4776 kg/ha. In the subplot, among the weed management practices, the sequential application of the PE Pretilachlor on 8 DAS, followed by the EPoE bispyribac sodium herbicide 2 times at 25 and 45 DAS (S_4), recorded a higher grain yield (4745 kg/ha), which was on par with manual weeding thrice (S_1) (4694 kg/ha). The interaction effect between sowing methods and weed management practices was significant. The combinations of paddy drum seeder sowing with sequential application of PE herbicide Pretilachlor, followed by EPoE herbicide bispyribac sodium two times at 25 and 45 DAS (M_3S_4), resulted in the highest grain yield (5426 kg/ha), which was on par with manual weeding thrice (S_1) (M_3S_1) (5374 kg/ha) when compared to other treatments (Fig. 3).

Direct seeding of rice with a drum seeder has resulted in a 12% increase in yield and reduced labour costs

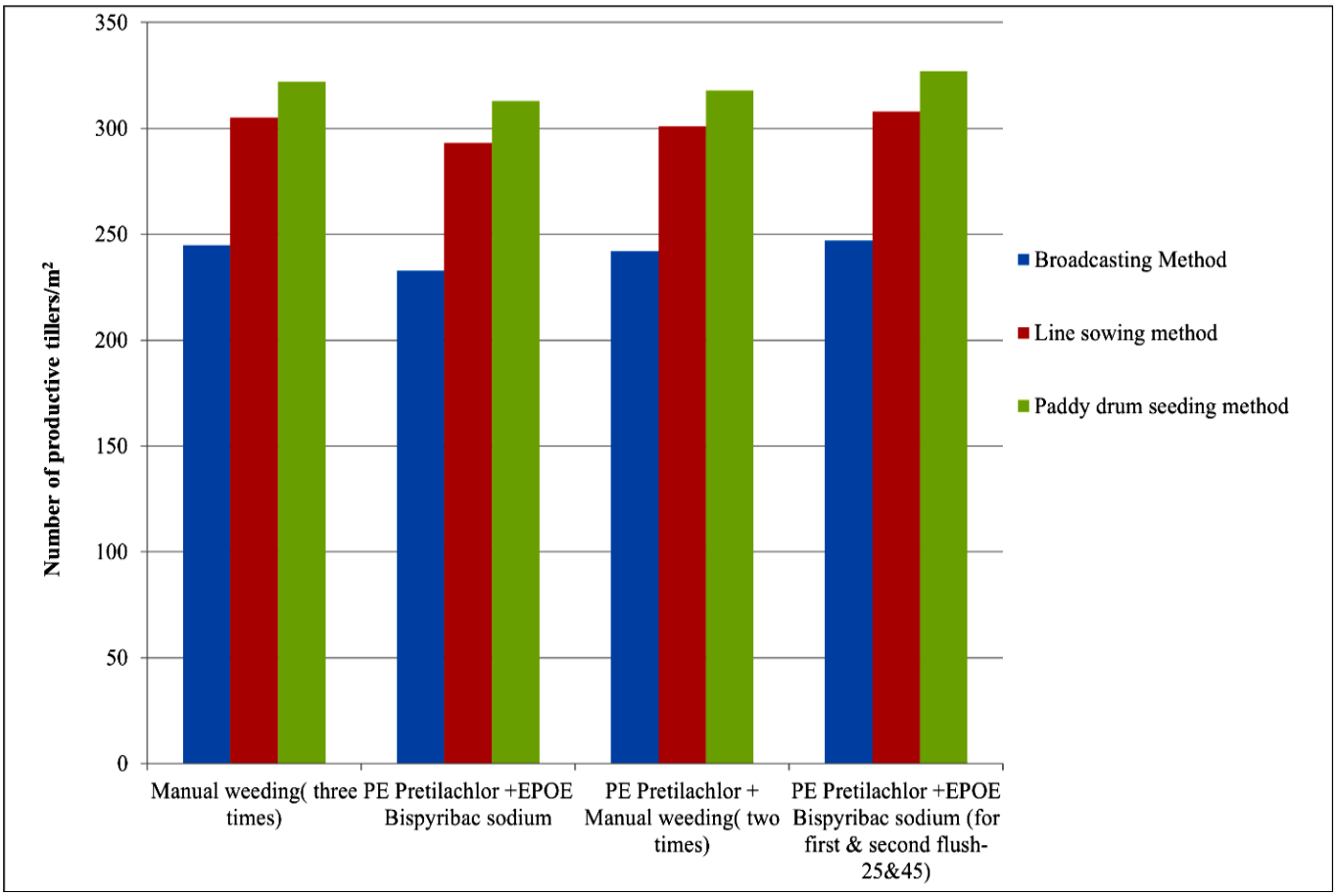

Fig. 2. Assessment of treatment effects on the number of productive tillers/m² in wet direct-seeded rice (Pooled analysis of 3 years of data)

compared to traditional transplanting methods (42). Research (41) also observed an improved grain yield with the drum seeder establishment method combined with herbicide application. Using the paddy drum seeder in the first fortnight of July (*Kharif* season) achieved a 33% higher grain yield than the broadcasting method (43). In direct-seeded rice, pre-emergence herbicide application and early post-emergence reduced weed density, leading to a higher grain yield (29, 44). The 2 applications of bispyribac sodium at 21 and 40 DAS provided higher yields by minimizing weed emergence (44). Applying bispyribac-sodium at the 2-3 leaf stage of weeds effectively reduced weed density, ultimately increasing rice grain yield without causing phytotoxicity or leaving residual effects on subsequent crops (45). Similar findings demonstrated that the sequential application of pre-emergence followed by post-emergence herbicide enhanced weed control and increased grain yield in wet direct-seeded rice (36). These integrated strategies effectively managed a broad spectrum of weed species, including grasses, sedges and broadleaf weeds, thus enhancing crop growth, yield components and overall productivity in rice cultivation systems.

application of the pre-emergence herbicide Pretilachlor, followed by the early post-emergence application of bispyribac sodium herbicide applications at two times at 25 and 45 DAS (M_3S_4), yielded the higher gross return (Rs.113946/ha) (Table 2), net return (Rs.67324/ha) and benefit: cost ratio (2.44) (Fig 5 & 6). In contrast, the broad-

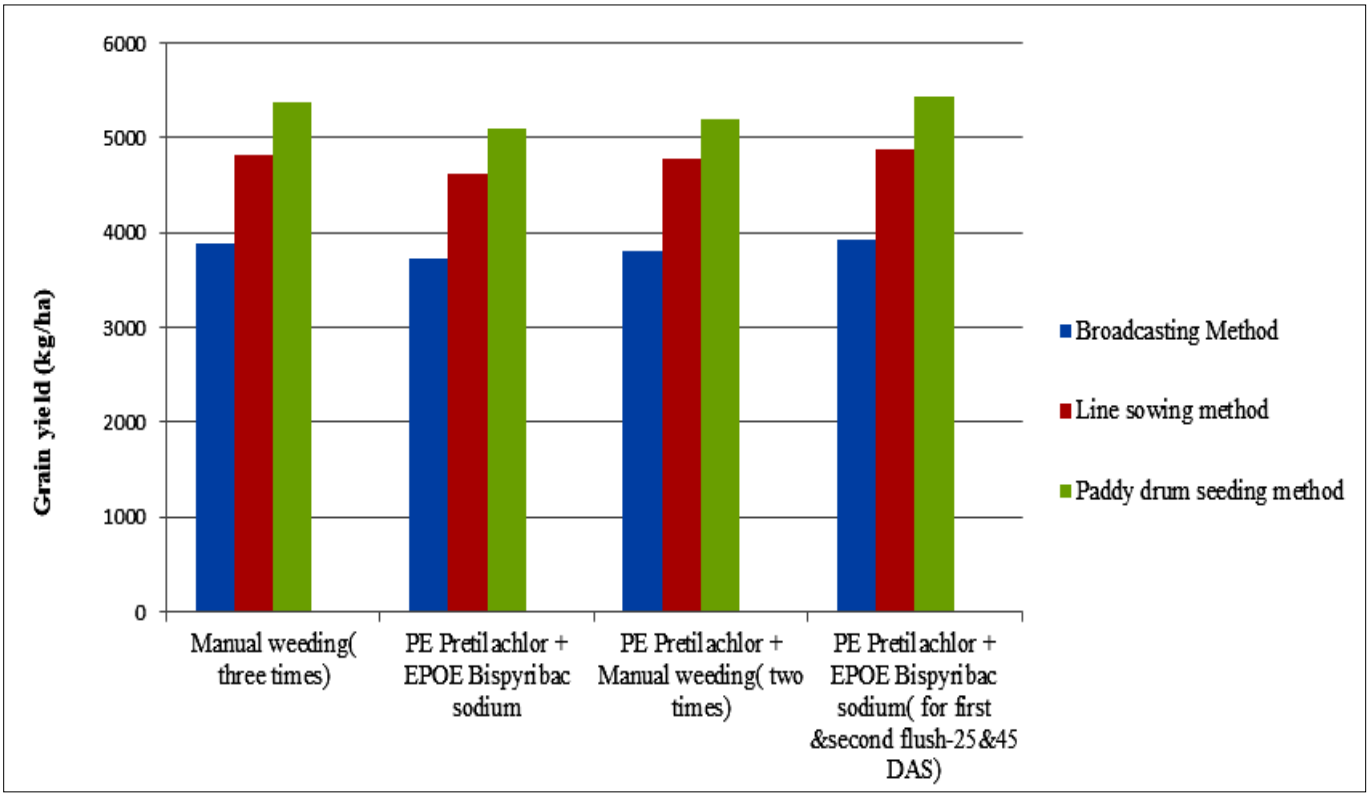

Fig. 3. Impact of treatments on grain yield (kg/ha) in wet direct-seeded rice (Pooled analysis of 3 years of data)

Grain yield showed a negative relationship with weed growth and a positive relationship with the number of productive tillers/m^2 (Fig. 4A and 4B). The R^2 value for the number of productive tillers/m^2 was 0.9823, indicating a strong correlation with the grain yield of *Kharif* rice. These results suggest that reducing weed population and biomass positively impacted rice productivity during the *kharif* season.

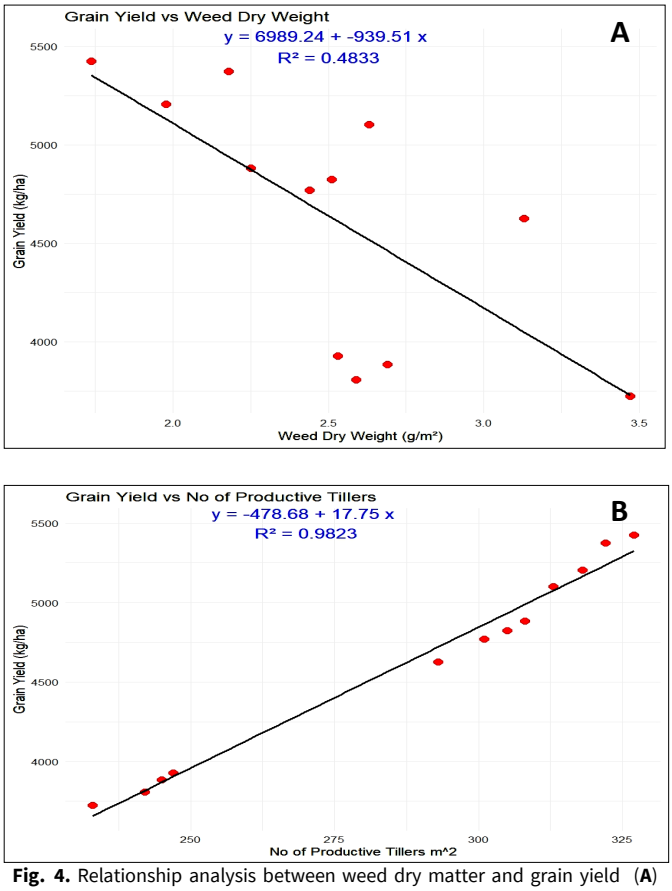

Fig. 4. Relationship analysis between weed dry matter and grain yield (**A**) Number of productive tillers/m^2 with grain yield (**B**) in *kharif* rice

Economics

Paddy drum seeder sowing, combined with the sequential

casting method with 3 manual weeding (M_1S_1) recorded the lowest net returns (Rs.35659/ha) and benefit-cost ratio (1.77) among all weed management practices due to the higher cost of cultivation. Combining drum seeding with effective herbicide applications improves weed control and economic returns in direct-seeded rice. The approach of pre-emergence followed by post-emergence herbicide application is recognized as a cost-efficient weed management strategy (30). This approach resulted in higher grain yields, gross returns and a better benefit-cost ratio than other methods (29). Drum seeding achieved higher gross and net returns than broadcasting and a superior benefit-cost ratio (11). Furthermore, the sequential application of pretilachlor and bispyribac sodium in drum-seeded rice effectively controlled weeds, increased grain yield and enhanced economic returns (46). Using a paddy drum shows a more significant net income per hectare and a higher benefit-cost ratio than traditional broadcasting methods (47). These findings indicate that integrating with suitable herbicide applications can improve weed management and economic viability in wet direct-seeded rice cultivation.

Table 2. Impact of treatments on economic returns (Rs/ha) in wet direct-seeded rice

Treatment combinations	Grain yield (kg/ha)	Total cost of cultivation (Rs./ha)	Gross returns (Rs./ha)
M_1S_1	3885	45926	81585
M_1S_2	3725	41352	78225
M_1S_3	3806	43468	79926
M_1S_4	3927	42326	82467
M_2S_1	4824	46873	101304
M_2S_2	4625	43365	97125
M_2S_3	4771	45436	100191
M_2S_4	4883	44220	102543
M_3S_1	5374	47982	112854
M_3S_2	5102	45435	107142
M_3S_3	5206	47766	109326
M_3S_4	5426	46622	113946

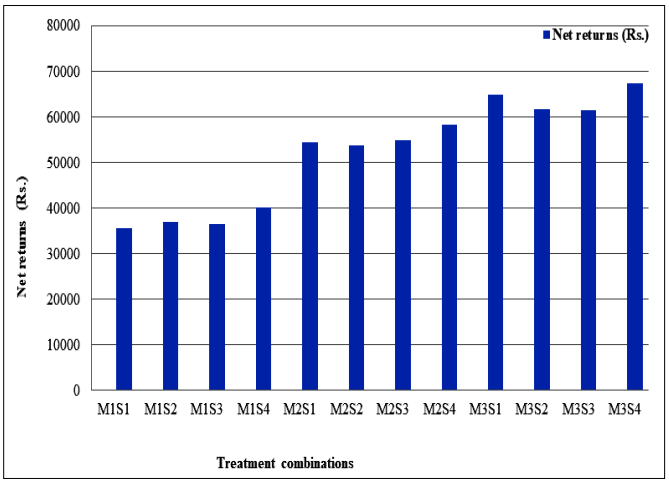

Fig. 5. Analysis of treatment effect on Net returns (Rs/ha) on wet direct-seeded rice

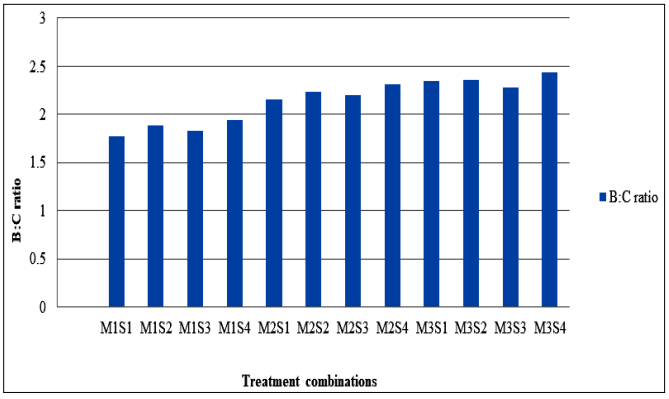

Fig. 6. Analysis of treatment effect on B:C ratio on wet direct seeded rice

Conclusion

An appropriate sowing method with effective weed management in wet, direct-seeded rice offers a promising solution to current issues related to global water scarcity, rising labour shortages and increased labour costs. It was concluded that the paddy drum seeder method of sowing is more feasible and practical than broadcasting and line sowing methods for enhancing productivity and ensuring efficient weed management in wet, direct-seeded rice. Additionally, among the various weed management strategies, the sequential application of the pre-emergence Pretilachlor, followed by the early post-emergence application of bispyribac sodium for the first and second flushes of weeds at 25 and 45 days after sowing, effectively reduced weed density and weed dry weight. This approach resulted in more productive tillers and greater grain yield than other methods. In the future, direct-seeded rice could potentially replace the traditional transplanting method in Tamil Nadu due to labour and water shortages.

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Authors' contributions

GSK conceptualized and conducted the experiment, collected the data and analyzed the data; NS, RS and SM were involved in designing and coordinating the experiment. GS, CB, KS and PP contributed to preparing the manuscript. All authors read and approved the final manuscript.

Compliance with ethical standards

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

Ethical issues: None

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