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RESEARCH ARTICLE

Weed biology and crop-weed competition dynamics in direct-seeded rice ecosystems

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Abstract

The field experiment was conducted to assess the effects of weed competition on the growth and yield of direct-seeded rice (DSR) under puddled and unpuddled conditions at Tamil Nadu Rice Research Institute, Aduthurai, Thanjavur, during the Kharif seasons of 2019 and 2020. The experimental site, characterized by a sub-tropical climate and alluvial clay soil, demonstrated significant differences in weed emergence, with earlier sprouting observed in unpuddled conditions. Weed biology, particularly the germination patterns and growth rates of various weed species, was crucial in shaping weed competition dynamics. In unpuddled conditions, certain weeds, especially annual grasses, exhibited rapid seedling establishment, benefiting from the more open, less waterlogged soil conditions. Weed density assessments indicated higher competition levels in weedy plots, particularly 30 days after sowing, with grasses dominating the weed population. This was due to the higher viability and faster germination rates of these species under unpuddled conditions. Weed biology also revealed that weed species with deep root systems were better able to access nutrients and water deeper in the soil, which further intensified competition with the rice crop, particularly in unpuddled plots. In contrast, puddled conditions inhibited the growth of certain weed species by restricting oxygen access to their roots and promoting anaerobic soil conditions, which helped reduce the weed biomass and competition. Plant growth attributes, including height and tiller counts, were significantly greater in puddled DSR plots, resulting in higher yields than unpuddled plots. Notably, yield losses due to weed competition were most pronounced between 30 and 45 days after sowing, a critical growth phase when rice plants are most vulnerable to weed pressure. This period coincided with peak weed germination and establishment, which led to severe competition for light, nutrients and water. These results underscore the importance of understanding weed biology in the context of weed management strategies. Effective control measures, tailored to the biology of the dominant weed species in each system, are essential to maximizing DSR productivity. Furthermore, the advantages of puddled cultivation, which limit weed growth and improve rice yield, highlight its importance as a key practice in sustainable rice farming.

Keywords: direct-seeded rice (DSR); plant growth attributes; puddled conditions; weed competition; weed density; unpuddled conditions; yield

Introduction

Rice serves as a principal food source for more than half of the world's population, with particular significance in South and Southeast Asia and Latin America, where it supports local diets and economies. Additionally, rice has emerged as a high-value commodity crop in non-traditional regions. Over the past two decades, many Asian countries have transitioned from the traditional method of transplanting rice seedlings to direct-seeding practices. This change has been mainly driven by rising production costs, particularly in labour and water, which have posed significant challenges to farmers. Direct-seeding of rice (DSR) encompasses various methodologies, including sowing pre-germinated seeds onto puddled soil surfaces (wet-seeding), into shallow standing water (water-seeding), or using dry seed in prepared seedbeds (dry-seeding). In regions such as Europe, Australia and the United States, DSR has entered a phase of high mechanization, enhancing its efficiency. However, a primary concern across all seeding methods is the increased risk of crop yield loss due to weed competition. Unlike transplanted rice, where the growth conditions often suppress weed development, DSR faces challenges due to the simultaneous emergence of weeds and crop seedlings. This lack of initial size differential allows weeds, adapted to rapid growth, to compete effectively for essential resources, ultimately impacting rice yield. Yield loss in rice due to weed infestation can vary significantly depending on various factors such as the type of weeds, rice variety, growth stage of the plants and management practices. Generally, it is estimated that weeds can cause yield losses in rice ranging from 20 % to as high as 80 % if not controlled appropriately (1).

With the production of conventional puddled transplanted rice increasingly constrained by water scarcity, labour shortages and climatic variability, DSR presents a viable alternative that conserves water and reduces labour demands while also contributing to lower greenhouse gas (GHG) emissions. When properly managed, the yields obtained from

DSR can be comparable to those from transplanted rice. Recent advancements in agronomic practices and the promotion of suitable rice varieties have further encouraged the adoption of DSR practices. Despite these advantages, DSR systems are beset by significant constraints, particularly related to high weed infestation. Weeds substantially threaten crop yield, quality and overall production costs by competing for light, nutrients and water. Research indicated that weeds can cause yield losses ranging from 15 to 20 %, with extreme cases leading to losses exceeding 50 % or even complete crop failure (1). Notably, prolonged weed competition in wet-seeded rice caused grain yield reductions of 69.71 % and 67.40 % during the kharif and rabi seasons, respectively (2).

In DSR systems, the competition between crops and weeds is especially critical given that both often emerge simultaneously. This dynamic diminishes the competitive advantage of rice seedlings, exacerbated by intermittent wetting and drying conditions that facilitate weed growth. The severity of competition is influenced by the weed species involved and factors such as weed density, competition duration and soil fertility. In DSR, weeds emerge simultaneously with crop seedlings and grow more quickly in moist soil than in puddled transplanted rice, resulting in severe competition for resources to the crop (3).

Acknowledging the importance of effective Weed management in Direct Seeded Rice (DSR) systems is crucial for optimizing production and resource utilization, with the critical period for weed control spanning from 2 to 6 weeks after sowing. Understanding weed biology, including seed germination and emergence, growth habits, reproductive strategies, competitive ability and life cycles, is essential for developing effective management strategies. Key management approaches include cultural practices (crop rotation, altering planting dates and competitive rice varieties), mechanical control (timely tillage and manual weeding), chemical control (judicious use of herbicides) and Integrated Weed Management (IWM) combining multiple strategies for enhanced efficacy and sustainability. Implementing these strategies during this critical period can significantly reduce yield losses and improve rice productivity. Similarly, the critical period for mixed weed infestations extends from 12 to 60 days after sowing (4). The ability to control weeds effectively during the initial growth stages (0 to 40 days) is closely linked to improved productivity in DSR. Maintaining a weed-free environment during the first 60 to 70 days after sowing can yield comparable results to a weed-free scenario until harvest (3). Thus, understanding weed biology and assessing crop-weed competition are imperative to improving DSR practices. Given this context, the present research trial aims to document weed biology and assess crop-weed competition during the critical growth intervals of 15, 30, 45 and 60 days after sowing in wet and dry direct-seeded rice ecosystems. Insights gained from this study will contribute to developing effective weed management strategies, ultimately enhancing productivity and sustainability in rice cultivation.

Materials and Methods

Experimental site

Field experiments were conducted at the Tamil Nadu Rice Research Institute, Aduthurai, Thanjavur, during the kharif seasons of 2019 and 2020. The experimental site is situated at a latitude of 11 °N and a longitude of 79 °E, at an altitude of 19.5 m above Mean Sea Level (MSL). The variety selected for the experiment is ADT 57, which was released in 2022 by the Tamil Nadu Rice Research Institute, TNAU, Aduthurai. It is a short-duration variety (115 days) with special characters such as resistance to blast and moderate resistance to sheath blight, brown plant hopper and also tolerance to brown spot, tungro, stem borer and leaf folder.

Climate and weather conditions

The region experiences a sub-tropical climate, characterized by a hot and dry summer from March to June, followed by an extended wet period from September to February. The average annual rainfall recorded at the site is approximately 1078 mm, most occurring during the North East Monsoon.

Soil characteristics

The soil at the experimental site is classified as clay in texture, moderately drained and is characterized as alluvial clay. The soil composition was 13.6 % sand, 61.2 % silt and 25.3 % clay. The soil pH was 7.5 (1:5 H_2O) and the electrical conductivity (EC) was recorded at 11.6 mS m^{-1}. Nutrient analysis revealed that the soil is medium in available nitrogen (252 kg ha^{-1}) and phosphorus (45.7 kg ha^{-1}) content, while potassium levels were assessed to be high (126 kg ha^{-1}).

Experimental design

The experiments were laid out in a split-plot design with three replications. The treatments such as DSR under puddled condition (M_1) and DSR under unpuddled condition (M_2) in main plot and Weedy up to 15 DAS (S_1), 30 DAS (S_2), 45 DAS (S_3), 60 DAS (S_4), Weedy condition (Weedy check) (S_5), WF upto 15 DAS (S_6), 30 DAS (S_7), 45 DAS (S_8), 60 DAS (S_9), WF condition (Check) (S_{10}) in Sub plot were imposed. Recommended doses of fertilizers and irrigations were given uniformly. Herbicides for concerned treatments were applied with a knapsack sprayer with a spray volume of 500 l/ha in the weed-free plots. The rest of the management practices were following the recommended package of practices for the individual crop. Weed counts (monocots and dicots) were recorded at the flowering stage with the help of 50 x 50 cm quadrates at two random places in each plot. The data on weed density and dry weight were recorded and statistical analysis was adopted. Crop growth and yield attributes were also statistically analysed. The statistical analysis was done as per the procedure (5). The critical difference at a 5 % probability level was calculated for the treatments with a significant difference. Treatments without significant difference were denoted by NS (Non-Significant).

Results and Discussion

Weed flora

The important weeds observed in the experimental field include grasses such as *Echinochloa colona* L., *Leptochloa chinensis* L., *Panicum repens* L., *Dactyloctenium aegyptium* Beauv. and *Cynodon dactylon* L. Pers. Among sedges, Cyperus *rotundus and Fimbristylis miliacea* are predominant in direct-seeded rice. In case of broadleaf weeds, *Ludwigia parviflora* and *Marsilea quadrifoliate* are dominant weeds (Fig. 1).

Effect of treatments on time of weed emergence

Irrespective of weed species, early emergence of weeds was observed under unpuddled conditions compared to puddled conditions. Studies have shown that in unpuddled fields, the edaphic conditions favour weed germination due to better soil aeration and moisture retention (6). Specific soil properties, such as texture and organic matter content, can significantly affect the germination rates of different weed species. Their research illustrated that fine-textured soils in unpuddled fields provided optimal conditions for early weed emergence due to better moisture retention (7). During the kharif season, the timing of weed emergence was consistent across two years of observation, indicating that grasses generally emerged earlier than sedges and broadleaf weeds in both puddled and unpuddled situations. This is further supported by research highlighting that maintaining flooded conditions can serve as an effective weed control strategy, particularly against annual grasses and certain perennial weeds (8). Similarly, various weed species exhibit differential emergence patterns influenced by soil conditions (4). Specifically, all observed weed species demonstrated earlier emergence in unpuddled conditions, supporting earlier research which concluded that puddled conditions create a less favourable environment for initial weed growth due to increased soil saturation and the suppressive effects of standing water on certain weeds (9) (Table 1) .

Effect of treatments on weed parameters

The weed density was recorded at different stages (15, 30, 45 and 60 days after sowing) during the kharif seasons of 2019 and 2020 (Tables 2 & 3). A significant influence on weed density was observed under both puddled and unpuddled DSR conditions. Notably, higher weed density was recorded in weedy plots compared to weed-free plots across all stages of crop growth. Lesser weed density was observed under puddled conditions than in unpuddled situations, likely due to the suppressive effects of anaerobic soil conditions on weed germination and establishment (10).

The most excellent weed density was noted 30 days after sowing (DAS), aligning with reports indicating that weed competition intensifies as weeds establish themselves and resources become limited (11). Additionally, grass weed densities were consistently higher than sedges and broadleaf weeds throughout the growing season. Grass species often exhibit more aggressive growth patterns compared to other weed types. A similar trend regarding weed dry weight was also observed in both years (Tables 4 & 5), confirming the competitive nature of grass weeds and their impact on rice crop growth and yield (12).

Managing weed competition is vital for maximizing crop productivity, particularly in rice systems where weeds can severely impact yield (13). Furthermore, variations in weed species composition can also significantly affect the competitive outcomes in cropping systems (14). Subsequently, the role of soil management practices in moderating weed dynamics and their subsequent impact on crop yield (15).

Effect of treatments on growth and yield attributes of rice

The plant attributes, such as plant height, number of tillers, productive tillers and yield, were significantly influenced by treatments in both seasons under puddled and unpuddled DSR conditions. Notably, higher plant height (104 cm and 106.5 cm), number of tillers (354 and 361.1 Nos.m^{-2}), number of productive tillers (339.9 and 341.1 Nos. m^{-2}) and yield (5577 kg ha^{-1} and 5724 kg ha^{-1}) were recorded under puddled DSR conditions compared to unpuddled DSR during kharif 2019 and 2020, respectively which was increased by 12.6 and 19.3 % over unweeded plot. Puddling enhances soil moisture retention and nutrient availability, ultimately improving rice's growth parameters and yield (16) (Table 6).

Regarding weed management, weedy plots registered significantly lower yields compared to weed-free situations. The data suggest that the critical period for weed control occurs between 30 and 45 days after sowing (DAS), during which greater yield losses were observed. This aligns with findings from several studies, which state that unchecked weed growth during this crucial growth phase can severely hinder plant development and reduce competitive ability (6). The greater weed menace during this period consequently influenced yield reductions more than at other developmental stages, affirming the importance of timely weed management strategies to mitigate yield losses in both kharif seasons. Moreover, a peak weed competition occurs as the crop establishes, especially around 30 DAS, underscoring the need for effective weed management practices to enhance rice productivity (12).

As illustrated in your study's findings, the detrimental effects of weeds on nutrient uptake and light availability directly correlate to reduced growth indicators and yield. Additional studies suggest that covering crops and crop rotation can significantly suppress weed emergence and improve crop performance (17). Furthermore, integrating allelopathic crops could be an effective bio-weed management strategy in rice fields (18). The timing of herbicide application plays a crucial role in managing weed populations during critical growth periods for rice, suggesting that effective chemical strategies must be aligned with crop development phases (19).

Table 1. Time of weed emergence under puddled and unpuddled DSR

GRASSES	Puddled condition	Unpuddled condition
Echinochloa crusgalli, Cynodon dactylon, Leptochloa chinensis, *Panicum repens*, *Dactyloctenium aegyptium*	6-7 days after sowing	5 days after sowing
EDGES		
Cyperus rotundus. Fimbristylis miliacea	10 - 12 days after sowing	7-8 days after sowing
BROAD LEAF WEEDS		
Ludwigia parviflora, Marsilea	14 days after sowing	10-12 days after sowing

Echinochloa crus galli

Cynodon dactylon

Cyperus rotundus

Fimbristylis miliacea

Ludwigia purviflora

Marsilea quadrifolia

Fig. 1. Weed flora identified in direct-seeded rice.

Table 2. Influence of treatments on weed density of grasses, sedges and BLW at different stages under direct seeded rice during kharif 2019 (Numbers m^{-2})

Treatments	Grasses				Sedges				BLW			
	15 DAS	30 DAS	45 DAS	60DAS	15 DAS	30 DAS	45 DAS	60DAS	15 DAS	30 DAS	45 DAS	60DAS
M1S1	20.8	5.0	1.7	1.7	13.7	3.0	1.0	0.7	10.33	1.0	1	0.7
M1S2	22.6	29.3	3.7	1.7	17.3	19.3	1.7	1.3	10.67	13.0	1	1.3
M1S3	23.7	35.7	29.0	3.7	16.0	25.7	23.0	1.7	12.00	17.3	12	1.7
M1S4	25.8	31.3	24.3	21.3	18.7	25.7	24.3	11.3	15.33	19.0	14	10.7
M1S5	25.3	36.0	39.7	40.3	20.3	24.3	32.7	18.7	16.00	19.3	19	14.3
M1S6	0.0	11.3	7.0	5.7	0.0	5.3	2.3	2.0	0	3.3	2	0.3
M1S7	0.0	0.0	5.0	5.3	0.0	0.0	2.3	2.3	0	0.0	2	1.7
M1S8	0.0	0.0	0.0	1.3	0.0	0.0	0.0	0.7	0	0.0	0	0.7
M1S9	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0	0.0	0	0.0
M1S10	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0	0.0	0	0.0
M2S1	30.2	17.0	9.3	2.0	24.7	8.3	4.3	1.3	13.67	2.7	4	0.7
M2S2	32.3	40.7	13.0	5.7	24.0	28.0	9.3	2.3	13.67	14.0	9	1.7
M2S3	31.9	40.3	31.7	7.0	23.0	29.0	29.3	3.7	14.00	15.0	20	2.0
M2S4	29.0	37.0	39.0	39.0	24.0	29.0	33.3	29.3	16.67	19.3	21	18.7
M2S5	29.1	42.3	43.3	43.0	25.7	36.3	36.3	31.7	18.00	22.7	23	19.0
M2S6	0.0	12.7	7.7	1.3	0.0	4.0	2.7	0.7	0	1.3	1	0.3
M2S7	0.0	0.0	3.3	1.7	0.0	0.0	1.7	1.3	0	0.0	1	1.0
M2S8	0.0	0.0	0.0	2.0	0.0	0.0	0.0	1.3	0	0.0	0	1.3
M2S9	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0	0.0	0	0.0
M2S10	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0	0.0	0	0.0

Table 3. Influence of treatments on weed density of grasses, sedges and BLW at different stages under direct seeded rice during kharif 2020 (Numbers m^{-2})

Treatments	Grasses				Sedges				BLW			
	15 DAS	30 DAS	45 DAS	60DAS	15 DAS	30 DAS	45 DAS	60DAS	15 DAS	30 DAS	45 DAS	60DAS
M_1S_1	28.3	6.3	2.0	1.0	16.3	2.3	2.0	1.3	14.7	1.3	1.7	1.7
M_1S2	26.0	31.3	4.3	2.3	19.7	20.7	2.0	1.7	16.0	14.0	2.3	1.7
M1S3	26.0	35.3	34.3	3.7	20.7	24.3	25.7	2.0	14.7	18.3	12.7	2.0
M1S4	28.7	37.3	32.7	22.7	22.0	26.0	26.3	12.7	16.3	19.7	17.0	12.0
M1S5	29.3	39.0	42.3	43.0	21.3	27.7	33.3	19.3	18.0	19.7	20.3	15.7
M1S6	0.0	11.7	5.7	4.3	0.0	5.3	2.0	2.0	0.0	2.3	1.7	1.0
M1S7	0.0	0.0	4.0	3.7	0.0	0.0	2.7	2.3	0.0	0.0	1.7	2.0
M1S8	0.0	0.0	0.0	2.7	0.0	0.0	0.0	0.7	0.0	0.0	0.0	1.7
M1S9	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
M1S10	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
M2S1	36.3	19.0	9.3	1.7	26.0	5.7	4.0	1.3	15.3	1.7	4.3	1.7
M2S2	36.0	38.0	13.0	4.7	27.0	29.3	7.7	2.3	16.3	16.0	10.0	2.3
M2S3	37.0	41.7	36.3	5.0	26.0	31.0	31.0	3.3	17.3	16.7	21.0	2.7
M2S4	35.7	42.7	35.0	41.3	25.7	33.0	34.3	32.3	18.7	21.0	22.3	22.0
M2S5	38.0	45.0	46.3	44.0	27.0	37.3	38.7	33.3	19.3	24.3	24.3	20.0
M2S6	0.0	11.3	5.0	1.7	0.0	3.3	2.7	1.3	0.0	1.0	1.3	1.7
M2S7	0.0	0.0	3.3	2.3	0.0	0.0	2.0	2.0	0.0	0.0	0.7	1.0
M2S8	0.0	0.0	0.0	2.3	0.0	0.0	0.0	2.7	0.0	0.0	0.0	1.0
M2S9	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
M2S10	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0

Main plot: M_1 - DSR under puddled condition; M_2 - DSR under unpuddled condition. Sub plot: S_1 - Weedy upto 15 DAS; S_2 - Weedy upto 30 DAS; S_3 - Weedy upto 45 DAS; S_4 - Weedy upto 60 DAS; S_5 - Weedy condition (Weedy check); S_6 - WF upto 15 DAS; S_7 - WF upto 30 DAS; S_8 - WF upto 45 DAS; S_9 - WF upto 60 DAS; S_{10} - WF condition (Check)

Table 4. Influence of treatments on weed dry weight of grasses, sedges and BLW at different stages under direct seeded rice during kharif 2019 (g m^{-2})

Treatments	Grasses				Sedges				BLW			
	15 DAS	30 DAS	45 DAS	60DAS	15 DAS	30 DAS	45 DAS	60DAS	15 DAS	30 DAS	45 DAS	60DAS
M1S1	1.25	0.45	0.17	0.20	1.01	0.27	0.09	0.07	0.85	0.09	0.07	0.08
M1S2	1.35	2.64	0.37	0.20	1.28	1.72	0.15	0.15	0.87	1.18	0.13	0.16
M1S3	1.42	3.21	2.90	0.44	1.18	2.28	2.12	0.18	0.98	1.58	1.18	0.20
M1S4	1.55	2.82	2.43	2.56	1.38	2.28	2.24	1.25	1.26	1.73	1.40	1.28
M1S5	1.52	3.24	3.97	4.84	1.50	2.17	3.01	2.05	1.31	1.76	1.89	1.72
M1S6	0	1.02	0.70	0.68	0	0.47	0.21	0.22	0	0.30	0.23	0.04
M1S7	0	0	0.50	0.64	0	0	0.21	0.26	0	0	0.23	0.20
M1S8	0	0	0	0.16	0	0	0	0.07	0	0	0	0.08
M1S9	0	0	0	0	0	0	0	0	0	0	0	0
M1S10	0	0	0	0	0	0	0	0	0	0	0	0
M2S1	1.81	1.53	0.93	0.24	1.83	0.74	0.40	0.15	1.12	0.24	0.42	0.08
M2S2	1.94	3.66	1.30	0.68	1.78	2.49	0.86	0.26	1.12	1.27	0.91	0.20
M2S3	1.91	3.63	3.17	0.84	1.70	2.58	2.70	0.40	1.15	1.37	1.93	0.24
M2S4	1.74	3.33	3.90	4.68	1.78	2.58	3.07	3.23	1.37	1.76	2.03	2.24
M2S5	1.75	3.81	4.33	5.16	1.90	3.23	3.34	3.48	1.48	2.06	2.25	2.28
M2S6	0	1.14	0.77	0.16	0	0.36	0.25	0.07	0	0.12	0.10	0.04
M2S7	0	0	0.33	0.20	0	0	0.15	0.15	0	0	0.13	0.12
M2S8	0	0	0	0.24	0	0	0	0.15	0	0	0	0.16
M2S9	0	0	0	0	0	0	0	0	0	0	0	0
M2S10	0	0	0	0	0	0	0	0	0	0	0	0

Table 5. Influence of treatments on weed dry weight of grasses, sedges and BLW at different stages under direct seeded rice during kharif 2020 (g m^{-2})

Treatments	Grasses				Sedges				BLW			
	15 DAS	30 DAS	45 DAS	60DAS	15 DAS	30 DAS	45 DAS	60DAS	15 DAS	30 DAS	45 DAS	60DAS
M1S1	1.70	0.95	0.38	0.20	3.27	0.44	0.36	0.25	1.31	0.19	0.30	0.32
M1S2	1.56	4.70	0.81	0.46	3.93	3.89	0.36	0.32	1.42	1.96	0.42	0.32
M1S3	1.56	5.30	6.45	0.73	4.13	4.57	4.62	0.38	1.31	2.57	2.25	0.38
M1S4	1.72	5.60	6.14	4.51	4.40	4.89	4.74	2.41	1.45	2.75	3.03	2.28
M1S5	1.76	5.85	7.96	8.56	4.27	5.20	6.00	3.67	1.60	2.75	3.62	2.98
M1S6	0	1.75	1.07	0.86	0.00	1.00	0.36	0.38	0.00	0.33	0.30	0.19
M1S7	0	0.00	0.75	0.73	0.00	0.00	0.48	0.44	0.00	0.00	0.30	0.38
M1S8	0	0.00	0.00	0.53	0.00	0.00	0.00	0.13	0.00	0.00	0.00	0.32
M1S9	0	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
M1S10	0	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
M2S1	2.18	2.85	1.75	0.33	5.20	1.07	0.72	0.25	1.36	0.23	0.77	0.32
M2S2	2.16	5.70	2.44	0.93	5.40	5.51	1.38	0.44	1.45	2.24	1.78	0.44
M2S3	2.22	6.25	6.83	1.00	5.20	5.83	5.58	0.63	1.54	2.33	3.74	0.51
M2S4	2.14	6.40	6.58	8.23	5.13	6.20	6.18	6.14	1.66	2.94	3.98	4.18
M2S5	2.28	6.75	8.71	8.76	5.40	7.02	6.96	6.33	1.72	3.41	4.33	3.80
M2S6	0	1.70	0.94	0.33	0.00	0.63	0.48	0.25	0.00	0.14	0.24	0.32
M2S7	0	0.00	0.63	0.46	0.00	0.00	0.36	0.38	0.00	0.00	0.12	0.19
M2S8	0	0.00	0.00	0.46	0.00	0.00	0.00	0.51	0.00	0.00	0.00	0.19
M2S9	0	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
M2S10	0	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00

Main plot: M_1 - DSR under puddled condition; M_2 - DSR under unpuddled condition. Sub plot: S_1 - Weedy upto 15 DAS; S_2 - Weedy upto 30 DAS; S_3 - Weedy upto 45 DAS; S_4 - Weedy upto 60 DAS; S_5 - Weedy condition (Weedy check); S_6 - Weed Free upto 15 DAS; S_7 - WF upto 30 DAS; S_8 - WF upto 45 DAS; S_9 - WF upto 60 DAS; S_{10} - WF condition (Check)

Table 6. Influence of treatments on growth and yield of DSR under puddled and unpuddled conditions

Treatments	2019-20				2020-21			
	Plant height (cm)	No. of tillers (Nos.m^{-2})	No. of productive tillers (Nos.m^{-2})	Yield (kg/ha)	Plant height (cm)	No. of tillers (Nos.m^{-2})	No. of productive tillers (Nos.m^{-2})	Yield (kg/ha)
Main plot								
M1 - DSR under puddled	104.0	354.3	339.9	5577	106.50	361.1	341.1	5724
M2 - DSR under unpuddled	99.0	348.2	341.7	5321	103.26	354.0	324.9	5645
SEd	0.08	2.54	2.59	26.12	0.08	2.23	2.54	28.12
CD (0.05)	0.33	10.93	11.15	112.0	0.33	9,10	10.93	112.0
Sub plot								
S_1 - Weedy upto 15 DAS	103.4	342.1	336.8	5407	101.31	338.3	324.5	5600
S_2 -Weedy upto 30 DAS	100.4	339.8	325.0	5060	103.22	326.8	317.8	5294
S_3 - Weedy upto 45 DAS	99.5	345.6	310.6	5054	102.43	338.2	327.3	5165
S_4 – Weedy upto 60 DAS	98.6	340.2	305.3	5046	104.60	340.1	331.0	5661
S_5 – Weedy condition (Weedy check)	93.4	332.5	284.1	4950	102.57	312.5	301.8	4800
S_6 – Weed Free upto 15 DAS	101.8	359.3	340.0	5686	103.28	362.5	343.0	5661
S_7 – Weed Free upto 30 DAS	103.5	363.2	342.5	5737	105.17	341.0	338.1	5781
S_8 – Weed Free upto 45 DAS	104.3	359.5	349.0	5786	107.98	342.1	339.3	5771
S_9 – Weed Free upto 60 DAS	105.0	362.5	351.8	5801	108.80	345.2	337.8	5833
S_{10} – Weed Free condition (Check)	107.1	368.3	357.6	5824	109.48	356.6	349.5	5980
SEd	0.47	7.44	7.0	104	0.43	6.91	7.40	114
CD (0.05)	0.94	15.09	14.0	211	0.90	13.1	15.09	212

Conclusion

The findings of this study underscore the critical importance of effective weed management in direct-seeded rice (DSR) systems, particularly during the crucial growth period between 30 to 45 days after sowing, when significant yield losses can occur due to weed competition. The research indicates that puddled DSR conditions enhance rice growth and yield compared to unpuddled systems by optimizing soil moisture and nutrient availability, suppressing weed emergence. Additionally, the study highlights the dominance of grass species within weed populations, emphasizing the need for targeted management strategies to mitigate their competitive effects. By implementing timely and effective weed control practices, farmers can boost rice productivity and ensure the sustainability of rice cultivation in the face of increasing agricultural challenges.

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Compliance with ethical standards

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