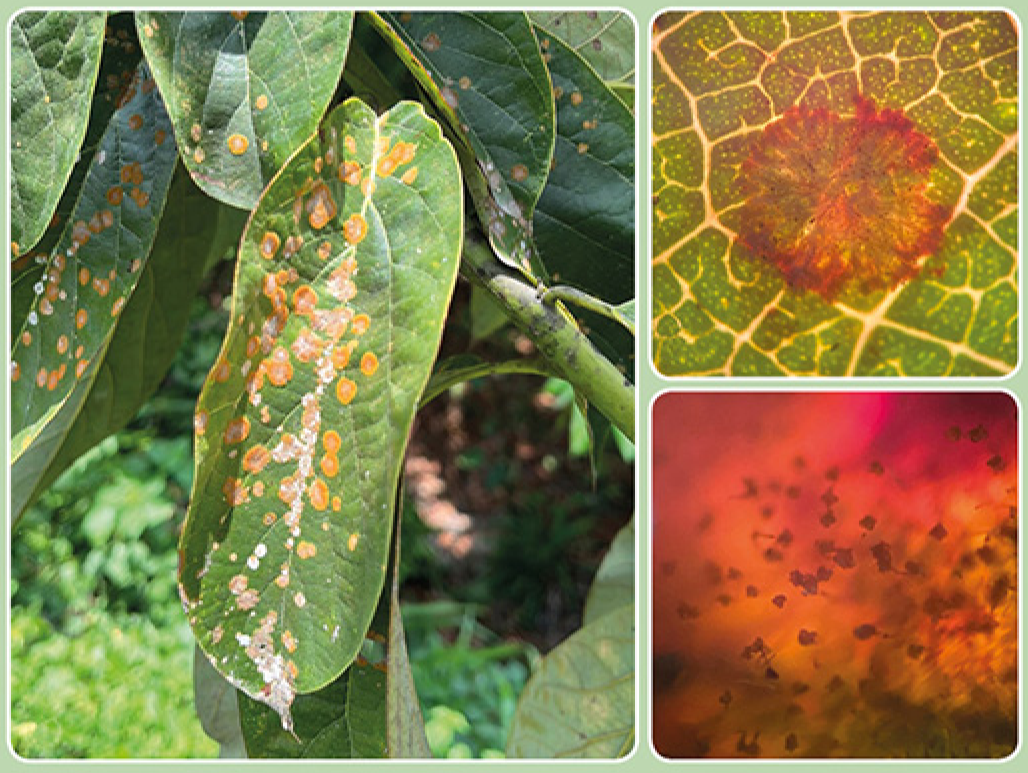
ISSN 1727-1320 (Print),
ISSN 2308-6459 (Online)

ВЕСТНИК
ЗАЩИТЫ РАСТЕНИЙ

PLANT PROTECTION NEWS

2025 ТОМ VOLUME 108 ВЫПУСК ISSUE 1



Санкт-Петербург
St. Petersburg, Russia

OECD+WoS: 4.01+AM (Agronomy) https://doi.org/10.31993/2308-6459-2025-108-1-16765

Full-text article

IMPACT OF WEED MANAGEMENT STRATEGIES ON THEIR GROWTH, COMMUNITY COMPOSITION, AND YIELD OF WET DIRECT-SEEDED RICE UNDER ALTERNATE WETTING AND DRYING IRRIGATION

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Water management systems of wet direct-seeded rice (WDSR) and alternate wetting and drying (AWD) have proven to be effective resource-conserving (RC) technologies for rice production. However, weed management (WM) practice in RC technology has not been adequately addressed in the literature. This study aimed to investigate weed dynamics and integrated weed management strategies in WDSR under the AWD irrigation system. Two field experiments were conducted with seven weed management options over two consecutive growing seasons, 2009–2010 and 2010–2011, at the Bangladesh Rice Research Institute, Gazipur. Results showed that the weed species *Scirpus juncoides*, *Echinochloa crus-galli,* and *Cynodon dactylon* were the most important. By contrast*, Fimbristylis miliaceae, Cyperus iria,* and *Lindernia floribunda* seemed to belong to the least important group. Weeds that interfered up to 55 days after seeding had a significant impact on rice growth and yield. Over time, weed dominance ranking changed. The application of herbicides mefenacet+bensulfuron methyl and pyrazosulfuron ethyl along with one-hand weeding effectively reduced weed growth, leading to higher weed control efficiency and grain yield. These two treatments reduced the weed-related indices, and increased the crop resistance.

Keywords: rice growing, weed dynamics, weed control, grain yield

Submitted: 24.12.2024 *Accepted: 04.04.2025*

Introduction

Rice cultivation using the transplanting method involves raising, uprooting, and transplanting seedlings. Labor for these operations accounts for nearly one-third of the total production cost in Bangladesh. To address these challenges, various rice cultivation methods have been developed. Wet direct-seeded rice (WDSR) with the drum seeder technique is one of the most resource-conserving technologies (RCTs). Moreover, alternate wetting and drying (AWD) irrigation systems, when combined with WDSR, are even more efficient and should be adopted by resource-poor farmers in Bangladesh. WDSR with the AWD irrigation system requires about 20–25 % less water than traditional transplantation methods while also significantly reduces labor. WDSR is now being adopted in Bangladesh, especially in single boro-cropped areas. To fully leverage this technology, weed management issues must be carefully addressed. Effective weed management is crucial for achieving optimum grain yield in the AWD irrigation system. The species composition and abundance of weeds in WDSR differ from those in the puddled flooded rice system (Mahajan et al., 2009). Information regarding weed flora composition, weed growth, and their responses to different herbicides in the WDSR system is insufficient in Bangladesh. Generally, most soil-applied rice herbicides require humid or even flooded conditions for effective weed control, which are not met under this system. Therefore, a broader range of herbicides should be evaluated to identify those best suited for these less humid conditions.

Weed management in the AWD system revolves around grass weeds, predominantly *Echinochloa* spp. AWD reduced broadleaf weed pressure (Vial, 2005) and increased a share of grass-type weeds, overall enhancing weed growth and development, which compete with rice and reduce yield. So proper weed management strategies are required for AWD irrigation systems.

In wet-seeded rice, oxadiazon (Alam et al., 2002), pretilachlor + safener (Awan et al., 2003; Bhuiyan et al., 2011), ethoxysulfuran, and butachlor (Bhuiyan et al., 2009) have proven effective in Bangladesh. However, only a limited number of herbicides suitable for WDSR are available in the country. There is no detailed information available to assist farmers in choosing which type of herbicide to apply. Additionally, there is a lack of knowledge regarding the appropriate application time, the chemical group of the herbicide, and water management during herbicide application. In recent years, several herbicides (mefenacet + bensulfuron methyl 53 % wp, oxadiargyl 400 SC, pendimethalin, pyrazosulfuron - ethyl) have demonstrated excellent efficacy in transplanted paddy (Bhuiyan and Ahmed, 2010; Bhuiyan et al., 2010).

However, effective weed control in WDSR by drum seeder with AWD irrigation is crucial. We hypothesized that in WDSR under the AWD irrigation system dynamics of weed pattern, weed abundance, weed growth may differ from transplanted rice, and grain yield would be increased if appropriate weed management strategies could be followed.

Therefore, the objectives of this study were to analyze weed occurrence, growth, and community composition in direct wet-seeded rice under the AWD irrigation system and to evaluate yield performance under different weed control systems.

Materials and Methods

Experimental site, soil, and climate

The field studies were conducted at the experiment site of Bangladesh Rice Research Institute (BRRI) farm, Gazipur, situated at 24°99’ North latitude and 90°40’ East longitude at an elevation of 8.4 m above mean sea level. This area is characterized by a subtropical climate. The soil of the experimental site was clay loam of the shallow brown terrace under the Madhupur tract (AEZ 28). The experimental field was classified as a Chhiata clay loam, a hyperthermic Vertic Endoaquept.

Climatic parameters, including rainfall, evaporation, maximum and minimum temperatures, were collected from the BRRI automatic weather station located near the experimental site. The daily values were averaged (maximum and minimum temperature, solar radiation) and summed (rainfall and evaporation) to monthly values (Figure 1). The experimental area received 110.90 mm and 605.40 mm of rainfall during the dry season (Boro) of 2009–2010 and 2010–2011, respectively. Mean maximum and minimum temperatures were 34.71 and 11.81, 33.48 and 10.31 °C during the same seasons.

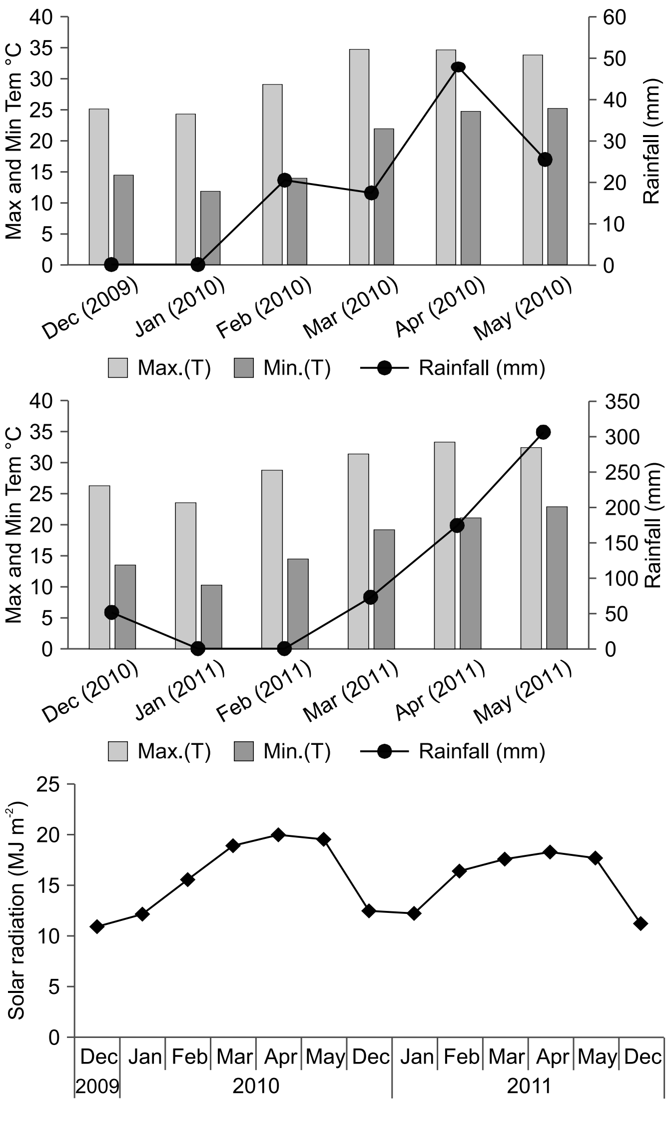

Figure 1. Monthly total rainfall (mm), average maximum and minimum temperature (°C), and average solar radiation (MJ m^{-2}) during the experimental periods of 2009–2010 and 2010–2011

Рисунок 1. Месячный объем осадков (мм), средние значения минимальной и максимальной температур (°C), и средняя солнечная радиация (МДж м$^{-2}$) в период экспериментов 2009–2010 и 2010–2011 гг.

Treatments and crop husbandry

During the dry seasons (boro) of 2009–2010 and 2010–2011, BRRI dhan29 was grown in the experimental field under alternate wetting and drying (AWD) irrigation conditions. The crop was established through direct wet seeding using a drum seeder in a single thick row. Irrigation was applied when the water was no longer visible in the AWD pipes. Weed management treatments and herbicide details of the experiment are presented in Table 1. The experiments were conducted in a randomized complete block design with three replications. The unit plot size measured 4.6 m × 4 m. The plots were surrounded by a 40 cm-high soil levee to prevent herbicide contamination between the plots. Details of the crop calendar are provided in Table 2.

Measurement and calculations

Yield and yield characters were sampled and calculated according to Gomez K.A., 1972. The grains and sterile spikelets were separated by a seed sorter (Kiya Seisakusho LDT, model 1973, Tokyo, Japan). After separation, the grains and sterile spikelets were counted by an automatic counter (Nagoya, model DC 1-0, Japan). Rice plants from a 5 m^2 preset area of the middle of each plot were harvested at ground level and threshed. Grain yield was adjusted to a 14 % moisture content (MC) as follows:

$$\mathbf{GY\_MC_{14}} = \frac{100 - MC_S}{100 - 14} \times FW,$$

where:
GY_MC_{14} = Grain yield at 14 % MC,
MC_S = Sample MC (%),
FW = fresh weight of grains at harvest.

Weed sampling

Weed dry matter and the number of weeds were calculated at 30, 55 and 80 days after seeding (DAS) from all experimental plots. Random samples were taken from within each plot using a 0.5 x 0.5 m quadrate (Kim and Moody, 1983). Data were recorded including weed species, the number of weeds and weed biomass etc.

Weed Vegetation analysis

Summed dominance ratio (SDR) of the weed species was computed using the following equation (Janiya and Moody, 1989):

$$\mathbf{SDR} = \frac{RD + RDW}{2},$$

where: RD = relative density,
RDW = relative dry weight.

$$\mathbf{RD} = \frac{Dx}{Dt} \times 100,$$

where:
Dx = density of a given species,
Dt = total density.

$$\mathbf{RDW} = \frac{DWx}{DWt} \times 100,$$

where:
DWx = dry weight of a given species,
DWt = total dry weight.

Table 1. Treatment details

Таблица 1. Детали обработок

Label Марки-ровка	Treatment Обработка	Active ingredi-ents, g ha^{-1} Активные ингри-диенты, г га$^{-1}$	Application rate per ha Норма расхо-да на гектар	Time of herbicide application and opera-tion of hand weeding, days after seeding Срок применения пестицидов и про-полки, дни после посева
T_1	Panida 33EC (pendimethalin) + 1HW on 55 DAS	825	2.5 L	5
T_2	Topstar 400 SC (oxadiargyl) + 1HW on 55 DAS	75	187.5 mL	5
T_3	Superclean 53 % WP (mefenac-et+bensulfuron methyl) + 1HW on 55 DAS	589	1111 g	5
T_4	Saathi (pyrazosulfuron - ethyl 10 WP) + 1HW on 55 DAS	15	150 g	14
T_5	Hand weeding, three times	-	-	30, 55 and 80
T_6	BRRI weeder + 1HW	-		30 (weeder operation) and 55 (one-hand weeding)
T_7	Unweeded (Control)	-	-	No weeding

Table 2. Crop calendar of the experiments

Таблица 2. Календарь выращивания культуры в ходе эксперимента

Activity Действие	I (2009–2010)	II (2010–2011)
Date of seed incubation	04.12.2009	06.12.2010
Periods of incubation	72hrs	72 hrs
Date of seeding	07.12.2009	09.12.2010
Date of panicle initiation	15.03.2010 (98 DAS)	16.03.2011(97 DAS)
Date of 100 % flowering	02.04.2010(113 DAS)	04.04.2011(115 DAS)
Date of Maturity	03.05.2010(147 DAS)	07.05.2011 (149 DAS)
Growth duration	147 days	149 days
Harvesting date	09.05.2010 (153 DAS)	10.05.2011(154 DAS)

DAS = days after seeding.

Weed Control Efficiency (WCE%), Relative Weed Density (RWD), Importance Value of Weed (IVW), and Weed Index (WI) were calculated according to Rao (1985) using the following formulas:

$$\mathbf{WCE} = \frac{\mathrm{WC} - \mathrm{Wt}}{\mathrm{WC}} \times 100,$$

where:
WC = average weed weight per unit area in weedy check,
Wt = average weed count or dry weed weight per unit area in the treated plot.
Higher values of WCE indicate greater effectiveness of the herbicide.

$$\mathbf{RWD} = \frac{\mathrm{DCx}}{\mathrm{DCt}} \times 100,$$

where:
DCx = density of individual weed species in the community,
DCt = total density of all weed species in the community.

$$\mathbf{IVW} = \frac{\mathrm{DWOx}}{\mathrm{DWOt}} \times 100,$$

where:
DWOx = dry weight of a given oven dried weed species,
DWOt = dry weight of all oven dried weed species.

$$\mathbf{WI} = \frac{\mathrm{YHW} - \mathrm{Yt}}{\mathrm{YHW}} \times 100,$$

where:
YHW = average yield of the crop in hand-weeded, weed-free plot or minimum weed competition plot,
Yt = average crop yield in a plot under other weed control treatments.
A higher value of the weed index indicates a lower yield, and a lower value of the weed index indicates a higher yield.

The percentage of yield loss (YL) of each infested plot was calculated according to Gill and Vijayakumar (1969), as follows:

$$\mathbf{YL}(\%) = \frac{\mathrm{Ywf} - \mathrm{Y}}{\mathrm{Ywf}} \times 100,$$

where:
Ywf = grain yield in weed-free plots or minimum competition plots,
Y = the grain yield from each weed-infested plot.

Weed indices were worked out using the formula of Misra and Misra (1997).

Weed persistence index (WPI) is used to indicate the resistance of weeds against various tested treatments and to confirm the efficiency of the herbicide applications.

$$\textbf{WPI} = \frac{\text{DWWt}}{\text{DWWc}} \times \frac{\text{WDc}}{\text{WDt}},$$

where:
DWWt = dry weight of weeds in treated plot,
DWWc = dry weight of weeds in treated plot,
WDt = weed density in treated plot
WDc = weed density in control plot

Crop resistance index (CRI) was calculated as follows:

$$\textbf{CRI} = \frac{\text{DMPt by crop}}{\text{DMPc by crop}} \times \frac{\text{DMPc by weeds}}{\text{DMPt by weeds}},$$

where:
DMPt = dry matter production in treated plot,
DMPc = dry matter production in control plot.

Weed Management Index (WMI) is the ratio between yield increase due to weed management and the control of weeds by the respective treatments:

$$\textbf{WMI} = \frac{\text{YI\%}}{\text{CW\%}},$$

where:
YI% = percent yield increase over control,
CW% = percent control of weeds.

Agronomic Management Index (AMI) is determined by the following formula:

$$\textbf{AMI} = \frac{\text{YI\%} - \text{CW\%}}{\text{CW\%}},$$

Integrated weed management index (IWM) is as follows:

$$\textbf{IWM} = \frac{\text{WMI} + \text{AMI}}{2},$$

where:
WMI = weed management index,
AMI = agronomic management index

Weed Control Index (WCI) is worked out by using the same formula of weed control efficiency (WCE) replacing weed populations by weed dry weight (Mishra and Tosh, 1979).

$$\textbf{WCI} = \frac{\text{DMPm2c} - \text{DMPm2t}}{\text{DMPm2c}} \times 100,$$

where:
DMPm2c = weed dry matter production per m^2 in control plot
DMPm2t = weed dry matter product per m^2 in treated plot.

Comparison of species composition among weed communities between treatments in each planting season were made using the Sorensen's index of similarity (Goldsmith *et al.,* 1986). The computation of the S values was as follows:

$$\textbf{S} = \frac{2\text{J}}{\text{A} + \text{B}} \times 100,$$

where:
S =Index of similarity between treatments A and B
J =Number of species common to both treatments A and B
A =Number of species present in treatment A
B =Number of species present in treatment B
Higher S values would indicate close similarity in species composition between treatments. Conversely, lower values reflect considerable differences in species composition.

Statistical Analysis

Year wise data were analyzed statistically by statistical software Mstat-C, version 1.41 (Russell, D.F. 1986) using analysis of variance and treatments were compared with least significant difference (LSD) at the P=0.05 level of significance. Correlations and regressions were calculated in the Microsoft Excel program. Correlation matrixes among different characters were determined by Pearson correlation using Minitab 13 statistical program.

Results

Weed growth

All the weed control treatments significantly reduced the weed population density (m^{-2}) and weed dry matter weight (gm^{-2}) at 30, 55, and 80 DAS in 2009–2010 and 2010–2011 (Table 3a,3b). In 2009–2010, the highest weed population densities were found in T_7, T_5, and the lowest (37 plants m^{-2}) in T_3 at 30 DAS throughout the entire observation period. In 2010–2011, the weed densities for control check plots (T_7) were 225, 369, and 279 weeds m^{-2} at 30, 55, and 80 DAS, respectively. Herbicide-treated, hand-weeded, and BRRI-weeded plots showed significantly lower weed densities than those of control plots at every observation date (Table 3a). The lowest weed population was found with T_3 and T_4 treatments at all observation dates.

Weed biomass was significantly affected by different weed control treatments in both growing seasons. In 2009–2010 (Table 3b) at 30 DAS, the highest weed biomass was observed in T_7 treatment (46.52g m^{-2}) which was at par with T_5 (46.19 g m^{-2}) and T_6 treatment (45.47g m^{-2}), whereas treatment T_3 (5.46 g m^{-2}) and T_4 (7.17 g m^{-2}) resulted in statistically similar and the lowest weed biomass. At 55 DAS, the weed biomass was the highest (134.16 g m^{-2}) with the T_7 and the lowest with the T_3 treatment (21.97 g m^{-2}). The highest weed biomass at 80 DAS was found with T_7 (109.49 g m^{-2}), which was significantly higher than with other weed control treatments. Weed biomass was lowest in T_3 and T_4 treatments at this stage.

In the 2010–11 Boro season, weed biomass varied significantly across herbicide treatments, following similar trends observed in 2009–10. In all cases, the highest weed biomass was recorded in the untreated control plots, which was significantly greater than in the treated plots. The lowest weed biomass occurred in treatments T3 and T4, followed by T5 and T6 (Table 3b). This indicates that T3 and T4 were the most effective in reducing both weed biomass and density.

Weed control efficiency

In the year 2009–2010 (Table 3c), at 30 DAS, the highest WCE (88%) was found in T_3, followed by T_4 (84%) treatment. The WCE was the lowest with the T_5 (1%) and T_6 (2%) treatments. At 55 DAS, the WCE of T_3 and T_4 were 84% and 81% and were close to those of T_2 (77%), T_5 (75%), and T_6 (74%) treatments. At 80 DAS, the WCE was the highest with T_3 (90%), which was closely followed by T_4 (87%) and T_5 (81%). The WCE of T_6 and T_2 attained 78%, and T_1 produced the lowest WCE (73%) at 80 DAS. In 2010–2011, WCE, at different days after seeding, followed approximately the same pattern as in 2009–2010.

Weed infestation

Most weed species found belonged to the families of Poaceae, Cyperaceae, Pontederiaceae, Onagraceae and Scrophulariaceae (Table 4). In 2009, the most dominant weed species at 30 DAS was *Scirpus juncoides* (37%), followed by *Echinochloa crus-galli* (28%). By 55 DAS, *E. crus-galli* (30%) became the most important, overtaking *S. juncoides* (21%), which declined in importance. *Cynodon dactylon* consistently ranked among the top three species, with values ranging from 26% to 29% across all time points. By 80 DAS, *E. crus-galli* (30%) remained the most dominant, while *C. dactylon* (26%) showed an increasing trend. Broadleaf weeds, such as *Sphenoclea zeylanica* and *Monochoria vaginalis*, remained minor components throughout, each contributing less than 5% importance. A similar pattern was observed in 2010, with *E. crus-galli*, *C. dactylon*, and *S. juncoides* maintaining dominance across all stages, though *S. juncoides* showed a sharper decline in importance over time.

Relative proportions of different weed types

During 2009–10, grass and sedge weeds dominated across all treatments at 30, 55, and 80 DAS, collectively contributing over 80% of the weed community (Figure 2). Sedges remained the most dominant group in terms of density throughout the season. However, by 80 DAS, the relative biomass contribution of sedges and broadleaf weeds increased, indicating a shift in weed composition. In the 2010–11 season, similar patterns were observed at 30 DAS. At 55 DAS, grasses became more dominant, while by 80 DAS, broadleaf weeds contributed the most to total weed density, with grass and sedge densities becoming lower and nearly equal. In terms of weed biomass, grasses and sedges accounted for the majority of dry matter at 30 DAS, while broadleaf weeds made a minimal contribution.

Table 3. Influence (%) of different weed control methods on weed density (a), dry matter weight (b), and weed control efficiency (c) of wet direct-seeded rice under alternate wetting and drying irrigation condition during Boro 2009–2010

Таблица 3. Влияние (%) различных методов борьбы с сорными растениями на плотность их популяции, вес сухого вещества, и эффективность борьбы (%) при выращивании влажного риса прямого посева с попеременным увлажнением и осушением в сезон боры

a.

Treatment Обработка	Weed densities (pieces m^{-2}) Плотность популяции сорных растений (шт $м^{-2}$)					
	30 DAS		55 DAS		80 DAS	
	2009–2010	2010–2011	2009–2010	2010–2011	2009–2010	2010–2011
T_1	100	90	165	130	78	70
T_2	98	65	140	98	72	62
T_3	37	39	97	51	43	38
T_4	48	48	110	62	52	53
T_5	212	205	137	124	66	66
T_6	205	206	137	123	79	85
T_7	212	225	374	369	256	279
$LSD_{(.05)}$	21.04	9.16	33.31	17.65	10.62	6.57
CV(%)	9.08	4.10	11.30	7.25	6.46	3.96

b.

Treatment Обработка	Weed dry matter weight (g m^{-2}) Вес сухого вещества сорных растений (г $м^{-2}$)					
	30 DAS		55 DAS		80 DAS	
	2009–2010	2010–2011	2009–2010	2010–2011	2009–2010	2010–2011
T_1	16.65	17.21	44.62	48.39	29.23	22.91
T_2	16.07	12.38	30.81	39.63	24.02	20.79
T_3	5.46	6.68	21.97	18.36	11.37	7.37
T_4	7.17	9.56	24.82	22.67	14.20	13.67
T_5	46.19	44.46	34.00	45.50	21.11	17.26
T_6	45.47	42.35	34.54	45.11	24.06	19.56
T_7	46.52	51.12	134.16	150.29	109.49	96.05
$LSD_{(.05)}$	3.07	2.01	10.13	7.74	8.17	2.24
CV(%)	6.60	4.31	12.31	8.24	13.78	4.47

c.

Treatment Обработка	Weed Control efficiency (%) Эффективность борьбы с сорными растениями (%)					
	30 DAS		55 DAS		80 DAS	
	2009–2010	2010–2011	2009–2010	2010–2011	2009–2010	2010–2011
T_1	64	66	68	68	73	76
T_2	65	76	77	74	78	78
T_3	88	87	84	88	90	92
T_4	84	81	81	85	87	86
T_5	1	13	75	70	81	82
T_6	2	17	74	70	78	80

T_1–T_7 annotation is given in Table 1; **DAS** = days after seeding.

Table 4. Relative density and importance value of weeds over time in wet direct-seeded rice under alternate wetting and drying condition

Таблица 4. Относительная плотность популяции и значимость сорных растений во времени при выращивании влажного риса прямого посева с попеременным увлажнением и осушением

Weed species Вид сорного растения	Family Семейство	Weed Type Тип сорного растения	Relative density, % Относительная плотность, %		Importance value, % Значимость, %	
			2009–2010	2010–2011	2009–2010	2010–2011
30 Days After Seeding (DAS)						
Cynodon dactylon	Poaceae	Grass	17.36	15.10	26.17	23.57
Echinochloa crus-galli	Poaceae	Grass	21.83	24.00	28.45	27.99
Scirpus juncoides	Cyperaceae	Sedge	52.15	46.09	36.77	33.55
Sphenoclea zeylanica	Campanulaceae	Broadleaf	1.58	4.89	1.65	3.27
Monochoria vaginalis	Pontederiaceae	Broadleaf	2.21	1.48	2.16	2.85
Cyperus difformis	Cyperaceae	Sedge	1.57	1.19	1.52	2.10
Cyperus iria	Cyperaceae	Sedge	1.40	3.25	0.88	3.06
Leptochloa chinensis	Poaceae	Grass	1.90	1.63	2.40	1.38
Ludwigia octovalvis	Onagraceae	Broadleaf	-	1.48	-	1.50
Marsilea minuta	Marsileaceae	Broadleaf	-	0.88	-	0.73
55 DAS						
Cynodon dactylon	Poaceae	Grass	16.14	15.08	29.39	24.06
Echinochloa crus-galli	Poaceae	Grass	18.88	19.23	30.24	27.30
Scirpus juncoides	Cyperaceae	Sedge	39.97	37.19	20.98	24.47
Sphenoclea zeylanica	Campanulaceae	Broadleaf	3.94	3.36	3.40	2.60
Monochoria vaginalis	Pontederiaceae	Broadleaf	3.92	3.70	2.87	2.55
Cyperus difformis	Cyperaceae	Sedge	4.75	3.26	4.39	2.50
Cyperus iria	Cyperaceae	Sedge	1.61	2.82	1.61	2.48
Leptochloa chinensis	Poaceae	Grass	3.65	3.26	2.62	3.97
Fimbristylis miliaceae	Cyperaceae	Sedge	1.08	2.88	0.77	2.86
Lindernia floribunda	Scrophulariaceae	Broadleaf	6.07	5.97	3.73	3.47
Ludwigia octovalvis	Onagraceae	Broadleaf	-	1.54	-	2.18
Marsilea minuta	Marsileaceae	Broadleaf	-	1.70	-	1.55
80 DAS						
Cynodon dactylon	Poaceae	Grass	20.54	19.14	25.59	21.60
Echinochloa crus-galli	Poaceae	Grass	21.47	21.05	29.99	30.19
Scirpus juncoides	Cyperaceae	Sedge	25.65	25.84	19.21	12.57
Sphenoclea zeylanica	Campanulaceae	Broadleaf	4.27	3.71	4.37	5.77
Monochoria vaginalis	Pontederiaceae	Broadleaf	4.29	4.07	4.08	4.66
Cyperus difformis	Cyperaceae	Sedge	5.43	4.42	4.25	5.01
Cyperus iria	Cyperaceae	Sedge	2.60	2.99	3.00	4.65
Leptochloa chinensis	Poaceae	Grass	4.18	2.87	3.06	3.38
Fimbristylis miliaceae	Cyperaceae	Sedge	2.48	3.59	2.07	3.69
Lindernia floribunda	Scrophulariaceae	Broadleaf	9.10	8.97	4.37	4.70
Ludwigia octovalvis	Onagraceae	Broadleaf	-	1.68	-	2.62
Marsilea minuta	Marsileaceae	Broadleaf	-	1.67	-	1.16

Their biomass contribution, however, increased noticeably at 55 and 80 DAS, by which time grasses and sedges showed comparable biomass levels.

Weed Composition and Summed Dominance Ratio

SDR is more informative than any single measure in reflecting the contribution of a species in the community. During the 2009–10 growing season, eight weed species were recorded at 30 DAS, increasing to ten species at both 55 and 80 DAS (Table 5). Weed communities at this early stage were characterized by a predominance of *Scirpus juncoides*, especially in treatments T1 and T2, with SDR values of 59.22 % and 58.13 %, respectively. Other treatments also showed *S. juncoides* as the dominant species, except in T4, where *Echinochloa crus-galli* (34.95 %) and *Cynodon dactylon* (22.38 %) were more abundant, followed by *S. juncoides* (19.61 %). At 55 DAS, *S. juncoides* continued to dominate in T3 and T4 with SDR values of 31.24 % and 29 %, respectively.

As the season progressed, the weed composition shifted. By 80 DAS, sedge weeds were increasingly replaced by broadleaf species. At this stage, *Lindernia floribunda* emerged as the most dominant species across all treatments, followed by *Leptochloa chinensis*. However, in the unweeded check plot, grass and sedge weeds remained dominant, with *E. crus-galli*

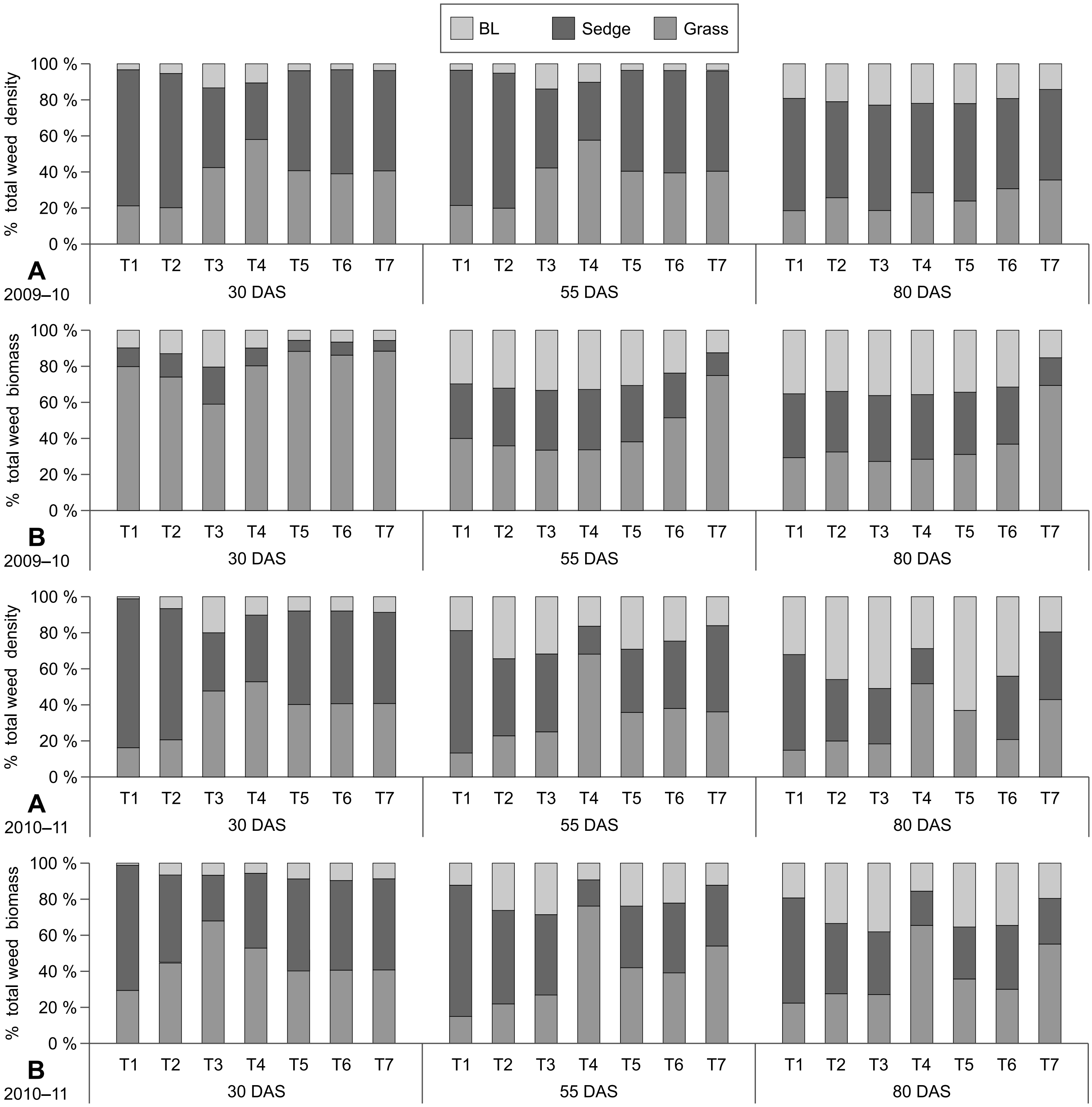

Figure 2. Relative proportion of different weed types in total weed density (A) and biomass (B) over 30–80 days after seeding (DAS). BL – broadleaf weeds

Рисунок 2. Относительная доля различных типов сорных растений в общей плотности (A) и биомассе (B) на 30–80 сутки после посева (DAS). BL – широколиственные сорные растения

(25.73 %), *C. dactylon* (23.07 %), and *S. juncoides* (22.43 %) maintaining a high share of total weed coverage.

In 2010–11, ten weed species were recorded at 30 DAS, increasing to twelve at 55 and 80 DAS (Table 6). At 30 DAS, sedge weeds dominated in T1, T2, T5, T6, and T7, with *S. juncoides* contributing SDR values of 62.92 %, 48.29 %, 42.00 %, 40.26 %, and 39.82 %, respectively. These communities were also characterized by notable shares of *E. crus-galli* and *C. dactylon*. By contrast, treatment T3 was dominated by *C. dactylon* (27.01 %) and *E. crus-galli* (24.53 %), while in T4, *E. crus-galli* led with 26.03 %, followed by *S. juncoides* and *C. dactylon*. Additionally, T5, T6, and T7 were distinguished by the appearance of two new species, though they contributed minimally to overall coverage.

Weed infestation at 55 DAS was characterized by noticeable shifts in community composition. During this intermediate stage, the composition was more evenly distributed among grasses, sedges, and broadleaf weeds, with no clear dominance pattern. Treatments T1, T2, and T3 still showed the highest SDR values for *S. juncoides* (44.01 %, 21.24 %, and 17.53 %, respectively), while in T5, T6, and T7, *E. crus-galli* was most dominant, followed by *S. juncoides*.

By 80 DAS, the weed community composition had shifted further, with broadleaf weeds becoming more dominant.

Lindernia floribunda attained the highest SDR across all treatments, indicating its strong late-season presence. In T4 and T7, *E. crus-galli* continued to contribute substantially, with SDR values of 22.39 % and 25.62 %, respectively

Coefficient of similarity

Comparison of species composition among weed communities across treatments in each planting season were made using the Sorensen's Index of Similarity (S). In 2009–2010 the Sorenson's Index of Similarity" reached its maximum value (100 %) at different observation periods (30, 55 and 80 DAS) across all treatments, indicating 100 % similarity in weed species composition between treatments. During the growing season of 2010–2011 (Tables 7) the coefficient of similarity remained rather high, varying from 82.35 to 100 % across different treatments. At 30 DAS, the similarity indices ranged from 82.35 % to 100 %, with treatments T2, T3, and T4 exhibiting complete similarity. At 55 DAS, similarity values ranged from 86.95 % to 100 %, with complete similarity recorded in treatments T2, T6, and T7. By 80 DAS, weed communities across treatments became even more homogeneous, with similarity values varied between 90.0 % and 100 %. The consistently high similarity across treatments and observation dates suggests that the weed flora remained largely stable across the experimental plots and that management practices had relatively minor effects on species presence, though may have influenced weed density or dominance.

Weed indices and crop relationship

In 2009–2010 at 30 DAS, the lowest WPI value (0.66) was recorded for T_3 plot followed by $T_4$2009–2010 (Table 8). Both T_6 and unweeded control (T_7) showed the highest WPI values. At 80 DAS, T_3 treatment yielded the lowest WPI followed by T_4 treatment. The highest WPI was observed in T_1 treatment. At 30 DAS, crop resistance index (CRI) was highest in T_3 treatment (27.19) followed by T_4 treatment (19.45). At 80 DAS, the highest value of CRI was observed also in T_3 plot (30.80) followed by the T_4 plot (23.74). Lower values were observed in T_1 (10.49) and T_2 (13.03) plots. Higher CRI values were found to be consistently correlated with lower WPI and vice-versa. In the growing season of 2010–2011, similar relationships between WPI and CRI were observed (Table 9), where T_3 and T_4 treatments demonstrated lower WPI and

Table 5. Summed dominance ratio of weeds in wet direct-seeded rice under alternate wetting and drying in different periods across various weed management options during Boro season 2009–2010

Таблица 5. Суммированный уровень доминирования сорных растений при выращивании влажного риса прямого посева с попеременным увлажнением и осушением в сезон боры 2009–2010 гг.

Treatment Обработка	Weed Species /Вид сорных растений									
	CD	ECG	SJ	SZY	MV	CDF	CI	LC	FM	LF
30 days after seeding (DAS)										
T_1	12.62	17.63	59.22	2.84	1.93	2.18	1.78	1.80	-	-
T_2	13.44	15.05	58.13	3.48	2.64	2.33	2.23	2.70	-	-
T_3	20.53	20.07	27.40	9.65	6.63	5.47	3.98	6.26	-	-
T_4	22.38	34.95	19.61	4.72	4.29	5.52	4.52	4.00	-	-
T_5	21.47	26.50	43.15	2.01	1.76	1.36	1.31	2.46	-	-
T_6	18.61	26.45	45.40	1.30	2.82	1.61	1.47	2.34	-	-
T_7	21.76	25.14	44.46	1.61	2.18	1.54	1.14	2.15	-	-
SE(±)	1.53	2.53	5.54	1.09	0.66	0.69	0.51	0.59		
55 DAS										
T_1	7.65	12.81	42.38	7.00	5.49	5.77	4.34	2.62	3.04	8.90
T_2	6.37	16.28	32.87	6.17	5.83	5.64	6.34	4.42	4.31	11.77
T_3	8.66	8.63	31.24	6.17	6.20	6.48	7.87	6.09	5.72	12.94
T_4	8.06	11.13	29.00	6.42	6.66	6.66	8.16	5.82	6.00	12.09
T_5	7.27	16.08	29.05	7.19	5.81	6.49	6.32	4.66	5.29	11.83
T_6	6.07	30.27	24.21	6.10	4.11	6.50	4.03	3.81	5.18	9.72
T_7	22.76	24.56	30.48	3.67	3.39	4.57	3.14	0.92	1.61	4.90
SE(±)	2.23	2.91	2.11	0.44	0.44	0.28	0.74	0.68	0.60	1.05
80 DAS										
T_1	7.13	10.45	16.96	7.48	7.40	6.91	7.10	10.31	5.35	20.92
T_2	6.83	11.64	14.22	7.11	7.65	7.89	6.86	12.11	3.44	22.24
T_3	6.40	7.69	10.27	6.88	7.43	7.59	6.23	15.09	5.12	27.31
T_4	6.27	8.39	11.04	7.81	6.30	7.21	9.56	13.77	6.17	23.49
T_5	7.01	9.48	11.69	7.78	5.98	6.69	9.23	13.06	5.81	23.28
T_6	7.70	11.63	13.64	6.48	7.23	8.05	7.09	13.46	6.23	18.50
T_7	23.07	25.73	22.43	4.32	4.19	4.84	3.62	2.28	2.80	6.73
SE(±)	2.32	2.34	1.60	0.46	0.47	0.41	0.75	1.63	0.51	2.49

CD = *Cynodon dactylon,* **ECG** = *Echinochloa crus-galli,* **SJ** = *Scirpus juncoides,* **SZY** = *Sphenoclea zeylanica,*
MV = *Monochoria vaginalis,* **CDF**= *Cyperus difformis*, **CI**= *Cyperus iria,* **LC**= *Leptochloa chinensis*
FM= *Fimbristylis miliaceae,* **LF**= *Lindernia floribunda;*
T_1–T_7 annotation is given in Table 1.

higher CRI over different observation periods compared to other weed management treatments. Again, in the growing season of 2009–2010 (Table 10), T_3 and T_4 treatments showed a lower weed management index (WMI) at 30, 55, and 80 DAS compared to others treatments. At 80 DAS, higher WMI – 1.11 and 1.09I – were obtained in T_1 and T_6 treatments, respectively, and lower WMII – 0.96 and 0.98I – were recorded for T3 and T4 treatments. Regarding the agronomic management index (AMI), lower values were also obtained in T_3 and T_4 treatments at all observation periods (30, 55, and 80 DAS). Considering the integrated weed management index (IWMI), the lowest value of IWMI was found in T_3 plots followed by T_4 plots at 30, 55, and 80 DAS, while T_1, T_2, T_5, and T_6 plots recorded higher IWMI at the same observation period. At 80 DAS, the IWMI values showed notable variation among treatments. Lower values were observed in T3 (0.46) and T4 (0.48), while significantly higher values were recorded for T5 (0.56), T6 (0.59), and T1 (0.61), highlighting a clear difference in water management efficiency across the treatments.

During the 2010–2011 growing season (as shown in Table 11), WMI, AMI, and IWMI showed similar trends as in the 2009–2010 season. However, the values of these indices were generally lower in 2010–2011 compared to the previous year.

Impact of weed biomass on yield loss

Average data from the 2009–2010 and 2010–2011 growing seasons showed no significant yield loss at 30 DAS. But at 55 DAS, significant yield loss was recorded, and yield loss showed linear and significant correlation with weed biomass. The relationship between weed biomass and yield loss at different crop growth periods (30, 55, and 80 DAS) is illustrated in Figure 3. At 30 DAS, the regression equation was: $Y = 0.5626x + 14.681$. The coefficient of determination: $R^2 = 0.1125$ (non-significant). The relationship between weed biomass and yield loss was not statistically significant. This suggests that weed biomass had no notable impact on rice yield early in the crop's growth (30 DAS). At 55 DAS, the regression equation was: $Y = 0.6465x - 3.9319$. The coefficient of determination: $R^2 = 0.8463$ (highly significant, $p < 0.01$). A strong and significant positive linear relationship was observed. This means that yield loss increased substantially with rising weed biomass, approximately 9.1 to 13.7 g/m² of weed biomass caused

Table 6. Summed dominance ratio (SDR) of weeds in wet direct-seeded rice under alternate wetting and drying in different periods across various weed management options in Boro season 2010–2011

Таблица 6. Суммированный уровень доминирования (SDR) сорных растений при выращивании влажного риса прямого посева с попеременным увлажнением и осушением в сезон боры 2010–2011 гг.

Treatment Обработка	Weed Species /Вид сорных растений											
	CD	ECG	SJ	SZY	MV	CDF	CI	LC	LO	MN	LF	FM
30 days after seeding (DAS)												
T_1	9.00	11.60	62.92	0.00	1.47	7.25	5.31	2.44	0.00	0.00	-	-
T_2	11.72	17.95	48.29	2.45	4.24	6.11	5.15	4.10	0.00	0.00	-	-
T_3	27.01	24.53	13.30	6.92	6.26	10.56	4.90	6.51	0.00	0.00	-	-
T_4	19.56	26.03	23.43	5.00	2.81	3.95	5.87	13.35	0.00	0.00	-	-
T_5	19.30	25.78	42.00	4.24	2.50	2.29	1.24	0.97	1.00	0.67	-	-
T_6	17.38	28.63	40.26	4.75	2.45	1.34	1.85	1.77	0.85	0.71	-	-
T_7	19.34	25.99	39.82	4.08	2.16	1.64	3.16	1.51	1.49	0.81	-	-
SE(±)	2.22	2.26	6.12	0.82	0.61	1.29	0.69	1.66	0.24	0.15		
55 DAS												
T_1	6.03	8.49	44.01	4.86	0.00	13.43	5.90	0.00	2.26	1.44	6.48	7.10
T_2	6.84	12.40	21.24	5.49	9.30	9.93	9.14	3.46	2.39	2.71	10.20	6.91
T_3	7.88	11.85	17.53	8.94	7.12	7.87	10.39	6.95	0.00	5.53	8.49	7.44
T_4	24.66	34.21	5.73	2.52	0.00	4.09	2.29	13.63	3.14	3.52	3.28	2.93
T_5	10.50	21.88	19.34	5.41	0.00	3.87	6.42	6.70	5.23	4.72	11.15	4.77
T_6	5.61	29.65	19.50	3.54	3.18	5.38	7.94	3.61	3.53	2.43	10.46	5.17
T_7	19.57	23.27	30.83	2.98	3.13	2.88	3.61	2.87	1.86	1.63	4.72	2.65
SE(±)	2.84	3.67	4.52	0.82	1.41	1.45	1.10	1.65	0.61	0.58	1.16	0.75
80 DAS												
T_1	7.20	7.22	26.79	4.81	0.00	10.53	9.10	4.56	3.78	0.00	17.26	8.76
T_2	9.22	6.96	13.25	7.81	7.11	7.08	6.60	7.89	3.42	2.62	18.62	9.41
T_3	7.70	6.56	8.12	6.42	5.29	8.43	8.71	8.57	4.80	1.18	26.54	7.68
T_4	21.22	22.39	3.85	0.00	3.22	4.24	7.77	14.95	3.33	0.00	15.46	3.58
T_5	5.94	12.76	6.53	8.63	4.09	5.37	9.50	13.40	2.59	3.22	22.98	4.99
T_6	6.11	9.75	15.28	7.44	6.80	6.35	6.48	10.12	4.81	1.89	18.23	6.74
T_7	20.37	25.62	19.21	4.74	4.36	4.71	3.13	3.64	2.15	1.42	6.83	3.82
SE(±)	2.54	2.97	3.02	1.10	0.91	0.84	0.83	1.59	0.38	0.46	2.34	0.89

CD = *Cynodon dactylon,* **ECG** = *Echinochloa crus-galli,* **SJ** = *Scirpus juncoides,* **SZY** = *Sphenoclea zeylanica,*
MV = *Monochoria vaginalis,* **CDF** = *Cyperus difformis*, **CI** = *Cyperus iria,* **LC** = *Leptochloa chinensis*,
LO = *Ludwigia octovalvis,* **MN** = *Marcelia minuta,* **LF** = *Lindernia floribunda,* **FM** = *Fimbristylis miliaceae;*
T_1–T_7 annotation is given in Table 1.

Table 7. Sorensen's Index of similarity in weed species among different weed management treatments of wet direct-seeded rice under alternate wetting and drying irrigation in Boro 2010–2011

Таблица 7. Индекс сходства Соренсена состава сорных растений в зависимости от обработки при выращивании влажного риса прямого посева с попеременным увлажнением и осушением в сезон боры 2010–2011 гг.

Treatment Обработка	T_1	T_2	T_3	T_4	T_5	T_6	T_7
30 days after seeding (DAS)							
T_1	-	93.33	93.33	93.33	82.35	82.35	82.35
T_2	93.33	-	100	100	88.88	88.88	88.88
T_3	93.33	93.33	-	100	88.88	88.88	88.88
T_4	93.33	100	100	-	88.88	88.88	88.88
T_5	82.35	88.88	88.88	88.88	-	100	100
T_6	82.35	88.88	88.88	88.88	100	-	100
T_7	82.35	88.88	88.88	88.88	100	100	-
55 DAS							
T_1	-	90.90	85.71	95.23	95.23	90.90	90.90
T_2	90.90	-	95.65	95.65	95.65	100	100
T_3	85.71	95.65	-	90.90	90.90	95.65	95.65
T_4	95.23	95.65	90.90	-	100	95.65	95.65
T_5	95.23	95.65	90.90	100	-	86.95	95.65
T_6	90.90	100	95.65	95.65	86.95	-	100
T_7	90.90	100	95.65	95.65	95.65	100	-
80 DAS							
T_1	-	90.90	90.90	90.0	90.90	90.90	90.90
T_2	90.90	-	100	90.90	100	100	100
T_3	90.90	100	-	90.90	100	100	100
T_4	90.0	90.90	90.90	-	90.90	90.90	90.90
T_5	90.90	100	100	90.90	-	100	100
T_6	90.90	90.90	100	90.90	100	-	100
T_7	90.90	100	100	90.90	100	100	-

T_1–T_7 annotation is given in Table 1.

Table 8. Effect of weed control methods on Weed Persistence Index (WPI) and Crop Resistance Index (CRI) in wet direct-seeded rice at 30, 55 and 80 days after seeding (DAS) during Boro season 2009–2010

Таблица 8. Влияние методов борьбы с сорными растениями на индекс персистирования сорных растений (WPI) и индекс резистентности культуры (CRI) при выращивании влажного риса прямого посева через 30, 55 и 80 дней после посева (DAS) в сезон боры 2009–2010 гг.

Treatment Обработка	WPI			CRI		
	30 DAS	55 DAS	80 DAS	30 DAS	55 DAS	80 DAS
T_1	0.763	0.735	0.869	7.80	8.59	10.49
T_2	0.767	0.715	0.769	8.07	12.11	13.03
T_3	0.666	0.660	0.618	27.19	19.53	30.80
T_4	0.692	0.666	0.630	19.45	16.12	23.74
T_5	0.995	0.718	0.734	2.93	11.52	15.79
T_6	1.013	0.717	0.759	2.90	11.01	13.06
T_7	1.0	1.0	1.0	1.0	1.0	1.0

T_1– T_7 annotation is given in Table 1.

1 % to 10 % yield loss, respectively. At 80 DAS, the regression equation was: $Y = 0.8382x + 2.5279$. The coefficient of determination: $R^2 = 0.8522$ (highly significant, $p < 0.01$). The relationship was again strong and significant, even more pronounced than at 55 DAS. A weed biomass of just 9.01 g/m² resulted in a 10 % yield loss at 80 DAS. These findings clearly indicate that weed biomass has an increasingly severe impact on yield loss as the crop matures. While early-season weeds (30 DAS) may not significantly affect yield, unchecked weed growth during the mid to late periods (55 and 80 DAS) results in substantial yield reductions. Rice plants become more sensitive to weed competition at later stages, and even small amounts of weed biomass can cause significant yield losses by 80 DAS (Figure 3).

Table 9. Effect of weed control methods on Weed Persistence Index (WPI) and Crop Resistance Index (CRI) in wet direct-seeded rice at 30, 55 and 80 days after seeding (DAS) during Boro season 2010–2011

Таблица 9. Влияние методов борьбы с сорными растениями на индекс персистирования сорных растений (WPI) и индекс резистентности культуры (CRI) при выращивании влажного риса прямого посева через 30, 55 и 80 дней после посева (DAS) в сезон боры 2010–2011 гг.

Treatment Обработка	WPI			CRI		
	30 DAS	55 DAS	80 DAS	30 DAS	55 DAS	80 DAS
T_1	0.84	0.84	0.95	3.25	4.01	3.88
T_2	0.85	0.85	0.97	4.88	4.89	4.82
T_3	0.75	0.75	0.56	11.26	13.78	14.67
T_4	0.87	0.87	0.75	8.09	11.04	11.14
T_5	0.96	0.96	0.76	1.58	4.46	5.82
T_6	0.91	0.91	0.67	1.52	4.93	4.16
T_7	1.0	1.0	1.0	1.0	1.0	1.0

T_1–T_7 annotation is given in Table 1.

Table 10. Effect of weed control methods on three agronomic indices of weed-crop relationships in wet direct-seeded rice at 30, 55 and 80 days after seeding (DAS) during Boro season 2009–2010

Таблица 10. Влияние методов борьбы на отношения сорных растений с культурой владного риса прямого посева через 30, 55 и 80 дней после посева (DAS) в сезон боры 2009–2010

Treatment Обработка	Weed Management Index Индекс контроля сорных растений			Agronomic Management Index Индекс агротехнического контроля			Integrated weed Management Index Индекс интегрированного контроля сорных растений		
	30 DAS	55 DAS	80 DAS	30 DAS	55 DAS	80 DAS	30 DAS	55 DAS	80 DAS
T_1	1.26	1.198	1.11	0.26	0.198	0.105	0.76	0.698	0.61
T_2	1.27	1.075	1.06	0.27	0.075	0.058	0.77	0.575	0.56
T_3	0.98	1.034	0.96	-0.02	0.034	-0.036	0.48	0.534	0.46
T_4	1.01	1.052	0.98	0.01	0.052	-0.017	0.51	0.552	0.48
T_5	162.76	1.143	1.06	161.76	0.143	0.055	162.26	0.643	0.56
T_6	41.84	1.142	1.09	40.84	0.142	0.087	41.34	0.642	0.59
T_7	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00

T_1–T_7 annotation is given in Table 1.

Table 11. Effect of weed control methods on three agronomic indices of weed-crop relationships in wet direct-seeded rice at 30, 55 and 80 days after seeding (DAS) during Boro season 2010–2011

Таблица 11. Влияние методов борьбы на отношения сорных растений с культурой владного риса прямого посева через 30, 55 и 80 дней после посева (DAS) в сезон боры 2010–2011

Treatment	Weed Management Index Индекс контроля сорных растений			Agronomic Management Index Индекс агротехнического контроля			Integrated weed Management Index Индекс интегрированного контроля сорных растений		
	30 DAS	55 DAS	80 DAS	30 DAS	55 DAS	80 DAS	30 DAS	55 DAS	80 DAS
T_1	0.51	0.47	0.31	0.13	0.11	0.001	0.57	0.53	0.31
T_2	0.32	0.36	0.28	0.05	0.07	0.014	0.35	0.40	0.28
T_3	0.15	0.14	0.08	-0.01	-0.02	-0.071	0.15	0.13	0.05
T_4	0.23	0.18	0.17	0.05	0.01	0.001	0.26	0.18	0.17
T_5	7.96	0.43	0.22	0.85	0.18	0.033	8.38	0.52	0.24
T_6	5.13	0.43	0.26	0.80	0.16	0.047	5.53	0.51	0.28
T_7	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00

T_1–T_7 annotation is given in Table 1.

Grain yield and yield components

In 2009–2010 (Table 12), the number of panicles m^{-2} was the highest (389) under the treatment mefenacet+bensulfuron methyl with 1HW (T_3) which was statistically identical to treatment with pyrazosulfuron ethyl with 1HW (T_4) that produced 373 panicles m^{-2} followed by hand weeding performed three times (T_5) and BRRI weeder + 1 HW (T_6). The lowest panicle density (136) was observed in control (T_7). Similarly, the highest number of grains per panicle was produced in T_3 treatment (89) although it did not differ statistically from all other weeding treatment except control plot (T_7). Mefenacet + bensulfuran methyl with 1HW (T_3) resulted in the longest

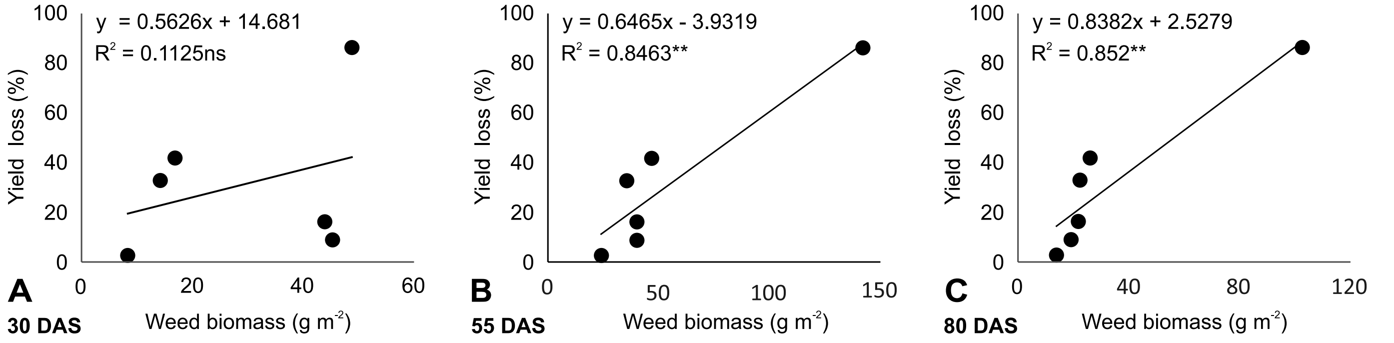

Figure 3. Relationship between weed biomass and yield loss in wet direct-seeded rice under alternate wetting and drying irrigation condition on 30, 55 and 80 days after seeding (DAS)

Рисунок 3. Взаимодействие между биомассой сорной растений и потерей урожая влажного риса прямого посева при попеременном увлажнении и осушении на 30, 55 и 80 сутки после посева (DAS)

Table 12. Yield and yield contributing characters of WDSR in different weed management options under AWD condition during the Boro seasons of 2009–2010 and 2010–2011

Таблица 12. Урожай и показатели урожайности влажного риса прямого посева при попеременном увлажнении и осушении в сезон боры 2009–2010 и 2010–2011 гг.

Treatment Обработка	Panicle number, ex. m^{-2} Число метелок, шт. m^{-2}		Number of grains per panicle Число зерен на метелку		Weight of 1000 grains, g Вес 1000 зерен, г		Grain yield, t ha^{-1} Урожай зерна, т $га^{-1}$	
	2009–2010	2010–2011	2009–2010	2010–2011	2009–2010	2010–2011	2009–2010	2010–2011
T_1	231	300	81	85	23.65	23.23	4.92	4.61
T_2	261	317	82	87	23.07	23.09	5.41	5.32
T_3	389	421	89	96	24.41	24.48	6.88	7.91
T_4	373	395	85	93	24.00	24.09	6.53	7.71
T_5	325	388	84	90	23.63	23.66	6.44	7.22
T_6	316	352	83	88	24.35	23.32	6.19	6.64
T_7	136	197	31	48	20.48	20.76	0.94	1.09
LSD($_{.05}$)	46.40	29.90	14.03	15.83	1.47	1.62	1.33	0.48
CV(%)	8.98	4.96	10.31	10.59	2.76	3.93	14.07	4.68

T_1–T_7 annotation is given in Table 1.

(22.53 cm) panicles which albeit were statistically not different from those treated with pyrazosulfuron ethyl with 1HW (T_4). The shortest (17.08 cm) panicle length was obtained from the control treatment (T_7). A 1000-grain weight also varied significantly among the treatments. The highest weight was attained with T_3 treatment which was similar with triple hand-weeding (T_6). In the growing season of 2010–2011, similar patterns were observed in the yield outcome. During 2009–2010 & 2010–2011, the highest grain yield (6.88 and 7.91 t ha^{-1}) was produced from the treatment mefenacet+bensulfuron methyl with 1HW (T_3) which was on par with pyrazosulfuron -ethyl + 1HW (T_4) with grain yields of 6.53 and 7.71 t ha^{-1}. The control treatment produced significantly lower yield and yield components during both seasons.

Discussion

Weed growth and weed control efficiency (%)

In general, weed density and biomass were lowest with the herbicide mefenacet+bensulfuron methyl followed by pyrazosulfuron ethyl at all observation dates during both planting seasons, whereas the weedy control plot produced the highest density and biomass of weeds. At 30 DAS, weed density and biomass were comparable in the control, triple hand-weeding, and BRRI weeder + one hand-weeding plots, as no weeding had been applied in any of these treatments at that time. At 30 DAS, a maximum reduction (as percentages to weedy control) in total weed density and weed dry weight was recorded 82.55% and 88.26%, respectively, in the mefenacet+bensulfuron methyl treated plot followed by pyrazosulfuron ethyl treatment with 77.36% and 84.59%. Similarly, at 55 and 80 DAS, the reduction of average weed number and biomass was more than 70% and 80% for the treatment of mefenacet+bensulfuron methyl and pyrazosulfuron-ethyl. A significant impact of treatments on weeds as observed in this study confirms the findings of many other researchers (Jaya *et al*., 2011; Rao *et al*., 2007, Mahajan *et al.,* 2009). During both growing seasons, higher effectiveness of weed control (WCE>80%) was achieved with the treatment mefenacet + bensulfuron methyl and Pyrazosulfuron. These data agree with those by Bhuiyan and Gazi (2010), who reported that mefenacet + bensulfuron methyl 53%WP @ 594g ai ha^{-1} lead to higher WCE (> 80%) and lower density and dry weight of weeds which ultimately resulted in higher yield components and grain yield of rice.

Weed infestation

In this study, rice fields were infested with different weed species, exhibiting notable variation in their relative density and importance value across different stages of the growing season. During the 2009–2010 season, ten weed species were identified in the unweeded control plots, while twelve species were observed in the 2010–2011 season. Weed communities consisted of a mixture of grasses, sedges, and broadleaf species throughout both years. *Scirpus juncoides* was the most dominant and consistently occurring species in both growing seasons. In 2009–2010, *Fimbristylis miliacea* and *Lindernia floribunda* were significantly present at 55 days after seeding (DAS), likely due to their phenological traits and favorable environmental conditions at that time. By contrast, during the 2010–2011 season, two other species, *Ludwigia octovalvis* and *Marsilea minuta* were recorded, which may also relate to conducive environmental factors specific to that season. Analysis of weed relative density indicated that the sedge *Scirpus juncoides*, along with the grasses *Echinochloa crus-galli* and *Cynodon dactylon*, were the most prevalent species in the weed community. Notably, the relative density of broadleaf weeds increased in the later stages of the growing season, while that of grasses and sedges declined. These findings align with previous reports by Bhuiyan et al. (2010) and Hasanuzzaman et al. (2008), who documented similar patterns in weed population dynamics in rice ecosystems.

Relative proportions of different weed types

Weed management decisions may be efficient if based on the relative weed density and dry matter weight in a given weed community. In the present study up to 30 DAS, densities of sedge weeds contributed over 80 % in most of the treatments while broadleaf weeds contributed less, but over time, the contribution of broadleaf weeds increased. At 55 and 80 DAS, the relative contribution was also higher in sedges followed by grass. At 30 DAS, weed dry matter contribution was much higher in grasses followed by sedges and broadleaves. However, at 55 and 80 DAS, the contribution of sedges and broadleaves increased, although grasses still contributed the most. Although sedges showed the highest densities, grasses contributed more dry matter at all sampling times in both growing seasons. Weed species composition changed over time according to the period of the growing season and weed management treatment in both years. The results of the present study disagree with previous findings of Khaliq *et al.* (2011) who found that broad-leaved weeds account for >50 % of total weed dry biomass in the early season while grasses and sedges contributed over 80 % in the late season. The local climate and hydrology of the experimental site were conducive to luxurious weed growth and diversity, as the fields were not immersed in water due to AWD irrigation. The differences in weed density, dry biomass, and relative proportions of different weed types can be attributed partly to treatment differences and partly to the inherent weed flora of the site. Understanding the structure of weed communities, in terms of dry matter and density of various weed types, will facilitate the development of effective and economical weed management strategies in WDSR under AWD irrigation system.

Weed Composition and Summed Dominance Ratio

SDR is more informative than any single measure in reflecting the contribution of a weed species in the community. During both growing seasons, at 30 and 55 DAS, the most dominant weed species was *Scirpus juncoides.* After 55 DAS, the weed species dominance pattern changed, with broadleaf weeds dominated over sedges and grasses. However, in control plots, grasses and sedges always showed the highest dominance. The treatment mefenacet + bensulfuron methyl and pyrazosulfuron - ethyl was also dominated by *Scirpus juncoides* followed by *Echinochloa crus-galli* and *Cynodon dactylon* at 30 DAS but grasses and sedges were replaced by broadleaves at 55 and 80 DAS in both growing seasons. In the later sampling time (80 DAS), *Lindernia floribunda* was the most dominant weed species in plots treated with mefenacet + bensulfuron methyl and pyrazosulfuron ethyl treatment, accompanied with some other broadleaf and grass weeds. *Sphenoclea zeylanica, Lindernia floribunda* and *Leptochloa chinensis* started to dominate the weed community after 30 DAS in both growing seasons. Bhagat *et al*. (1999) stated that the period from 45 to 60 DAS is the stage when maximum weed pressure against the rice crop is observed. Rice yields drastically declined to their lowest production when rice and weeds competed in the absence of weed control measures between 56 and 72 DAS (Mahfuza, 2006). In the present study, it was found that sedges and grass weeds were highly dominant in the early competition stages (30–55 DAS) across treatments, while the broadleaves started to dominate after 55 DAS, reaching their peak at the latest stage. Based on summed dominance ratio (SDR), averaged over two planting seasons, the most dominant weed species could be arranged in the next order: *Scirpus juncoides* > *Echinochloa crus-galli* > *Cynodon dactylon* > *Lindernia floribunda* > *Leptochloa chinensis* > *Sphenoclea zeylanica* > *Cyperus iria* > *Cyperus difformis*> *Fimbristylis miliaceae*> *Monochoria vaginalis.* Anwar *et al*. (2012) observed similar species dominance in aerobic rice system in different weed management systems. Grass and sedge weeds were found to be more aggressive in this study, which might be due to AWD irrigation conditions that favored grass and sedge weeds more than the broadleaf weeds at early growing season. The abundance of broadleaf weeds under water-saturated conditions has also been reported by Juraimi *et al*. (2011).

Coefficient of similarity

Comparison of weed species composition between treatments in each planting season were made using the Sorensen Index of Similarity (S) (Goldsmith *et al*., 1986). During 2009–2010, S value was 100 % indicating no difference in weed species across treatments. In this planting season, eight weed species were observed in each treatment. But during 2010–2011, the S value was observed to range from 82.35 to 100 % at 30 DAS. Later, at 55 DAS the S value ranged from 85.71 to 100 % and at 80 DAS from 90.90 to 100 %. These results revealed that differences in weed management treatments did not significantly affect the composition of weed species. These results are consistent with the observations of Bhagat *et al.*(1999).

Weed indices and crop relationships

A lower Weed Persistence Index (WPI) was consistently observed in plots treated with mefenacet + bensulfuron-methyl and pyrazosulfuron-ethyl across all observation periods, indicating the higher weed control effectiveness (WCE) of these treatments during both growing seasons. At the initial observation (30 DAS), the three hand weedings (3HW) and BRRI weeder + one hand weeding (1HW) treatments recorded higher WPI values, as no weed control measures had yet been applied, making these plots comparable to untreated controls. During this stage, grasses and sedges contributed predominantly to the higher WPI values. The application of mefenacet + bensulfuron-methyl and pyrazosulfuron-ethyl also resulted in consistently higher Crop Resistance Index (CRI) values at all crop growth stages across both seasons, reflecting improved crop competitiveness. These findings align with those of Khaliq et al. (2011), who reported a lower WPI (0.28) value under manual weeding and a higher WPI (0.88) with bispyribac-sodium application. Furthermore, lower values of the Weed Management Index (WMI), Agronomic Management Index (AMI), and Integrated Weed Management Index (IWMI) were recorded in the chemically treated plots, confirming their superior weed control performance under WDSR conditions with alternate wetting and drying (AWD) irrigation. These results are consistent with Singh et al. (2008), who also reported improved weed indices under integrated weed control strategies.

Yield, yield components, and yield loss

Grain yield increased with weed management treatments compared to the unweeded control in both years. The treatment mefenacet+bensulfuron methyl achieved grain yields of 6.88 and 7.91 t ha^{-1} in 2009–2010 and 2010–2011 years respectively. This might be due to proper weed management in these plots, which enhanced the efficiency of weed control resulting in higher photosynthetic capacity, growth and development of rice. The herbicides, oxadiargyl and pendimethalin, did not produce better yield due to their phytotoxic effect on rice seedlings and lower weed control efficiency. Our results agree with those of many authors (Jaya *et al*., 2011; Bhuiyan *et al*., 2010; Johnson *et al*., 2004). Weeding treatments consistently resulted in higher yield and better yield components. Average yield losses due to weed infestation were recorded at 83% in the 2009–2010 season and 84% in the 2010–2011 season, regardless of the weeding treatments applied.

Conclusion

Weeds are a major biological constraint in WDSR due to the parallel emergence of weeds and rice seedlings, making them difficult to control. Effective strategies for weed management in WDSR depend on the critical period of weed control, the local weed flora and the implementation method. In order to achieve effective management of weeds in WDSR under AWD irrigation multiple weed management techniques were examined. Under AWD conditions in WDSR, *Scirpus juncoides*, *Echinochloa crus-galli* and *Cynodon dactylon* were the most dominant weed species while *Fimbristylis miliaceae, Cyperus iria* and *Lindernia floribunda* were only sporadically recorded. Weed persistence index, weed management index, and agronomic management index were lower in the mefenacet + bensulfuron methyl + 1HW and pyrazosulfuron - ethyl + 1HW treatments at 30, 55 and 80 DAS. The application of pyrazosulfuron ethyl or mixture of mefenacet and bensulfuran methyl, followed by hand weeding at 55 DAS resulted in higher grain yield and proved to be the best weed management option for WDSR under the AWD irrigation system**.**

Acknowledgments

The authors are thankful to Bangladesh Rice Research Institute (BRRI), Gazipur, Bangladesh, for providing the necessary research facilities and fund from the project of "Strengthening and capacity building of biotechnology laboratory in BRRI, Ministry of Agriculture, Bangladesh.

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Вестник защиты растений, 2025, 108(1), с. 35–49

OECD+WoS: 4.01+AM (Agronomy) https://doi.org/10.31993/2308-6459-2025-108-1-16765

Полнотекстовая статья

ВЛИЯНИЕ СТРАТЕГИЙ БОРЬБЫ С СОРНЫМИ РАСТЕНИЯМИ НА ИХ РОСТ И СОСТАВ СООБЩЕСТВА, А ТАКЖЕ УРОЖАЙНОСТЬ ВЛАЖНОГО РИСА ПРЯМОГО ПОСЕВА ПРИ ПОПЕРЕМЕННОМ УВЛАЖНЕНИИ И ОСУШЕНИИ

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Системы управления водными ресурсами для влажного риса прямого посева (WDSR) с попеременным увлажнением и осушением (AWD) оказались эффективными ресурсосберегающими (RC) технологиями для производства риса. Однако практика борьбы с сорными растениями в ресурсосберегающих технологиях не была должным образом рассмотрена в литературе. Целью данного исследования было изучение динамики сорных растений и интегрированных стратегий борьбы с ними в WDSR в системе орошения AWD. Было проведено два полевых эксперимента с семью вариантами борьбы с сорняками в течение двух последовательных вегетационных сезонов, 2009–2010 и 2010–2011, в Бангладешском институте исследований риса, Газипур. Результаты показали, что наиболее важными были такие виды, как *Scirpus juncoides, Echinochloa crus-galli* и *Cynodon dactylon*. Напротив, *Fimbristylis miliaceae, Cyperus iria* и *Lindernia floribunda*, по-видимому, принадлежали к наименее важной группе. Сорные растения, которые вмешивались в течение 55 дней после посева, оказали значительное влияние на рост и урожайность риса. Со временем рейтинг доминирования сорных растений изменился. Применение гербицидов мефенацет+бенсульфуронметил и пиразосульфуронэтил вместе с однoручной прополкой эффективно снижало рост сорных растений, что приводило к более высокой эффективности борьбы с ними и урожайности зерна. Эти две обработки снижали показатели, связанные с сорными растениями, и повышали устойчивость культур.

Ключевые слова: выращивание риса, динамика сорных растений, борьба с сорными растениями, урожай зерна

Поступила в редакцию: 24.12.2024 *Принята к печати: 04.04.2025*