Journal of Applied Biology & Biotechnology Vol. 12(4), pp. 248-255, Jul-Aug, 2024
Available online at http://www.jabonline.in
DOI: 10.7324/JABB.2024.170795

Crop establishment methods and herbicide mixtures induced weed dynamics, productivity, and profitability of summer rice

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ARTICLE INFO

Article history:
Received on: January 25, 2024
Accepted on: April 14, 2024
Available online: May 20, 2024

Key words:
Weed control,
Crop establishment methods,
Herbicide mixtures,
Transplanted rice,
Wet seeded rice

ABSTRACT

Rice farmers face challenges in achieving higher yield and profit during the summer season due to improper establishment and weed control. To address this, a study was conducted to assess the effects of herbicide combinations on the growth and yield of CR Dhan 206 (Gopinath), a high-yielding rice variety. The research took place from January to May 2022 at the PG Research Farm of M. S. Swaminathan School of Agriculture, Centurion University of Technology and Management, Paralakhemundi, Odisha. The experiment followed a split plot design with two main plots (transplanted rice and wet seeded rice) and five subplots (fenoxaprop-p-ethyl + ethoxysulfuron (Tank mix) @ (50+15) g ha-1 at 18 days after transplanting/sowing (DAT/S); triafamone + ethoxysulfuron (Ready mix) @ (45+22.5) g ha-1 at 12 DAT/S; pretilachlor + bensulfuron-methyl (Ready mix) @ (600+60) g ha-1 at 4 DAT/S; weed-free (Hand weeding at 20,40,60 DAT/S); and weedy check) replicated thrice. The dominant weeds observed were *Echinochloa colona, Leptochloa chinensis, Cyanotis auxiliaris, Physalis minima, Ludwigia parviflora, Cyperus iria,* and *Fimbristylis miliacea*. Results indicated that the establishment methods did not significantly affect crop growth, yield attributes, crop yield, and weed infestation. However, the application of triafamone + ethoxysulfuron in both transplanted and wet seeded rice demonstrated superior growth, yield, weed control, and comparable results to the weed-free check. The combination of wet seeded rice and triafamone + ethoxysulfuron showed the highest net return and benefit-cost ratio, suggesting its recommendation for effective weed control and profitability in rice farming in summer season.

1. INTRODUCTION

In Asian countries, rice (*Oryza sativa* L.) is an important crop because it is a staple diet. 165.25 million hectares are used for rice cultivation worldwide [1]. India is the second-largest rice producer in Asia, after only China, accounting for 21.1% of global rice production. The adage "Rice is life" is especially applicable to India, where rice plays a critical role in sustaining food production, contributing roughly 15% of India's annual GDP and meeting 31% of the country's total energy requirements, as well as meeting the calorie and protein needs of over 70% of the Indian population. India attained an average rice yield of 2.7 t/ha, resulting in 116.42 M t of rice production from 43 M ha area. The main method for growing rice in wetlands is by transplanting seedlings into puddle fields. In South and South-east Asia, traditional transplanting is still the most common technique for growing rice. However, in many rice-growing countries, labor scarcity during transplanting seasons combined with delayed transplanting has resulted in lower yields and lower earnings. Direct-seeded rice (DSR) is emerging as a viable alternative to conventional transplanted rice (TPR) as a result of issues like limited irrigation water availability, lack of farm laborers at the peak time of transplanting, and rising cultivation costs in conventional transplanting within puddled soil [3].

The main biotic issue reducing rice yields is weeds, especially in DSR. Both TPR and DSR can suffer significant yield reductions in weedy situations, with losses of up to 50–60% and 70–80%, respectively [4]. Due to the identical growth and development needs of rice plants and weeds, there is fierce competition for resources like sunlight, space, nutrients, and moisture, which eventually reduces crop yields [5]. Due to their exceptional flexibility and quick growth rates, weeds frequently rule the crop environment, which can seriously impair crop output. Chemical weed management is the most effective and efficient way to suppress the diverse weed flora before they compete with the crop among the several weed control techniques, saving time, labor, and weed control costs [6]. However, repeated use of a single herbicide may cause changes in the weed population and the emergence of herbicide resistance in weeds [7,8]. Resistance to 21 out of 31 known herbicide action sites and to 165 different herbicides has evolved in weeds. At present, in 72 countries, herbicide resistance has been

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reported in 96 crops, and globally, 513 unique cases of weed resistance involving 267 species have been reported [9]. At present, the weed issue in rice farming cannot be solved effectively or practically by relying entirely on a single herbicide. According to research, using herbicide combinations that combine various mechanisms of action gives a more promising alternative. In comparison to using individual herbicides, these mixes increase effectiveness by controlling a wider range of weeds, decrease the risk that weeds will develop herbicide resistance, produce synergistic effects, and offer a more economically advantageous method of weed control [10,11]. This experiment was created to offer a solution to this challenging problem in view of these factors relating to rice establishment techniques and weed infestations.

2. MATERIALS AND METHODS

2.1. Experimental Site

During the summer season, from January to May 2021–2022, a field experiment was conducted to examine the effects of crop establishment techniques and herbicide combinations on the growth and yield of the high-yielding CR Dhan 206 (Gopinath) variety. The experiment was conducted at the Centurion University of Technology and Management's PG Research Farm at the M. S. Swaminathan School of Agriculture in Paralakhemundi, Odisha. The location was in the sub-humid and sub-tropical North-Eastern Ghat Zone of Odisha, India, with coordinates of 18.80° N latitude and 84.20° E longitude at an elevation of 145 m above mean sea level. The maximum temperature ranged from 27 to 40°C throughout the cropping season, and the minimum temperature ranged from 15°C to 27°C. The total amount of rain that fell during this time was 88.1 mm. The soil at the location had a sandy loam texture and was made up of 67.20% sand, 18.30% silt, and 17.30% clay. The soil had a pH of 6.4, an electrical conductivity of 0.25 dS/m, 0.32% organic carbon, 178 kg/ha of total nitrogen, 17 kg/ha of accessible phosphorus, and 192 kg/ha of available potassium.

2.2. Treatment Details

Ten treatment combinations were included in the experiment, which was set up as a split-plot design with three replications. Two crop establishment methods, namely, E_1 – TPR and E_2 – Wet seeded rice (WSR), were used in the main plot. Five weed management techniques were used in the subplot, including: W_1 – Fenoxaprop-p-ethyl + Ethoxysulfuron (FPE + ES) (Tank mix) at a rate of (50 + 15) g/ha at 18 days after transplanting or seeding (DAT/S), W_2 – Triafamone + Ethoxysulfuron (TFM + ES) (Ready mix) at a rate of (45 + 22.5) g/ha at 12 DAT/S, W_3 – Pretilachlor + Bensulfuron methyl (Pret + BSM) (Ready mix) at a rate of (600 + 60) g/ha at 4 DAT/S, W_4 – Weed free check (Hand weeding [HW] at 20, 40, 60 DAT/S), and W_5 - weedy check.

2.3. Crop Management

Sowing was done on January 21, 2022, in plots of WSR and nursery bed for TPR. After 23 days, seedlings were transplanted on the experimental field for TPR on February 12, 2022, using 2–3 seedlings per hills at a spacing of 15 cm × 10 cm. The prescribed fertilizer application consisted of 120 kg/ha of nitrogen (N), 60 kg/ha of phosphorous (P), and 60 kg/ha of potassium (K). This fertilizer regimen was employed, with an initial application of one-third of the N and the full doses of P and K. The remaining portion of N was split into equal portions and applied at 20 and 40 DAT/S. Irrigation was administered as required by the crop to maintain a continuously flooded condition until maturity. Herbicides were applied using battery-operated knapsack sprayers. The weedy check plots were left untreated for weed control throughout the entire growth period. The WSR and TPR were harvested on May 15–25, 2022, respectively.

2.4. Observations and Calculations

Data on weed biomass and density were gathered at two different intervals, namely, 30 and 60 DAT/S. In each plot, a 0.50 m^2 quadrat was randomly employed for this purpose and the weeds within it were categorized into three groups: Grasses, broadleaf weeds (BLWs), and sedges. The total weed population and the population within each group were quantified in terms of individuals per square meter (m^2). The weed samples were divided into categories and placed in paper bags. The samples were then dried, first in the shade, then in an oven at 80°C for 24 h. Next, the weeds' dry weight was calculated and represented as g m^{-2}. Equations 1 and 2 were used to compute the weed control efficiency (WCE) and weed index (WI) based on the dry matter of the weeds and grain yield, respectively.

$$\text{WCE (\%)} = \frac{W_0 - W_1}{W_0} \times 100 \tag{1}$$

Where
W_0 = Weed dry weight of weedy check
W_1 = Weed dry weight of treated plot.

$$\text{WI} = \frac{Y_{wf} - Y_1}{Y_{wf}} \times 100 \tag{2}$$

Where
Y_{wf} = Grain yield of weed-free plot.
Y_1 = Grain yield of treated plot.

At various time points: 30, 60, and 90 DAT/S, as well as at the time of harvest, crop growth parameters, such as plant height, the number of tillers per square meter (m^{-2}), dry matter accumulation (measured in grams per square meter, g m^{-2}), and leaf area index (LAI), were assessed. The number of panicles per square meter (m^{-2}), the number of spikelets per panicle, the number of grains per panicle, the number of empty spikelets per panicle, and the test weight (measured in 1000 grain weight) were all yield-related measurements that were kept. Following crop harvest, grain and straw weights were recorded to determine productivity. Sterility percentage and harvest index were computed using the formulas specified in Equations 3 and 4, respectively.

$$\text{Sterility (\%)} = \frac{No.of\ unfilled\ speikelets\ per\ panicle}{No.of\ spikelets\ per\ panicle} \times 100 \tag{3}$$

$$\text{Harvest index} = \frac{Grain\ yield}{Grain\ yield + Straw\ yield} \times 100 \tag{4}$$

Under economical parameters, cost of cultivation, gross return, net return, and B: C ratio were calculated taking into consideration the prevailing costs of the region and minimum support price of 2021–2022, that is, ₹1940/- per quintal, for common paddy [12].

2.5. Statistical Analysis

The collected data were statistically analyzed using the analysis of variance method as described by Gomez and Gomez (1984), and the F value was calculated at a 5% level of probability. The software adopted for statistical analysis was OPSTAT statistical package [13].

Table 1: Effect of crop establishment and weed management treatments on crop growth parameters.

Treatment	Plant height (cm)	No. of tillers (m^{-2})	Dry matter accumulation (g m^{-2})	Leaf area index
Main plot				
E1				
Transplanted rice	125	387	980	3.97
E2				
Wet seeded rice	126	362	939	3.73
SEm±	3	9	24	0.09
CD (*P*=0.05)	NS	NS	NS	NS
Subplot				
W1				
FPE+ES at (50+15) g/ha	127[a]	375[b]	961[b]	3.86[b]
W2				
TFM+ES at (45+22.5) g/ha	130[a]	416[a]	1028[a]	4.26[a]
W3				
Pret+BSM at (600+60) g/ha	126[a]	353[b]	925[b]	3.64[b]
W4				
Weed Free (HW at 20, 40 and 60 DAT/S)	132[a]	442[a]	1070[a]	4.52[a]
W5				
Weedy check	113[b]	285[c]	814[c]	2.97[c]
SEm±	3	9	25	0.10
CD (*P*=0.05)	10	28	74	0.29
Interaction				
E x W	NS	NS	NS	NS

*DAT: Days after transplanting, DAS: Days after sowing, FPE: Fenoxaprop-p-ethyl, ES: Ethoxysulfuron, TFM: Triafamone, Pret: Pretilachlor, BSM: Bensulfuron-methyl, HW: Hand weeding. NS: Non-significant

3. RESULTS

3.1. Weed Flora

Grasses, namely, *Echinochloa colona* and *Leptochloa chinensis*; sedges, namely, *Cyperus iria* and *Fimbristylis miliacea*; and BLWs, namely, *Cyanotis auxiliaris*, *Physalis minima*, and *Ludwigia parviflora* were the dominant weed species found in the experimental field. Notably, among the grass species, *L. chinensis* grew more prevalent in the latter stages of crop growth whereas *E. colona* predominated in the early stages.

3.2. Crop Growth Parameters

Table 1 provides a summary of the growth metrics, including plant height, tillers per square meter (m^{-2}), dry matter accumulation (g m^{-2}), and LAI after 90 DAT/S. There was no significant difference between the growth parameters obtained from TPR and WSR. However, the effect was significant in the case of weed management treatments in subplots. The highest plant height was observed at par in all the subplot treatments except weedy check (W_5) (108 cm) which was the lowest. The highest number of tillers was observed in weed-free check (W_4) (442 m^{-2}) which was found at par with TFM + ES (W_2) (416 m^{-2}). The other two herbicide mixtures, that is, FPE + ES (W_1) (375 m^{-2}) and Pret + BSM (W_3) (355 m^{-2}) were found at par, whereas the lowest tiller number was noticed in weedy check (W_5) (285 m^{-2}).

3.3. Crop Yield Attributes

The data related to the number of panicles per square meter (m^{-2}), the total number of spikelets per panicle, the number of grains per panicle, the number of unfilled spikelets per panicle, sterility percentage (%), and the test weight are provided in Table 2. No significant effect was seen by the main plot treatments as well as interaction on the yield attributes, whereas it was significant in the case of subplot treatments except on sterility percentage and test weight, in which the effect is non-significant. Regarding the rest four yield attributes, that is, number of panicles per square meter (m^{-2}), the total number of spikelets per panicle, the number of grains per panicle, and the number of unfilled spikelets per panicle; all followed the same trend in which the highest values were obtained in TFM + ES (W_2) (247.7, 147.3, 117.7, and 28.9 respectively) among herbicides being at par with weed-free check (W_4) (258.6, 151.3, 122.3, and 29.6, respectively) and among the herbicides, the lowest values were obtained in Pret + BSM (W_3) (213.3, 127.3, 94.4, and 32.8, respectively) which was at par with FPE + ES (W_1) (220.1, 130.7, 98.4, and 32.3, respectively).

3.4. Crop Yield and WI

The data pertaining to grain yield, straw yield, harvest index, and WI are displayed in Table 3. Notably, there was no significant impact observed from the main plot treatments and their interaction. However, the subplot treatments exhibited significant effects. Among the herbicide mixtures, TFM + ES (W_2) yielded the highest grain and straw (4.2 and 4.7 t ha^{-1}, respectively) which were found at par with the weed-free (W_4) (4.5 and 5.0 t ha^{-1}, respectively) followed by the other two herbicide mixtures, that is, FPE + ES (W_1) (3.7 and 4.1 t ha^{-1} respectively) and Pret + BSM (W_3) (3.4 and 3.9 t ha^{-1}, respectively) which resulted at par with each other [Figure 1]. The lowest grain and

Table 2: Effect of crop establishment and weed management treatments on crop yield attributes.

Treatments	No. of Panicles m^{-2}	No. of spikelets $panicle^{-1}$	No. of grains $panicle^{-1}$	No. of unfilled spikelets $panicle^{-1}$	Sterility %	Test weight (g)
Main plot						
E_1						
Transplanted rice	217.7	131.6	102.9	28.7	22.1	20.1
E_2						
Wet seeded rice	207.4	126.2	96.6	29.5	23.9	20.0
SEm±	5.3	3.1	2.6	0.5	0.4	0.5
CD (*P*=0.05)	NS	NS	NS	NS	NS	NS
Subplot						
W1						
FPE+ES at (50+15) g/ha	220.1b	130.7b	98.4b	32.3b	24.7	20.2
W2						
TFM+ES at (45+22.5) g/ha	247.7a	147.3a	117.7a	28.9a	20.1	20.4
W3						
Pret+BSM at (600+60) g/ha	213.3b	127.3b	94.4b	32.8b	25.9	20.0
W4						
Weed free (HW at 20, 40 and 60 DAT/S)	258.6a	151.3a	122.3a	29.6a	19.1	20.5
W5						
Weedy check	123.1c	88.2c	66.3c	21.9c	25.6	19.2
SEm±	5.3	3.2	2.9	2.2	2.1	0.5
CD (P=0.05)	15.8	9.5	8.7	6.5	NS	NS
Interaction						
ExW	NS	NS	NS	NS	NS	NS

*DAT: Days after transplanting, DAS: Days after sowing, FPE: Fenoxaprop-p-ethyl, ES: Ethoxysulfuron, TFM: Triafamone, Pret: Pretilachlor, BSM: Bensulfuron-methyl, HW: Hand weeding, NS: Non-significant

Table 3: Effect of crop establishment and weed management treatments on crop yield.

Treatments	Grain yield (t/ha)	Straw yield (t/ha)	Harvest index	Weed index
Main plot				
E_1				
Transplanted rice	3.8	4.3	47.0	
E_2				
Wet seeded rice	3.5	4.0	46.7	
SEm±	0.1	0.1		
CD (*P*=0.05)	NS	NS		
Subplot				
W_1				
FPE+ES at (50+15) g ha^{-1}	3.7^b	4.1^b	47.2	17.4
W_2				
TFM+ES at (45+22.5) g ha^{-1}	4.2^a	4.7^a	47.2	6.9
W_3				
Pret+BSM at (600+60) g ha^{-1}	3.4^b	3.9^b	47.0	23.2
W_4				
Weed Free (HW at 20, 40 and 60 DAT/S)	4.5^a	5.0^a	47.4	0.0
W_5				
Weedy check	2.6^c	3.1^c	45.3	41.9
SEm±	0.1	0.1		
CD (*P*=0.05)	0.3	0.4		
Interaction				
E x W	NS	NS		

*DAT: Days after transplanting, DAS: Days after sowing, FPE: Fenoxaprop-p-ethyl, ES: Ethoxysulfuron, TFM: Triafamone, Pret: Pretilachlor, BSM: Bensulfuron-methyl, HW: Hand weeding, NS: Non-significant

Table 4: Effect of crop establishment and weed management treatments on weed density.

Treatments	Weed density (no. m^{-2})							
	Grasses		Sedges		BLWs		Total	
	30 DAT/S	60 DAT/S	30 DAT/S	60 DAT/S	30 DAT/S	60 DAT/S	30 DAT/S	60 DAT/S
Main plot								
E_1								
Transplanted rice	2.48 (6.67)	3.06 (13.13)	1.79 (2.67)	2.26 (5.60)	1.74 (2.33)	1.97 (3.59)	3.17 (11.67)	3.98 (22.32)
E_2								
Wet seeded rice	2.67 (7.80)	3.53 (17.76)	1.99 (3.67)	2.37 (6.33)	1.87 (3.00)	2.18 (4.87)	3.48 (14.47)	4.49 (28.96)
SEm±	0.1	0.14	0.09	0.02	0.08	0.09	0.08	0.14
CD (*P*=0.05)	NS	NS	NS	NS	NS	NS	NS	NS
Subplot								
W_1								
FPE+ES at (50+15) g ha^{-1}	2.31^{c} (4.50)	2.75^{b} (6.90)	1.66^{b} (2.00)	2.00^{b} (3.00)	1.76^{b} (2.17)	1.95^{b} (2.83)	3.09^{c} (8.67)	3.66^{b} (12.73)
W_2								
TFM+ES at (45+22.5) g ha^{-1}	2.00^{c} (3.00)	1.97^{c} (3.00)	1.72^{b} (2.00)	1.87^{b} (2.50)	1.63^{b} (1.67)	1.63^{c} (1.67)	2.77^{c} (6.67)	2.85^{c} (7.17)
W_3								
Pret+BSM at (600+60) g ha^{-1}	2.66^{b} (6.17)	3.14^{b} (9.50)	1.93^{b} (2.83)	2.03^{b} (3.17)	1.84^{b} (2.50)	2.04^{b} (3.30)	3.15^{b} (11.50)	4.05^{b} (15.97)
W_4								
Weed Free (HW at 20, 40 and 60 DAT/S)	0.74d (0.00)	0.74d (0.0)	0.74^{c} (0.00)	0.74^{c} (0.0)	0.74^{c} (0.00)	0.74d (0.0)	0.74d (0.00)	0.74d (0.0)
W_5								
Weedy check	4.83^{a} (22.50)	7.63^{a} (57.83)	3.14^{a} (9.00)	4.69^{a} (21.17)	2.81^{a} (7.00)	3.76^{a} (13.33)	6.26^{a} (38.50)	9.61^{a} (92.33)
SEm±	0.11	0.25	0.15	0.12	0.1	0.11	0.31	0.25
CD (P=0.05)	0.32	0.76	0.45	0.37	0.3	0.33	0.41	0.76
Interaction								
E x W	NS	NS	NS	NS	NS	NS	NS	NS

*Figures in parentheses are the original values. The data was transformed to SQRT (x+0.5) before analysis). **DAT: Days after transplanting, DAS: Days after sowing, FPE: Fenoxaprop-p-ethyl, ES: Ethoxysulfuron, TFM: Triafamone, Pret: Pretilachlor, BSM: Bensulfuron-methyl, HW: Hand weeding, NS: Non-significant.

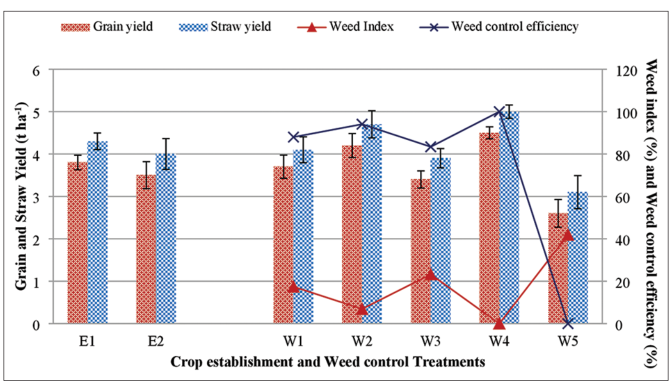

Figure 1: Effect of crop established and weed management treatments on grain yield, straw yield, weed index, and weed control efficiency. *DAT: Days after transplanting, DAS: Days after sowing, E_1: Transplant rice, E_2: Wet seeded rice, W_1: Fenoxaprop-p-ethly + Ethoxysulfuron at (50+15) g/ha, W_2: Triafamone + Ethoxysulfuron at (45+22.5) g/ha, W_3: Pretilachlor + Bensulfuron-methyl at (600+60) g/ha, W_4: Weed-free (HW at 20, 40 and 60 DAT/S), W_5: Weedy check.

straw yields were obtained in weedy check (W_5) (2.6 and 3.1 t ha^{-1}, respectively). The harvest index was about 46 in all the herbicide treatments except weedy check (W_5) (45.3). About 42% yields were compromised due to uncontrolled weed infestation in weedy check (W_5) in comparison to the grain yield obtained in weed-free (W_4). All the herbicide mixtures reduced the yield loss effectively, among which the treatment TFM + ES (W_2) (6.9%) had the best performance than FPE + ES (W_1) (17.4%) and Pret + ES (W_3) (23.2%) [Figure 1].

3.5. Weed Density, Biomass, and WCE

The data pertaining to weed density are presented in Table 4, and biomass and WCE are presented in Table 5. In both cases, there was no significant effect of main plot treatments and interaction. The highest weed density and biomass were observed in weedy check (W_5). Among herbicide mixtures, TFM + ES (W_2) (3.0) and FPE + ES (W_1) (4.5) resulted at par at 30 DAT/S in controlling the grasses whereas at 60 DAT/S, TFM + ES (W_2) (3.0) found better than FPE + ES (W_1) (6.9). All three herbicide mixtures performed at par in controlling the sedge densities at both 30 and 60 DAT/S and BLWs at 30 DAT/S. However, TFM + ES (W_2) (1.67) was found significantly superior than

Table 5: Effect of crop establishment and weed management treatments on weed biomass and weed control efficiency.

Treatments	Weed biomass (g m^{-2})								WCE %
	Grasses		Sedges		BLWs		Total		
	30 DAT/S	60 DAT/S	30 DAT/S	60 DAT/S	30 DAT/S	60 DAT/S	30 DAT/S	60 DAT/S	60 DAT/S
Main plot									
E_1									
Transplanted rice	1.65 (2.07)	3.36 (16.29)	1.14 (0.32)	1.51 (1.57)	1.14 (0.30)	1.29 (0.75)	1.80 (2.69)	3.59 (18.61)	
E_2									
Wet seeded rice	1.73 (2.42)	3.88 (22.02)	1.19 (0.44)	1.56 (1.77)	1.17 (0.39)	1.37 (1.02)	1.91 (3.25)	4.12 (24.82)	
SEm±	0.05	0.16	0.02	0.01	0.02	0.03	0.04	0.15	
CD (*P* = 0.05)	NS	NS	NS	NS	NS	NS	NS	NS	
Subplot									
W_1									
FPE + ES at (50 + 15) g ha^{-1}	1.54^{b} (1.40)	3.02^{b} (8.56)	1.11^{b} (0.24)	1.36^{b} (0.84)	1.13^{b} (0.28)	1.26^{b} (0.59)	1.70^{c} (1.92)	3.25^{b} (9.99)	87.99
W_2									
TFM + ES at (45 + 22.5) g ha^{-1}	1.39^{c} (0.93)	2.13^{c} (3.72)	1.11^{b} (0.24)	1.30^{b} (0.70)	1.10^{b} (0.22)	1.16^{c} (0.35)	1.54^{c} (1.39)	2.38^{c} (4.77)	94.07
W_3									
Pret + BSM at (600 + 60) g ha^{-1}	1.70^{b} (1.91)	3.48^{b} (11.78)	1.16^{b} (0.00)	1.37^{b} (0.89)	1.15^{b} (0.33)	1.30^{b} (0.70)	1.88^{b} (2.58)	3.69^{b} (13.36)	83.39
W_4									
Weed Free (HW at 20, 40 and 60 DAT/S)	0.71^{d} (0.00)	0.71^{d} (0.00)	0.71^{c} (1.08)	0.71^{c} (0.00)	0.71^{c} (0.00)	0.71^{d} (0.00)	0.71^{d} (0.00)	0.71^{d} (0.00)	100
W_5									
Weedy check	2.82^{a} (6.98)	8.48^{a} (71.71)	1.44^{a} (1.08)	2.62^{a} (5.93)	1.38^{a} (0.91)	1.94^{a} (2.80)	3.15^{a} (8.97)	8.97^{a} (80.44)	0
SEm±	0.05	0.28	0.04	0.06	0.02	0.04	0.06	0.28	
CD (*P* = 0.05)	0.16	0.86	0.13	0.18	0.07	0.12	0.17	0.84	
Interaction									
E x W	NS	NS	NS	NS	NS	NS	NS	NS	

*Figures in parentheses are the original values. The data was transformed to SQRT (x + 0.5) before analysis). **DAT: Days after transplanting, DAS: Days after sowing, FPE: Fenoxaprop-p-ethyl, ES: Ethoxysulfuron, TFM: Triafamone, Pret: Pretilachlor, BSM: Bensulfuron-methyl, HW: Hand weeding, NS: Non-significant

Table 6: Effect of crop establishment and weed management treatments on economics.

Treatment combinations	Cost of cultivation (₹ ha^{-1})	Gross return (₹ ha^{-1})	Net return (₹ ha^{-1})	B:C
E1 (TPR)+W1 (FPE+ES at (50+15) g ha^{-1})	39650	72944	33294	1.8
E1 (TPR)+W2 (TFM+ES at (45+22.5) g ha^{-1})	40742	81674	40932	2.0
E1 (TPR)+W3 (Pret+BSM at (600+60) g ha^{-1})	39509	72750	33241	1.8
E1 (TPR)+W4 (Weed Free (HW at 20, 40, and 60 DAT/S))	57409	87688	30279	1.5
E1 (TPR)+W5 (Weedy)	36409	56842	20433	1.6
E2 (WSR)+W1 (FPE+ES at (50+15) g ha^{-1})	31925	70422	38497	2.2
E2 (WSR)+W2 (TFM+ES at (45+22.5) g ha^{-1})	33017	79928	46911	2.4
E2 (WSR)+W3 (Pret+BSM at (600+60) g ha^{-1})	31784	60528	28744	1.9
E2 (WSR)+W4 (Weed Free [HW at 20, 40, and 60 DAT/S])	49684	85942	36258	1.7
E2 (WSR)+W5 (Weedy)	28684	44038	15354	1.5

*DAT: Days after transplanting, DAS: Days after sowing, TPR: Transplanted rice, WSR: Wet seeded rice, FPE: Fenoxaprop-p-ethyl, ES: Ethoxysulfuron, TFM: Triafamone, Pret: Pretilachlor, BSM: Bensulfuron-methyl, HW: Hand weeding

FPE + ES (W_1) (2.8) at 60 DAT/S. TFM + ES (W_2) (6.67) and FPE + ES (W_1) (8.67) resulted at par at 30 DAT/S whereas TFM + ES (W_2) (7.17) was the best in controlling the total weed densities at 60 DAT/S. Similar trend was also found in weed biomass. Among the herbicide mixtures, the highest WCE were noticed in TFM + ES (W_2) at both 30 and 60 DAT/S (84 and 94%, respectively) followed by FPE + ES (W_1) (78 and 88%, respectively) and Pret + BSM (W_3) (71 and 83%, respectively) [Figure 1].

3.6. Economics

The data showing the effect of crop establishment and weed management options on economics is presented in Table 6. The highest cost of cultivation and gross return was in the treatment E_1 (TPR) + W_4 (Weed free @ HW at 20, 40 and 60 DAT/S) (₹57,409/- ha^{-1} and ₹87,688/- ha^{-1}, respectively), whereas were the lowest in E_2 (WSR) + W_5 (Weedy check) (₹28,684/- ha^{-1} and ₹44,038/- $ha^{-1,}$ respectively). The highest net return and B: C ratio were obtained in the treatment E_2 (WSR) + W_2 (TFM + ES at (45+22.5) g/ha) (₹46,911/- ha^{-1} and 2.4, respectively) followed by E1 (TPR) + W2 (TFM + ES at (45 + 22.5) g/ha) (₹40,932/- ha^{-1} and 2.0, respectively).

4. DISCUSSION

The experiment was conducted to find out the best combination of crop establishment method and herbicide mixture in terms of productivity and weed control. WSR and TPR both showed comparable performance in terms of crop growth, yield, and weed control. This closeness in performance can be traced to the fact that both approaches include puddling. Puddling, which appears to have contributed to the similar results in both methods, entails saturating the soil with water and mechanically churning it to generate a puddled and anaerobic environment. This condition significantly reduced weed seed germination and emergence. The anaerobic conditions created by puddling inhibited the germination and growth of many weed species reducing the crop-weed competition which eventually favored growth and productivity in rice. This finding is supported by the result found by many investigators, where it was found that regardless of weed management practices, the crop growth and yield were comparable between TPR and WSR [15-19]. The weed species observed in this experiment align with the findings reported by various scientists working in different agro-climatic zones across the country under typical conditions, as documented in previous studies [20-22].

Triafamone, an acetolactate synthase inhibitor herbicide that is capable of killing wide range of grasses and sedges [23] and ethxysulfuron a sulfonylurea herbicide kills most of the sedges and BLWs by inhibiting the biosynthesis of essential amino acids [24]. Fenoxaprop-p-ethyl inhibits the synthesis of fatty acids and mostly kills the grassy weeds [25]. Pretilachlor is a cell division inhibitor herbicide and bensulfuron-methyl inhibits production of essential amino acids, that is, valine and isoleucine; which in combination have a great potential of reducing broad spectrum of weed flora [21]. All the herbicide combinations used in this research were proven to be promising in separate investigations in TPR [19,26,27] and WSR [28-30]. When compared to the weedy check, all of the herbicide mixtures used in the experiment showed a significant decrease in weed density and biomass, demonstrating excellent broad-spectrum weed control. Crop development is influenced by variables including dry matter accumulation, which includes development in plant height, the number of tillers, and LAI, all of which help to boost photosynthesis. The accessibility of vital resources such as nutrients, water, and space, among others, has an impact on these growth processes. The reduction of weed population led to reduction of crop-weed competition for the growth resources during the critical period. The treatments recording high crop growth parameters could be attributed to high weed control, reducing the critical crop-weed competition. On the contrary, crop growth was drastically hampered in weedy check due to severe crop-weed competition, resulting the lowest yield. The highest growth and yield in weed-free check was due to the absence of competition. Despite the highest grain yield in the weed-free plot, it fetched lower net return and B: C ratio; due to its high cost of cultivation due to inclusion of manual HW by laborers. Similarly, cost incurred by nursery preparation and transplanting in TPR rendered its net profit in combination with the proved best herbicide mixture than WSR.

5. CONCLUSION

Both TPR and WSR methods of crop establishments were found to be comparable influencing crop growth, yield, and weed infestation, regardless the weed management options. Among the herbicide mixtures, TFM + ES (Ready mix) @ (45 + 22.5) g ha^{-1} at 14 DAT/S was found to be the best with respect to all aspects of crop growth, yield attributes, grain yield (4.2 t ha^{-1}), weed control having the highest WCE (94%) irrespective of crop establishment methods; and fetching the highest net return (₹46,911/- ha^{-1}) and B: C (2.4) in combination with WSR.

6. ACKNOWLEDGMENT

The authors acknowledge M. S. Swaminathan School of Agriculture; Centurion University of Technology and Management, Odisha, for providing facilities for conducting this investigation.

7. AUTHORS' CONTRIBUTIONS

All authors agreed to submit the article to the current journal, gave final approval to the version to be published, made significant contributions to the conception and design, acquisition, analysis, and interpretation of data, participated in the writing of the article or critically revised it for important intellectual content, and agreed to be responsible for all aspects of the work.

8. FUNDING

There is no funding to report.

9. CONFLICTS OF INTEREST

The authors report no financial or any other conflicts of interest in this work.

10. ETHICAL APPROVALS

This study does not involve experiments on animals or human subjects.

11. DATA AVAILABILITY

The data analysed and interpreted in this article was collected from the research trial conducted from January to May of 2022 at PG Research Farm, M. S. Swaminathan School of Agriculture, Centurion University of Technology and Management, Paralakhemundi, Odisha. The data that support the findings of this study are available on request from the corresponding author.

12. PUBLISHER'S NOTE

This journal remains neutral with regard to jurisdictional claims in published institutional affiliation.

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How to cite this article:
Nongmaithem A, Mahapatra A, Kalasare RS, Barman S. Crop establishment methods and herbicide mixtures induced weed dynamics, productivity, and profitability of summer rice. J App Biol Biotech. 2024;12(4):248-255.
DOI: 10.7324/JABB.2024.170795