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Assessment of different herbicides for effective weed management in direct seeded rice technology

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ABSTRACT

Rice is one of the most important cereal crops grown worldwide, feeding 60% of the world. Direct-seeded rice replaces puddled transplanted rice due to an increasing water crisis and a labour shortage among farmers in many Asian regions. However, weeds pose a significant obstacle to the growth of direct-seeded rice. In this context, a field experiment was conducted at the research farm of JNKVV, Jabalpur, India (23º 90' N, 79º 58' E, and 411 m above MSL) under natural weed infestations during *the kharif* season of 2019. The objective was to evaluate the herbicidal effects on diversified weed flora, growth parameters, and rice yield to optimize herbicide doses for sustainable rice production. Two agro ecosystems, including rainfed and irrigated and eight weed control treatments, including herbicidal applications, hand weeding and weedy check, were laid out in a split-plot design with three replications. Among the herbicidal applications, bispyribac sodium at 25 g/ha effectively reduced total weed density (3.41/m^2) and dry weight (4.13 g/m^2) over control at 90 days after sowing and as a consequence, yielded a maximum (2768 kg/ha). Based on overall performance, bispyribac sodium at 25 g/ha may be considered the best herbicidal treatment for effective weed control and produced the most significant values for growth parameters, yield parameters and grain yield in direct-seeded rice.

***Key words**: Bispyribac sodium, Cereal crop, Diversified weed flora, Direct seeded rice, Yield parameters*

Introduction

Rice is the sole food consumed by the world's population more than any other crop. It helps to maintain food security and livelihoods for millions of people globally (Singh *et al*., 2016). Rice is grown in more than 100 countries, with a total harvested area of about 158 million hectares, producing 756.7 million tonnes annually (502.2 million tonnes of milled rice). Nearly 680 million tonnes of rice are grown in Asia, accounting for 90% of global production (FAO, 2017). Next to China, India is the world's second-largest producer of rice, where it is grown on an annual area of 43.2 mha with a production of 110 mt and makes up about 40% of the nation's production of food grains (GOI, 2017–18).

Mostly, rice is grown by manually transplanting 3 to 6 week-old seedlings into puddled soil and then flooding them continuously (Ghosh *et al*., 2016). Puddling decreases weed growth, improves nutrient uptake by fostering anaerobic conditions, improves water use efficiency by minimizing evaporation and percolation loss, and aids seedling establishment (Marahatta *et al*., 2017). However, trans-

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planting is becoming expensive and increasingly difficult due to shortages as well as the high cost of labour, scarcity of water, high cost of cultivation etc. Additionally, it harms soil qualities, succeeding crops like wheat, and the atmosphere by releasing methane gas (Marasini *et al*., 2016).

An alternative technique that could reduce the labour and irrigation water requirements for crop establishment is direct seeding of rice (Kumar and Ladha, 2011). It is likely the oldest method of planting rice directly from seed rather than transplanting seedlings from nurseries (Kaur and Singh, 2017). It avoids basic operations in rice cultivation like puddling, transplanting and maintaining standing water in the rice field. It also helps reduce overall water demand by minimizing the loss from evaporation, leaching, percolation and water needed for land preparation. It is becoming increasingly well-known as a practical and superior alternative method that overcomes all the drawbacks of transplanting.

Though DSR has several advantages and could be an effective alternative to traditional transplanting. But, poor germination, uneven crop stand, and high weed infestation are significant constraints in DSR (Farooq *et al*., 2010). It is difficult to manage weeds in a DSR system because of the severe and diverse weed infestation, high weed emergence during rice seed germination due to the absence of a standing water layer, and the advantage rice have over weed seedlings because both plants germinate at the same time. Therefore, timing and method of land preparation, the effectiveness of herbicides, and systematic, efficient, and effective weed management are urgently required relative to the dominant weed species.

These align with various studies on weed management in DSR, which suggest that applying herbicide might be a better option than hand weeding (Jana *et al*., 2020). Finding new herbicides is urgently required to lower the risk of weeds developing resistant biotypes and increase rice yield. Although many pre-emergence herbicides are available for weed control, post-emergence herbicides are frequently required to combat weeds that emerge during later stages of crop growth (Kundu *et al*., 2020). Therefore, to optimize the use of herbicides for a sustainable rice production system, this study assessed the herbicidal effects on weed flora, growth parameters and grain yield.

Materials and Methods

Experimental site and soil

To study the efficacy of different herbicides and combinations of herbicides against problematic weeds in direct-seeded rice, a field experiment was carried out in 2019 at Jawaharlal Nehru Krishi Vishwa Vidyalaya, Jabalpur (23º 90' N, 79º 58' E, and 411 m above MSL), Madhya Pradesh, India under usual weed infestations. The soil was a clay loam with a pH of 6.4 and an electrical conductivity of 0.08 ds/m, and it contained 61.70% sand, 22.40% clay and 16.50% silt.

Climatic conditions and weather

The climate of the study site was sub-tropical. There is an average annual rainfall of 1320 millimeters, with 70% falling between July and September. January saw the mean monthly minimum temperature of 4 °C, and May/June saw the mean monthly maximum temperature of 45 °C. In the summer, the relative humidity is usually very low (15 to 30%), moderate (60 to 75%) during the winter season, and increases to a higher value (80 to 95%) in the rainy season. At the Meteorological Observatory, JNKVV, Jabalpur, climatic information was recorded. The weather was highly suitable for the rice crop during the crop growing season. The monsoon season began the third week of June and ended the first week of November.

Layout and treatments

Split plot design was used for the experiment's layout and replicated thrice. On July 12, 2019, rice variety "MTU 1010" was sown with a row-to-row spacing of 20 cm (roughly 60 kg/ha seed rate). The factor comprised of 2 agroecosystems, i.e. rainfed and irrigated and 8 weed control treatments, i.e. bispyribac sodium at 25 g/ha, fenoxaprop-p-ethyl at 60 g/ha, fenoxaprop-p-ethyl + penoxsulam at 60 + 26.7 g/ha, cyhalofop + penoxsulam at 135 + 26.7 g/ha, bispyribac sodium + metsulfuron methyl + chlorimuron ethyl at 25+4 g/ha, triafamone + ethoxysulfuron at 40+20 g/ha, weedy check and hand weeding (two) at 20 and 40 DAS. Herbicides were applied with a power sprayer using 600 L water per hectare. The remaining management practices were followed with the recommended package of practices.

Observations on weeds

Two quadrates (0.25 m x 0.25 m) were set aside in each plot to measure the biomass and density of weeds. Weed density was measured as the number of weeds per unit area at 90 days after sowing. The destructed samples were washed in clean tap water before sun-drying and kept in an electric oven at 65 °C for 48 hours to achieve a constant weight. The data was then expressed in grams per square meter (g/m^2). The weed control efficiency of different treatments was calculated on the basis of diminution in weight in the treated plot compared to weedy check and expressed as a percentage.

$$WCE(\%) = \frac{\text{Dry matter of weeds in weedy check-Dry matter of weeds in treated check}}{\text{Dry matter of weeds in weedy check}}$$

Moisture content

With the help of a soil auger, soil samples from rainfed and irrigated rice fields were collected at depths of 0–15 cm and 15–30 cm, respectively, to determine the soil moisture content of the experimental area. The soil samples were then placed in an aluminum box to preserve the moisture in the soils, and they were then heated to 110 °C for 48 hours to achieve a constant weight. It was measured with the gravimetric method as per the formula

$$Soil\ moisture\ (\%) = \frac{Moist\ soil\ (g) - Dry\ soil\ (g)}{Dry\ soil\ (g)} x100$$

Statistical analysis

Statistical analysis was performed to test the variation of yield under different main treatments and sub-treatments. An analysis of variance was performed to determine the effects of herbicides and their interactions under rainfed and irrigated agroecosystems. The data recorded on different observations were tabulated and analyzed statistically by using the techniques of analysis of variance (ANOVA) as suggested by Gomez and Gomez (1984). Critical difference at 0.05 probability level was worked out to compare the treatments when the "F" test was found not to be significant.

Results and Discussion

Weed density

The experimental plots were infested with a mixed weed flora, with narrow-leaved weeds being the most prevalent, followed by broad-leaved weeds and sedges, irrespective of the dates of observations. The results of the experiment showed that the hand-weeding treatment observed the lowest weed population of grasses, sedges, and broadleaf weeds, while the weedy check recorded the highest weed density (Table 1). With the use of post-emergence herbicides, the total number of weeds gradually decreased. Applying bispyribac sodium at 25 g/ha resulted in the significantly lowest weed density ($3.41/m^2$), which was significantly at par with the fenoxaprop-p-ethyl + penoxsulam at 60+26.7 g/ha treated plot.

This necessitates the use of post-emergence herbicides for weed control in direct-seeded rice, which were comparatively more effective against broad-leaved, grassy, and sedge weeds. The findings of Kumar and Rana, 2013 and Sharma *et al.,* 2020 recorded lower weed density under bispyribac-sodium than other weed management treatments, were also consistent with these results. This was because the plant enzyme acetoacetate synthase (ALS), which was involved in the biosynthesis of the branched-chain amino acids, was inhibited by bispyribac sodium. Protein synthesis and growth are inhibited without these amino acids, ultimately resulting in plant death.

Weed biomass

The findings showed that the weed control treatments significantly affected the weed biomass (Table 1). Thus, minimum post-treatment weed biomass ($4.13 g/m^2$) was achieved with the application of bispyribac sodium at 25 g/ha. It was followed by the application of fenoxaprop-p-ethyl + penoxsulam at 60+26.7 g/ha, and these two treatments remained statistically at par with each other. The lowest weed biomass observed with this treatment was due to effective control of dominant weed flora from the start of crop growth, which resulted in broad-spectrum control of weeds (Verma *et al*., 2022). These findings also align with those of Kumar *et al.* (2013), who observed that the post-emergence application of bispyribac sodium at 25 g/ha had maximum efficacy with respect to dry biomass accumulation against broad-spectrum weed flora in rice.

Weed control efficiency

Weed control efficiency was calculated based on weed biomass, and data regarding the impact of weed management treatments on weed control effi-

Table 1. Influence of weed control treatments on total weed density, weed biomass and weed control efficiency in direct seeded rice

Treatments	Weed density (no./m²)	Weed biomass (g/m²)	WCE (%)
Agroecosystems	90 DAS	90 DAS	90 DAS
Rainfed	5.11 (33.60)	5.55 (39.15)	
Irrigated	4.84 (29.87)	5.35 (36.75)	
SEm±	0.24	0.31	
CD (P=0.05)	NS	NS	
Weed control treatments			
Bispyribac sodium at 25 g/ha	3.41 (11.93)	4.13 (17.26)	89.5
Fenoxaprop-p-ethyl at 60 g/ha	5.17 (26.93)	5.74 (33.23)	78.9
Fenoxaprop-p-ethyl + penoxsulam at 60+26.7 g/ha	3.95 (15.70)	4.32 (19.03)	88.2
Cyhalofop + penoxsulam at 135+26.7 g/ha	4.33 (19.21)	4.65 (21.73)	86.5
Bispyribac sodium + metsulfuon methyl + chlorimuron ethyl at 25+4 g/ha	4.88 (24.05)	5.31 (28.90)	81.9
Triafamone + ethoxysulfuron at 40+20 g/ha	4.46 (20.51)	4.77 (22.71)	85.7
Hand weeding	2.09 (3.95)	2.18 (4.30)	97.2
Weedy check	11.48 (131.60)	12.52 (156.43)	0.0
SEm±	0.34	0.35	-
CD (P=0.05)	1.01	1.03	-

Square root (X+0.5)-transformed values; values in the parentheses are original values; DAS- days after sowing

ciency are shown in Table 1. Plots that were manually weeded showed the best weed control efficiency compared to other weed control measures. However, hand weeding is more time-consuming and, therefore, more expensive than the application of herbicides. Among herbicidal treatments, the maximum weed control efficiency (89.5%) was recorded in bispyribac sodium at 25 g/ha. In contrast, minimum weed control efficiency (78.9%) was obtained with the treatment of fenoxaprop-p-ethyl at 60 g/ha. The highest weed control efficiency with bispyribac sodium at 25 g/ha were also observed by Veeraputhiran and Balasubramanian, 2013.

Growth parameters

The weed management practices significantly influenced the growth parameters, i.e., plant population, plant height and plant biomass (Table 2). Significantly highest values of growth parameters were observed in the hand-weeding treatment. In contrast, the lowest values of these parameters were observed in weedy check plots because weeds are showing high competition with rice plants for growth resources. Among herbicides, higher plant populations (153/m²), plant height (83.1 cm) and plant biomass (1200 g) were recorded under bispyribac sodium at 25 g/ha, followed by fenoxaprop-p-ethyl + penoxsulam at 60+26.7 g/ha. The results are in line with the findings of Patel *et al*., 2018 and Pavithra *et al.,* 2020. They reported that improved growth parameters in weed control treatments than the control treatment showed the enhancement in crop growth due to herbicide usage.

The data in relation to LAI being significantly influenced by different treatments are given in Table 2. The data indicate that the LAI was recorded at its maximum in hand weeding treatment. The minimum under the weedy check (control) plot may result from improperly developing the assimilatory surface area under treatment, allowing more weeds to grow. Among the herbicides, the value of LAI under treatment with bispyribac sodium at 25 g/ha was observed to be significantly higher (3.60) and at par with the plot treated with fenoxaprop-p-ethyl + penoxsulam at 60+26.7 g/ha and cyhalofop + penoxsulam at 135+26.7 g/ha as compared to other treatments. The weed-free environment provides more chance for leaves to expand and cover the area by their canopy in an appreciable manner (Sridhar *et al*., 2019).

Yield attributing traits and yield

Yield attributing characteristics of direct seeded rice significantly influenced by weed control treatments are presented in Table 3. Among all the weed control treatments, the lowest values of yield attributing traits (panicles/m^2 and panicle length) were recorded under weedy control due to severe weed competition creating a limited supply of growth resources. Heavy weed competition hampered the supply of growth resources below the demand resulting in poor vegetative growth and reduced assimilatory area per unit of ground area. While the highest values of these yield-attributing traits were recorded under hand weeding because of lower weed density and dry weight, there was no competition with base crops, resulting in better yield growth and development (Saravanane, 2020 and Biswas *et al*., 2023). Among the application of the herbicide, bispyribac sodium at 25 g/ha exhibited higher panicles/m^2 (350) and panicle length (20.9 cm), closely followed by fenoxaprop-p-ethyl + penoxsulam at 60 + 26.7 g/ha and cyhalofop + penoxsulam at 135 + 26.7 g/ha.

Results revealed that higher yield was exhibited from all the herbicide application treatments compared to non-treated checks. Among the herbicidal treatments, bispyribac sodium applied at 25 g/ha, recorded the significantly higher grain yield (2768 kg/ha) followed by fenoxaprop-p-ethyl + penoxsulam at 60 + 26.7 g/ha and cyhalofop + penoxsulam at 135 + 26.7 g/ha. However, the yield obtained from hand weeding was significantly superior over the remaining weed control treatments. In comparison, the minimum grain yield was found in the weedy check (1417 kg/ha). These encouraging findings of the current study revealed that herbicide application is highly efficient, non-laborious and strategically better than hand weeding (Rana *et al*., 2016 and Verma *et al*., 2022).

Economics

The benefit-cost ratio of the different applied weed control treatments is presented in Table 3. The re-

Table 2. Influence of weed control treatments on growth parameters in direct seeded rice

Treatments	Plant population/m^2 90 DAS	Plant height (cm) 90 DAS	Plant biomass (g) 90 DAS	LAI 90 DAS
Bispyribac sodium at 25 g/ha	153	83.1	1200	3.60
Fenoxaprop-p-ethyl at 60 g/ha	138	77.5	872	3.07
Fenoxaprop-p-ethyl + penoxsulam at 60+26.7 g/ha	150	82.1	1104	3.43
Cyhalofop + penoxsulam at 135+26.7 g/ha	144	80.6	1045	3.33
Bispyribac sodium + metsulfuon methyl + chlorimuron ethyl at 25+4 g/ha	139	78.1	897	3.19
Triafamone + ethoxysulfuron at 40+20 g/ha	141	79.0	985	3.25
Hand weeding	156	85.1	1354	3.79
Weedy check	129	76.0	652	2.94
SEm±	0.78	0.90	0.86	0.09
CD (P=0.05)	2.28	2.64	2.52	0.27

DAS- days after sowing

Table 3. Influence of weed control treatments on yield attributing traits, grain yield and economics in direct seeded rice

Treatments	Panicles/ m^2	Panicle length (cm)	Grain yield (kg/ha)	B:C ratio
Bispyribac sodium at 25 g/ha	350	20.9	2768	2.34
Fenoxaprop-p-ethyl at 60 g/ha	299	19.2	1990	1.79
Fenoxaprop-p-ethyl + penoxsulam at 60+26.7 g/ha	341	20.6	2503	2.03
Cyhalofop + penoxsulam at 135+26.7 g/ha	331	20.4	2303	1.88
Bispyribac sodium + metsulfuon methyl + chlorimuron ethyl at 25+4 g/ha	304	19.5	2092	1.78
Triafamone + ethoxysulfuron at 40+20 g/ha	320	20.2	2183	1.76
Hand weeding	358	21.8	3095	1.85
Weedy check	285	18.9	1417	1.34
SEm±	0.67	0.11	39.9	-
CD (P=0.05)	1.97	0.33	116.3	-

sults were similar to the findings of Hossain and Mondal, 2014. They proved bispyribac sodium at 25 g/ha exhibited optimal profit to the farmers for controlling weeds under direct-seeded rice. But the B: C ratio under hand weeding was less than bispyribac sodium at 25 g/ha because of the high cost of cultivation under hand weeding. At the same time, the weedy check was not advantageous as there was a loss of investment (Ramesha *et al.*, 2017).

Soil moisture content (%)

The soil moisture content was observed at weekly intervals at different soil depths in rainfed and irrigated agroecosystems; the results are given in Figure 1. The results revealed that there was more soil moisture in the upper 15 cm layer as compared to the lower 30 cm soil depth in both agroecosystems. The results showed that there is a marginal difference between rainfed and irrigated agroecosystems during the vegetative and panicle formation stages of crop growth. The soil moisture percent varies after September 27, preferably due to the withdrawal of the southwest monsoon during the last week of September, thereby causing a difference in soil moisture content. After that, irrigation was applied in irrigated agroecosystems, whereas irrigation was not applied in the case of rainfed agroecosystems. Due to this, moisture moves upward from the lower depth to the upper 15 cm soil depth by capillary forces, thereby minimizing the gap between the two layers under rainfed agroecosystems.

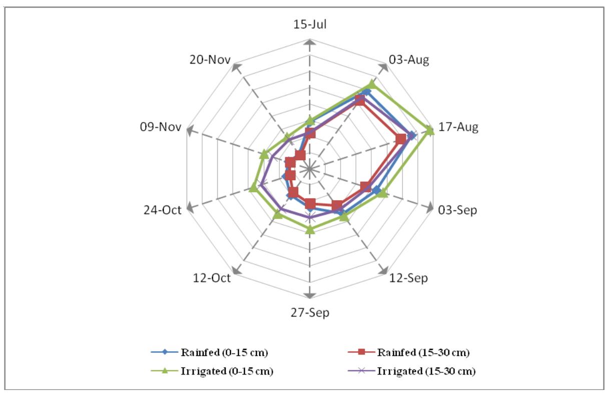

Fig. 1. Moisture content at different depths of soil in rainfed and irrigated agroecosystems during crop season

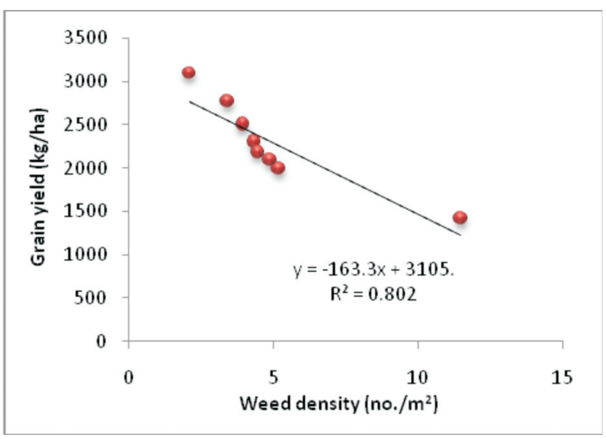

Fig. 2. Relationship between total weed density (no./m^2) and grain yield (kg/ha)

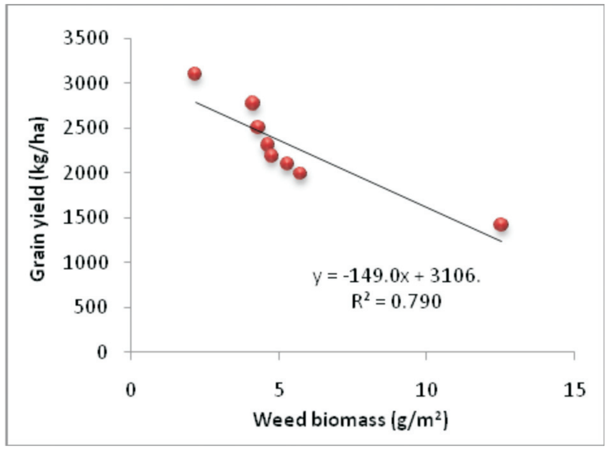

Fig. 3. Relationship between total weed biomass (g/m^2) and grain yield (kg/ha)

Conclusion

This research aimed to evaluate the effectiveness of herbicides applied to various weed species in direct-seeded rice. From this experiment, it can be concluded that the herbicide bispyribac sodium at 25 g/ha was the most suitable treatment for reducing the density and biomass of all the weeds and increasing rice output compared to the control. Based on overall results, using bispyribac sodium at 25 g/ha improves direct-seeded rice yield while generating higher net returns.

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Conflicts of Interest

The authors have no Conflicts of Interest to declare.

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