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Weed management in herbicide-tolerant rice under direct-seeded conditions

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Abstract
Rice is an important cereal that feeds billions of people globally. Weeds are a major biological constraint that poses 30-100% yield loss in rice. Therefore, a field experiment was conducted at ICAR-Directorate of Weed Research, Jabalpur to evaluate the bio-efficacy of imazethapyr (ALS inhibiting herbicide) against major weeds in herbicide-tolerant rice during *Kharif* season of 2021. The results revealed that the sequential application of imazethapyr at 200 g/ha as early post-emergence (at 14 DAS) followed by *(fb)* imazethapyr 200 g/ha as late post-emergence (at 28 DAS) provided broad-spectrum weed control with the lowest density and dry weight of all major weeds. Sequential application of imazethapyr at 100 and 125 g/ha at 14 and 28 DAS and hand weeding (20 and 40 DAS) also provided better weed control and was comparable to sequential application of imazethapyr at 200 g/ha. The highest grain and straw yield was recorded under sequential application of imazethapyr 100 g/ha, which was followed by sequential application of imazethapyr 125 g/ha. Weedy check witnessed the highest density and dry weight of weed and harvested with the lowest grain yield. Based on the findings, sequential application of imazethapyr 100 g/ha at 14 and 28 DAS was the best weed management practice which provided higher weed control, grain and straw yield over other weeds management practices.

Keywords: Direct-seeded rice, herbicide-tolerant rice, imazethapyr, weed management

Introduction

Rice is the staple food crop for the billions of people globally. The demand for rice is gradually increasing and in coming days it will further increase. But production is constant and in some cases, it's declining. Weeds are a major biological constraint in rice and severity further increase under direct-seeded rice ecology (Choudhary and Dixit, 2018) [1]. Weeds are the major menace to success of direct-seeded rice which competes aggressively for available natural resources at a site like above ground (light, CO_2 and space) and below ground (moisture and plant nutrients), imposing severe challenges to survival and yield of the crop (Choudhary and Dixit, 2021) [2]. Manual weed management is effective but costly practice, and in recent past the availability of trained manpower is meager and therefore wages are also higher. Under the circumstances, herbicides are considered important and reliable tools for weed management and have been contributing greatly over the past few decades. It is well established that herbicides are cost-effective, easy to apply, and an efficient way to control infesting weeds in the crop field (Nandula *et al.*, 2005) [9]. However, the incessant use of a single herbicide with the same mode of action several times in a single growing season increases the possible risk of the evolution of resistant weed biotypes, which has become a major concern in agriculture (Fartyal *et al.*, 2018; Choudhary *et al.*, 2021) [6, 2, 3]. But it is increasingly hard to discover a new herbicide and even more difficult to find one with a novel mode of action. Today, approximately five lakh compounds must be screened to discover a potential herbicide compared to one per 500 compounds screened in the 1940s (Gressel, 2002) [7]. Realizing the complexity of discovering new compounds with herbicidal properties, and expanding the utility of existing herbicides that have a broad spectrum of weed control and good environmental profile through genetically enhanced resistance is a useful approach for advancing the development of selective herbicides. In order to meet the demand for proper weed management in DSR, rice varieties were developed through conventional breeding, which is non-genetically modified and has the trait of herbicide tolerance against a certain group of herbicides.

In 1993, an imidazolinone tolerant 'IT' rice line '93-AS-3510' was discovered when variety was mutagenized with mutagen ethyl methane sulfonate (EMS) and a single mutated seedling survived the application of imazethapyr an imidazolinone group herbicide (Croughan, 1994). Since that discovery, several rice cultivars passing the herbicide-tolerance trait against imidazolinone group of herbicides have been developed through breeding programs using 93-AS-3510 as the male parent line i.e. CL 121 and CL 161, grown commercially between 2002 and 2003, respectively (Wenefrida *et al.*, 2004) [10].

Imidazolinone herbicides control weeds by inhibiting the enzyme acetohydroxyacid synthase (AHAS), also called acetolactate synthase (ALS), which is a crucial enzyme for the biosynthesis of branched-chain amino acids like valine, leucine, and isoleucine and results into death of susceptible plants. These herbicides control a wide range of grasses and broadleaf weeds, are effective at low application rates and possess a balanced environmental profile with low toxicity against mammals. Therefore, present study was conducted to know the bio-efficacy of imazethapyr in herbicide-tolerant rice under a direct-seeded rice ecosystem.

Materials and Methods

An experiment was conducted at ICAR-Directorate of Weed Research, Jabalpur (M.P.) (23°90' N, 79°58' E and 411.78 meter above mean sea level) during *Kharif* season of 2021. The experimental site receives an average annual rainfall of 1208 mm and the temperature varies from 15 °C to 45 °C during the winter and summer months, respectively. The soil of the experimental site was a clay (*Vertisol*) in texture having medium in organic carbon (0.58%), available nitrogen (266.0 kg/ha), available potassium (252.0 kg/ha) and high in available phosphorus (23.6 kg/ha). The crop was subjected to 120 kg N, 57.6 kg P_2O_5 and 40 kg K_2O/ha. Full P_2O_5 and ¾ of K_2O were applied just before sowing. The nitrogen was applied in splits (22.5 kg at basal, 25 kg at 10 DAS, 27.5 kg at 30 DAS, 25 kg at 45 DAS and 20 kg along with ¼ of K_2O at 65 DAS). The experiment was laid out in randomized block design (RBD) with 10 treatments (Table 1) and replicated thrice. The required amount of herbicides were sprayed with 375 L/ha water volume with the help of knapsack sprayer fitted with a flat fan nozzle.

Sampling for the determination of weed density and dry weight was done at 30 DAS by placing 50 cm × 50 cm (0.25 m^2) quadrate at two places in each plot. For density, weeds were counted species-wise in each quadrate and dry weight of weeds was determined after drying them in a hot air oven at 65±2 °C till they attained constant dry weight. Weed control efficiency and weed control index was calculated by the standard formula given by Mani *et al.* (1973) [8] and Das (2008) [5], respectively. The grain and straw yield was recorded from 10 m^2 area and extrapolated to a hectare. Data was analysed using the OPSTAT software. The weed data was heterogenous; to normalize them square root transformation ($\sqrt{x+0.5}$) was done, however, for better understanding original values were also given in parenthesis.

Result and Discussion

Weed flora

The experimental field comprised *Echinochloa* spp., *Dinebra retroflexa*, *Eleusine indica*, and *Oryza nivara* among the grasses, *Cyperus iria* and *Fimbristylis miliacea* among the sedges and *Alternanthera sessilis*, *Caesulia axillaris*, *Eclipta alba*, *Ludwigia parviflora*, and *Mecardonia procumbens* among broadleaf weeds (BLWs). The field was dominated by grassy weeds with a relative weed density of 52.2% followed by broadleaved weeds (25.7%) and the remaining were sedges (22.1%). The relative weed density of weeds is given in Figure 1.

Weed density

Weed management treatment has a significant (p=0.05) effect on density of grasses, BLWs and sedges (Table 1). Adoption of herbicide-based weed management considerably reduced the densities of all the groups of weeds over weedy check. However, sequential application of imazethapyr at 200 g/ha at 14 and 28 DAS was the most effective with 98.8% of WCE followed by sequential application of imazethapyr at 125, 100 and 75 g/ha (95.6-98.2%). Single application of imazethapyr also controlled the weeds but was less effective with 82.5-91.8% of WCE than that of weedy check. The efficacy was gradually increased with an increase in the concentration of imazethapyr. Among applied herbicides, bispyribac-sodium at 25 g/ha at 20 DAS was the least effective with 48.5% WCE, as the majority of the weeds were not controlled. The highest weed density was recorded with weedy check plots.

Table 1: Weed density, dry weight, weed control efficiency (WCE) and weed control index (WCI) of major weeds as influenced by weed management in HTR under DSR

Treatments	Weed density (no./m^2)			WCE (%)	Weed dry weight (g/m^2)			WCI (%)
	Grasses	sedges	BLW		Grasses	sedges	BLW	
Imazethapyr 100 g/ha	5.91 (34.7)	2.32 (6.7)	4.00 (17.3)	82.5	2.12 (4.00)	1.14 (0.80)	2.14 (5.00)	83.8
Imazethapyr 125 g/ha	5.13 (27.3)	2.31 (6.7)	3.40 (12.0)	86.8	1.78 (2.90)	0.97 (0.50)	2.46 (5.60)	84.5
Imazethapyr 200 g/ha	3.62 (12.7)	2.43 (6.8)	2.82 (8.0)	91.9	1.61 (2.10)	0.93 (0.40)	1.45 (1.80)	92.0
Imazethapyr 75g/ha (EPOST) *fb 75* g/ha (LPOST)	2.11 (4.0)	2.84 (7.3)	1.61 (2.7)	95.9	1.02 (0.60)	0.93 (0.40)	0.91 (0.40)	96.9
Imazethapyr 100 g/ha (EPOST) *fb* 100 g/ha (LPOST)	0.71 (0.0)	2.21 (4.7)	1.26 (1.4)	98.2	0.71 (0.00)	0.87 (0.30)	0.75 (0.07)	98.4
Imazethapyr 125 g/ha (EPOST) *fb* 125 g/ha (LPOST)	0.71 (0.0)	2.14 (5.3)	1.22 (1.3)	98.0	0.82 (0.20)	0.88 (0.28)	0.75 (0.07)	99.0
Imazethapyr 200 g/ha (EPOST) *fb* 200 g/ha (LPOST)	0.71 (0.0)	1.72 (4.7)	0.71 (0.0)	98.8	0.71 (0.00)	0.88 (0.32)	0.71 (0.00)	99.5
Bispyribac-Sodium 25 g/ha	9.74 (94.7)	4.93 (24.0)	6.91 (48.7)	48.5	3.68 (13.10)	1.35 (1.33)	4.52 (20.4)	42.9

Hand weeding at 20 and 40 DAS	2.14 (4.0)	0.71 (0.0)	2.14 (5.3)	96.3	0.96 (0.40)	0.71 (0.00)	0.92 (0.39)	98.9
Weedy check	13.2 (173.3)	8.63 (73.3)	9.23 (85.3)	0.0	4.58 (20.50)	2.91 (8.00)	5.53 (30.3)	0.0
SE(m)	0.37	0.69	0.61	-	0.15	0.11	0.29	-
C.D.	1.12	2.07	1.84	-	0.46	0.34	0.88	-

EPOST=Early post-emergence (14 DAS), LPOST=Late post-emergence (28 DAS), *fb*=followed by

Weed dry weight

Similar to weed density, weed dry weight followed the trend and recorded the lowest weed dry weight of grasses (0-20.5 g/m^2), BLWs (0.71-8.0 g/m^2) and sedges (0-30.3 g/m^2) with sequential application of imazethapyr at 200 g/ha at 14 and 28 DAS with 99.5% WCI. However, sequential applications of imazethapyr (75-125 g/ha) were also comparable to it and the increased rate of herbicide application has recorded an enhanced effect on weed control which resulted in lower weed dry weight with 96.9-99.0% WCI (Table 1). Among the post-emergence herbicides, application of imazethapyr at 200 g/ha was considerably better than the rest of herbicides, this suggests that a higher rate of application has an edge over the lower dose. The higher density of different groups of weeds was recorded with weedy check.

Grain and straw yields

Grain and straw yield and harvest index were significantly (p=0.05) influenced by weed management in herbicide-tolerant rice under DSR (Table 2). Sequential application of imazethapyr 100 g/ha (14 DAS) *fb* imazethapyr 100 g/ha (28 DAS) recorded the highest grain yield (4350 kg/ha). This was closely followed by sequential application of imazethapyr 125 g/ha *fb* imazethapyr 125 g/ha and two hand weeding at 20 and 40 DAS with grain yield of 4412 and 4332 kg/ha, respectively. The higher grain yield may be attributed to the reduced weed competition and thereby increased crop growth due to control of weeds at the initial stage by the application of early post-emergent (EPOST) application of imazethapyr, which controlled weeds at the early stage followed by late post-emergent (LPOST) application of imazthapyr which effectively controlled later flushes of weeds, thus offering broad-spectrum control of weed for the whole crop period. Among treatments comprised of POST applications, imazethapyr at 200 g/ha recorded a higher grain yield than other treatments which complements the higher bio-efficacy of imazethapyr at a higher dose. However, the efficacy was considerably low than the sequential application of any of the doses of imazethapyr at 14 and 28 DAS. The lowest grain yield was recorded in weedy check due to high weed pressure which offered more competition for the resources at the site (Choudhary *et al.*, 2021) [2, 3]. The efficacy of bispyribac-sodium at 25 g/ha was next to the weedy check mainly due to non-stagnation of water in the field allowing multiple flushes of the weeds especially *Dinebra retroflexa, Eleucine indica and digitaria sanguinalis, Alternanthera sessilis* and *Cyperus iria*. This resulted in poor rice grain yield. Grain yield has negatively correlated with weed density (no./m^2) following quadratic relation with R^2=0.98, likewise weed dry weight (g/m^2) has followed the negative linear relationship with R^2=0.89 under dry DSR (Figure 2). The PCA discriminate among the weed management practice where lesser weed density and weed dry weight was associated with higher grain yield in sequential application of imazethapyr at 75-125 g/ha and hand weeding at 20 and 40 DAS (Figure 3).

Table 2: Grain yield, straw yield and harvest index (%) as influenced by weed management in HTR under DSR

S. No.	Treatments	Grain yield (kg/ha)	Straw yield (kg/ha)	Harvest index (%)
T_1	Imazethapyr 100 g/ha	3,249	4,845	40.1
T_2	Imazethapyr 125 g/ha	3,350	5,146	39.4
T_3	Imazethapyr 200 g/ha	3,530	5,293	40.0
T_4	Imazethapyr 75g/ha (EPOST) *fb 75* g/ha (LPOST)	4,244	5,629	43.0
T_5	Imazethapyr 100 g/ha (EPOST) *fb* 100 g/ha (LPOST)	4,530	6,033	42.9
T_6	Imazethapyr 125 g/ha (EPOST) *fb* 125 g/ha (LPOST)	4,412	5,854	43.0
T_7	Imazethapyr 200 g/ha (EPOST) *fb* 200 g/ha (LPOST)	3,833	5,137	42.8
T_8	Bispyribac-Sodium 25 g/ha	2,108	3,562	37.2
T_9	Hand weeding at 20 and 40 DAS	4,332	5,718	43.1
T_{10}	Weedy check	739	1,308	36.2
S.Em (±)		99.2	88.6	0.81
CD at 5 %		296.9	265.2	2.43

EPOST=Early post-emergence (14 DAS), LPOST=Late post-emergence (28 DAS), *fb*=followed by

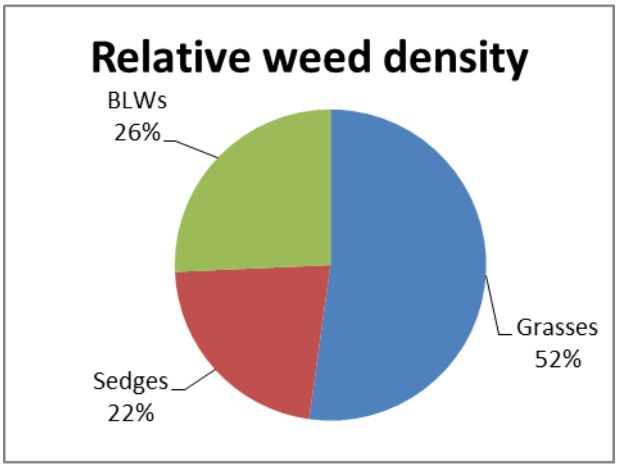

Fig 1: Relative weed density

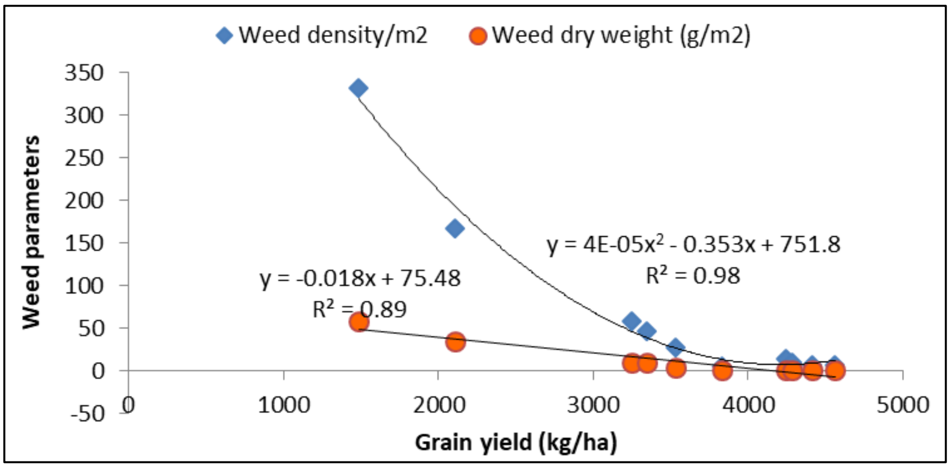

Fig 2: Relationship between grain yield and weed density and dry weight under DSR

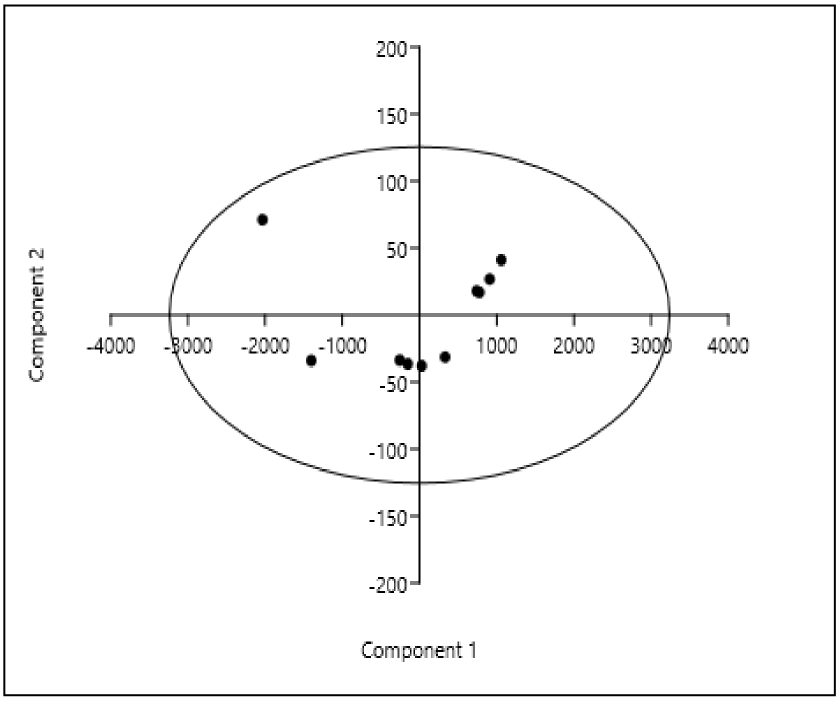

Fig 3: Principal component analysis (PCA) of weed density (no./m^2), weed dry weight (g/m^2) and grain yield of rice under dry DSR

Based on the findings it can be concluded that application of imazethapyr as early post emergence followed by late post-emergence offers broad-spectrum weed control than the single application at 20 DAS in herbicide tolerant rice. However, sequential application of imazethapyr at 100 g/ha *fb* imazethapyr 100 g/ha is the best among all treatments which significantly controlled grasses, sedges and broadleaved weeds, and produces higher grain yield.

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