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RESEARCH ARTICLE

Herbicide-based weed management on weed prevalence, crop productivity and profitability in transplanted rice

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ABSTRACT

The efficacy of pre- and post-emergence herbicide-based weed control methods was evaluated and compared with hand weeding twice and weedy check in transplanted rice. Hand weeding twice (20 and 40 days after transplanting) was found to be significantly (p=0.05) effective in controlling various groups of weeds, resulting in 86.4% weed control efficiency (WCE) and a rice grain yield of 6.99 t/ha. Additionally, sequential application of pyrazosulfuron 20 g/ha followed by (*fb*) bispyribac-sodium 25 g/ha and pendimethalin 1000 g/ha *fb* bispyribac-sodium was found to be highly effective in providing prolonged weed control. Bispyribac-sodium applied alone showed 78% WCE, which was significantly better than fenoxaprop and pyrazosulfuron. Pre-emergence *fb* post-emergence herbicides were found to be more profitable (B: C of 2.13-2.23) and productive (6.58-7.17 t/ha). The findings suggested that the sequential application of pyrazosulfuron 20 g/ ha or pendimethalin 1000 g/ha *fb* bispyribac-sodium 25 g/ha could provide broad-spectrum weed control, higher crop productivity, and profitability in transplanted rice.

Keywords: Economic return, Productivity, Transplanted rice, Weed prevalence

INTRODUCTION

In India, ~44 million hectares (M ha) area is under rice cultivation, with ~124 million tonne (Mt) production, which shares 21.5% of world rice production (DES 2024). India is largely self-sufficient in rice production, but to sustain self-sufficiency by 2050 and feed a projected population of 1.64 billion people, 197.4 Mt of rice will be needed. An additional challenge is that the extra rice will be produced with a lower environmental footprint with limited resources (*i.e.*, land, labour, water, agrochemicals, *etc*.) (Ahmad *et al.* 2021). Biotic and abiotic stresses are a major concern in the modern-day input-intensive agricultural production system as they cause serious economic losses. Among biotic stresses, weeds are major biological constraints and cause a 37% yield loss (Mishra *et al.* 2021). In majority, rice being a rainy season (June–October) crop, climatic and edaphic conditions are highly favourable for weed growth (Kabdal *et al.* 2018). Improper weed management may lead to a 95% yield reduction, and sometimes complete crop failure takes place in direct-seeded rice (DSR) (Maity and Mukharjee 2008, Naresh *et al.* 2011).

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Puddle-transplanted rice has several advantages, including the retention of a thin layer of water, formation of hardpan that prevents percolation losses, the suppression of weeds, and supply of nutrients (Choudhary *et al.* 2021). Rice crop is heavily infested with annual grasses, broad-leaf weeds, and sedges, posing a challenge to weed management (Choudhary and Dixit 2018). The depth of standing water affects the type and density of weed flora and the efficacy of applied herbicides. However, despite these benefits, multiple weed flushes lead to heavy weed pressure during the cropping period, resulting in a serious yield penalty that cannot be controlled by adopting one or two methods. Manual weeding is suggested as the best weed management method, but frequent rains, labour shortages, and high labour wages make it challenging, time-consuming, and uneconomical, especially during the critical period of weed competition (Choudhary and Dixit 2018).

Pre-emergence (PE) herbicides can effectively control weeds during the initial stages of crop growth, while post-emergence (PoE) herbicides are best used for killing the initial flush of weeds. Maintaining desired water levels after herbicide application can enhance their efficacy (Kaur *et al.* 2016). Sequential application of PE followed by (*fb*) PoE herbicides either premixes or tank mixes of herbicides with different modes of action can provide broad-spectrum weed control and found better results than using PE or PoE herbicides alone. Additionally, use of tank mix or premix can also reduce herbicide load, leads to cost savings. Despite its importance, comprehensive information on these aspects is scarce, and there is a need to develop productive and cost-effective weed management options as a substitute for costly and labour-intensive weeding of transplanted rice.

MATERIALS AND METHODS

A field study was carried out between June and November in 2015 and 2016 at the research farm of ICAR-National Institute of Biotic Stress Management, Raipur (21° 22' 50.4" N 81° 49' 31.9" E, 289 m above mean sea level), India. The study site experienced an average annual rainfall of 1250 mm, with 80% received during the south-west monsoon from July to September. The region has a subtropical climate with hot summers and a mean minimum temperature of 12°C in December, while May is the hottest month with a mean maximum temperature of 45°C. The soil was of Arang Series with a loamy texture containing 26% clay, 42% silt and 32% sand. The soil had a neutral pH of 6.9 and low soil organic carbon content of 0.37%. The soil was low in $KMnO_4$ oxidizable nitrogen (220.8 kg/ha), medium in 0.5 N $NaHCO_3$ extractable phosphorus (17.8 kg/ha) and high in 1 N NH_4OAc exchangeable potassium (345.0 kg/ha) in 0–20 cm soil depth.

The study was conducted with rice variety '*Swarna*', 21 days old seedlings were transplanted in a puddled field at a spacing of 20 × 10 cm, which was prepared by using two passes of a cultivator in dry condition and one pass of a rotavator after flooding. The treatments were pyrazosulfuron 20 g/ha (2 days after transplanting, DAT) followed by (*fb)* bispyribac-sodium 25 g/ha (25 DAT); fenoxaprop + 2,4-D (tank mix) 60 + 500 g/ha (25 DAT); pretilachlor + pyrazosulfuron (premix) 615 g/ha (6 DAT); pretilachlor + pyrazosulfuron (tank mix) 600+15 g/ha (6 DAT); bispyribac-sodium + 2,4-D (tank mix) 25 + 500 g/ha (25 DAT); fenoxaprop + chlorimuron + metsulfuron (tank mix) 60 + 4 g/ha (25 DAT); pendimethalin 1000 (2 DAT) *fb* bispyribac-sodium 25 g/ha (25 DAT); bispyribac-sodium 25 g/ha (25 DAT); pyrazosulfuron 20 g/ha (2 DAT); fenoxaprop 60 g/ha (25 DAT); hand weeding at 20 and 40 DAT and weedy check were imposed using a randomized complete block design (RCBD) with three replications with a gross plot size of 8 m × 20 m. Herbicide application was done using a backpack knapsack sprayer equipped with a flat fan nozzle. Spray volume of 500 L/ha was used for herbicides applied at 2 DAT, while 375 L/ha spray volume for herbicides applied at 25 DAT. The crop was fertilized with 100: 60: 40 kg N, P and K/ha through urea (N), di-ammonium phosphate (part of N and complete P) and muriate of potash (K), where the full dose of P and 75% of K fertilizers were applied at the time of transplanting. Nitrogen was applied in three splits at 22, 22, 32 kg N/ha at 10, 30 and 60 DAT. At 60 DAT, the remaining 10 kg/ha of potash was applied along with nitrogen. To prevent insect infestation, one spray of flubendiamide at 24 g/ha (against stem borer and leaf folders), dinetofuron at 35 g/ha (against brown plant hoppers and other sucking insects) was applied. Additionally, mancozeb + carbendazim at 563 g/ha was applied to control diseases.

Weed parameters (density and biomass) were recorded, at two random locations using quadrates measuring 0.25 m^2 (0.5 m × 0.5 m dimension) at 45 and 75 DAT. Weeds of different groups were identified, counted and cut at collar portion of the plants and placed them separately in brown paper bags for sun drying for 3–5 days. After drying off the excess moisture, these paper bags were placed in an oven at 70±2°C for 72 hours (h) until the weed samples attained a constant weight, which was considered the biomass of the respective weed species. The mean of both quadrates was converted into numbers/m^2 and g/m^2, respectively, for analysis and interpretation. The weed control efficiency was calculated from total weed biomass.

To homogenize the variance, a square root ($\sqrt{x + 0.5}$) transformation was performed to the weed data (density and biomass). Statistical analysis of all field data was conducted using SAS statistical software (version 9.3). The Tukey's Honest Significant Difference test was selected, and analysis of variance (ANOVA) was performed to determine the level of significance (p=0.05) between treatment means. As the effect of year was significant in most of the cases, results were presented separately for each year.

RESULTS AND DISCUSSION

The study area was found to have a significant presence of various grassy and broad-leaf weeds, as well as sedges. Among grassy weeds, jungle rice [*Echinochloa colona* (L.)], saramolla grass [*Ischaemum rugosum* (Salisb.)], viper grass [*Dinebra retroflexa* (Jacq.)], knot grass [*Paspalum distichium* (L.)] and large crabgrass [*Digitaria sanguinalis* (L.)] were identified. In addition, broad-leaf weeds like primerose willow [*Ludwigia parviflora* (Jacq.)], water clover [*Marselia quadrifolia* (L.)], smooth joyweed [*Alternanthera sessilis* (L.)], false daisy [*Eclipta alba* (L.)], and common dayflower [*Commelina communis* (L.)], as well as sedges like fimbry [*Fimbristylis miliacea* (L.)], rice flatsedge [*Cyperus iria* (L.)], gooseweed [*Sphenoclea zeylanica* (Gaertn.)] and smallflower umbrella sedge [*Cyperus difformis* (L.)] were also present. During cropping season in both the years, the dominant grassy weeds were *Echinochloa colona* and *Ischaemum rugosum,* while *Ludwigia parviflora* and *Alternanthera sessilis* were broad-leaf weeds. Among sedges, *Cyperus iria* and *Fimbristylis miliacea* were most prevalent.

Weed parameters

In both 2015 and 2016, weed density at 45 DAT followed almost a similar trend. The highest total weed density was observed in the weedy check (114–125/m^2) with a composition of 31–33% grasses, 42% broad-leaf weeds, and 25–27% sedges (**Table 1**). However, hand weeding at 20 and 40 DAT completely controlled both grassy and broad-leaf weeds, but only counted 2 sedges/m^2 during both years. Herbicide-based weed management showed a wide range of efficacy, with the suppression of grassy weeds ranging between 11–94%, broad-leaf weeds by 4–94%, and sedges by 6–89% over weedy check. The majority of grassy weeds were suppressed with pendimethalin 1.0 kg/ha *fb* bispyribac sodium 25 g/ha, while broad-leaf weeds and sedges were controlled with sequential application of pyrazosulfuron 20 g/ha *fb* bispyribac-sodium 25 g/ha and a tank mix of bispyribac-sodium + 2, 4 D (25 + 500 g/ha). These herbicides noticeably suppressed all the weeds and were found to be more effective than other weed management practices. Twice hand weeding resulted in the minimum weed biomass accumulation (1 g/m^2), while the weedy check had the highest (15.6–19.6 g/m^2) in both years. Pyrazosulfuron *fb* bispyribac-sodium resulted in WCE of 83% followed by pendimethalin *fb* bispyribac-sodium (82%) than the weedy check. At 75 DAT, weed parameters were also influenced by weed management practices (**Table 2**). The weedy check had the highest number of grasses (76/m^2), broad-leaf weeds (109–113/m^2), sedges (52–56/m^2), and total weed density (238–245/m^2), while twice hand weeding had the lowest density for all group of weeds. Among the herbicide-based treatments, pyrazosulfuron *fb* bispyribac-sodium suppressed weeds by 92% grasses, 94% broad-leaf weeds, 83% sedges and 88% total weeds, followed by pendimethalin *fb* bispyribac-sodium (91, 90, 83 and 89%, respectively) over the weedy check. Suppression of weeds reduced the total weed biomass, resulting in a higher WCE in the sequential application of PE *fb* PoE herbicides. The results demonstrate that the use of a sole application of pyrazosulfuron was weak against grasses, controlling only 11–27%, while sole application of fenoxaprop was weak against broad-leaf (4–7%) and sedges (6–

Table 1. Weed density and biomass at 45 DAT as influenced by different treatments in transplanted rice

Treatment	Grasses (no./m^2)		BLW (no./m^2)		Sedges (no./m^2)		Total weed density (no./m^2)		Weed biomass (g/m^2)		WCE (%)	
	2015	2016	2015	2016	2015	2016	2015	2016	2015	2016	2015	2016
Pyrazosulfuron 20 g/ha 2 DAT *fb* bispyribac-sodium 25 g/ha (25 DAT)	2.4(5)	2.6(6)	2.2(4)	1.9(3)	2.0(3)	2.4(5)	3.7(13)	3.9(15)	1.9(3)	1.9(3)	81.2	83.8
Fenoxaprop + 2,4-D (TM) 60 + 500 g/ha (25 DAT)	2.5(6)	2.3(5)	3.2(10)	2.5(6)	2.7(7)	2.7(7)	4.8(23)	4.2(17)	2.4(5)	2.6(6)	66.9	67.5
Pretilachlor + pyrazosulfuron (PM) 615 g/ha (6 DAT)	2.0(4)	2.0(3)	2.8(7)	2.3(5)	2.5(6)	2.4(5)	4.1(17)	3.8(14)	2.1(4)	2.3(5)	75.6	76.4
Pretilachlor + pyrazosulfuron (TM) 600+15 g/ha (6 DAT)	2.4(5)	2.5(6)	4.0(16)	3.2(10)	3.6(12)	3.3(10)	5.8(33)	5.1(26)	2.3(5)	2.5(6)	68.6	71.6
Bispyribac-sodium + 2,4-D (TM) 25 + 500 g/ha (25 DAT)	2.5(6)	2.5(6)	2.4(5)	1.9(3)	2.0(4)	2.0(4)	3.9(15)	3.6(13)	2.6(7)	2.9(8)	58.3	59.4
Fenoxaprop + chlorimuron + metsulfuron (TM) 60 + 4 g/ha (25 DAT)	2.3(5)	2.0(4)	2.7(7)	2.2(4)	2.9(8)	2.3(5)	4.4(19)	3.7(13)	2.5(6)	2.4(5)	61.8	72.3
Pendimethalin 1000 (2 DAT) *fb* bispyribac-sodium 25 g/ha (25 DAT)	1.7(2)	1.7(2)	2.5(6)	2.3(5)	2.4(5)	2.5(6)	3.7(13)	3.7(13)	1.9(3)	1.8(3)	78.8	85.2
Bispyribac-sodium 25 g/ha (25 DAT)	2.4(5)	2.8(7)	2.9(8)	3.0(9)	2.5(6)	3.2(10)	4.4(19)	5.2(26)	2.2(4)	2.5(6)	73.3	69.7
Pyrazosulfuron 20 g/ha (2 DAT)	5.8(34)	5.4(29)	3.5(12)	3.3(10)	2.9(8)	2.8(7)	7.3(53)	6.8(46)	2.6(6)	2.7(7)	61.3	65.5
Fenoxaprop 60 g/ha (25 DAT)	2.5(6)	2.3(5)	6.8(46)	7.0(48)	5.3(27.3)	5.6(31)	8.9(79)	9.2(84)	3.0(9)	3.2(9)	44.9	51.5
Hand weeding at 20 and 40 DAT	0.7(0)	0.7(0)	0.7(0)	0.7(0)	1.6(2)	1.7(2)	1.6(2)	1.7(2)	1.2(1)	1.3(1)	93.8	94.0
Weedy check	6.2(38)	6.3(39)	6.9(48)	7.2(52)	5.4(29)	5.8(34)	10.7(114)	11.2(125)	4.0(16)	4.5(20)		
LSD (p=0.05)	0.37	0.35	0.45	0.40	0.54	0.56	0.31	0.20	0.60	0.56		

DAT: days after transplanting; BLW, broad-leaf weeds; WCE, weed control efficiency; HW, hand weeding; PM, premix; TM, tank mix; values in parenthesis are original and outside are transformed $\sqrt{x+0.5}$

9%). Thus, using only PE or PoE herbicides is not efficient enough to provide broad-spectrum weed control. Sequential use of PE herbicides such as pyrazosulfuron or pendimethalin followed by PoE herbicide (bispyribac-sodium) broadly controls mixtures of weed flora in transplanted rice. This is because broad-leaf weeds, sedges and some grasses were effectively controlled by pyrazosulfuron, whereas pendimethalin takes care of grasses and some broadleaved weeds. Subsequent applications of bispyribac-sodium control the large group of weeds left after PE herbicide or late emerged weeds. Mahajan and Chauhan (2013) also reported that bispyribac-sodium controlled around 52% of weed density and 50% of weed biomass, while pendimethalin *fb* bispyribac-sodium controlled 92% of weed density and 93% of weed biomass. Mixing auxin-based herbicides with other modes of action of herbicides requires compatibility study prior to mixing or application. As tank mix application of bispyribac-sodium + 2, 4-D recorded considerably poor weed control than bispyribac-sodium alone, possibly due to escape of grassy weeds and some shocks to the rice crop due to 2, 4-D. However, Tripathy *et al.* (2018) reported that bispyribac-sodium + 2, 4-D was more effective in controlling weeds. Applications of PE herbicides significantly suppress initial weed establishment, and subsequently, bispyribac-sodium (25 g/ha) takes care of the weeds at a later crop stage. Similarly, application of PE and PoE herbicides in sequence or compatible tank mix or premix herbicides with different mode of action is superior to weedy check in controlling weeds (**Tables 1** and **2**).

Crop growth and yield attributes

During 2015 and 2016, effective tillers per unit area were highest with pyrazosulfuron *fb* bispyribac (450–463/m^2), followed by twice hand weeding and pendimethalin *fb* bispyribac-sodium, while the weedy check had the least effective tillers (**Table 3**). Twice hand weeding and pyrazosulfuron *fb* bispyribac-sodium improved tiller production by 16.7–57.4%, leading to better establishment of seedlings with no negative effect on the rice crop. In addition, the LAI was higher with pendimethalin *fb* bispyribac-sodium (2.81–3.12), followed by pyrazosulfuron *fb* bispyribac-sodium, whereas the weedy check had the lowest LAI (1.69–1.89). Higher LAI was mainly due to more tillers, longer and wider leaves. However, the application of fenoxaprop was phytotoxic to the plants, which might have retarded the initial growth and development of leaves, resulting in a lesser LAI (Choudhary and Dixit 2018). Pendimethalin *fb*

Table 2. Weed density and biomass at 75 DAT as influenced by different treatments in transplanted rice

Treatment	Grasses (no./m^2)		BLW (no./m^2)		Sedges (no./m^2)		Total weed density (no./m^2)		Weed biomass (g/m^2)		WCE (%)	
	2015	2016	2015	2016	2015	2016	2015	2016	2015	2016	2015	2016
Pyrazosulfuron 20 g/ha 2 DAT *fb* bispyribac-sodium 25 g/ha (25 DAT)	3.4 (11)	3.7 (13)	2.5 (6)	2.9 (8)	2.3 (5)	3.7 (13)	4.7 (22)	5.9 (34)	2.1 (4)	2.9 (8)	80.9	81.8
Fenoxaprop + 2,4-D (tank mix) 60 + 500 g/ha (25 DAT)	2.9 (8)	3.1 (9)	4.0 (16)	3.8 (14)	3.3 (11)	3.6 (12)	5.9 (34)	6.0 (36)	2.6 (6)	3.59 (12)	70.3	71.8
Pretilachlor + pyrazosulfuron (premix) 615 g/ha (6 DAT)	3.3 (11)	3.7 (13)	3.8 (14)	3.4 (11)	3.7 (13)	3.5 (12)	6.2 (38)	6.1 (36)	2.2 (4)	3.1 (9)	79.1	79.2
Pretilachlor + pyrazosulfuron (tank mix) 600+15 g/ha (6 DAT)	4.1 (17)	4.5 (19)	5.7 (32)	4.8 (23)	5.0 (24)	4.7 (22)	8.6 (73)	8.1 (64)	2.5 (6)	3.5 (12)	72.3	72.8
Bispyribac-sodium + 2,4-D (tank mix) 25 + 500 g/ha (25 DAT)	3.9 (15)	4.1 (16)	3.1 (9)	3.2 (10)	2.3 (5)	3.0 (8)	5.4 (29)	5.9 (35)	2.7 (7)	3.9 (15)	65.9	66.6
Fenoxaprop + chlorimuron + metsulfuron (tank mix) 60 + 4 g/ha (25 DAT)	2.5 (6)	2.5 (6)	4.1 (16)	3.5 (12)	3.4 (11)	3.7 (13)	5.8 (33)	5.6 (31)	2.7 (7)	3.8 (14)	67.6	68.8
Pendimethalin 1000 (2 DAT) *fb* bispyribac-sodium 25 g/ha (25 DAT)	2.5 (6)	2.9 (8)	3.3 (11)	3.4 (11)	2.7 (7)	3.4 (11)	4.9 (24)	5.6 (31)	2.1 (4)	2.9 (8)	81.1	81.5
Bispyribac-sodium 25 g/ha (25 DAT)	3.8 (14)	4.0 (16)	3.7 (13)	3.9 (15)	3.4 (11)	4.2 (17)	6.2 (38)	6.9 (48)	2.3 (5)	3.2 (9)	77.7	78.6
Pyrazosulfuron 20 g/ha (2 DAT)	8.1 (65)	8.5 (72)	4.4 (19)	4.3 (18)	4.1 (16)	3.9 (15)	10.0 (100)	10.3 (105)	2.8 (7)	4.0 (15)	64.0	65.3
Fenoxaprop 60 g/ha (25 DAT)	3.0 (9)	2.8 (8)	9.5 (90)	9.3 (86)	6.7 (45)	7.1 (50)	12.0 (143)	12.0 (143)	2.8 (7)	4.1 (16)	63.8	62.9
Hand weeding at 20 and 40 DAT	2.2 (4)	2.6 (6)	2.6 (6)	3.2 (10)	2.4 (5)	2.7 (7)	4.1 (16)	4.8 (23)	1.9 (3)	2.4 (5)	84.8	88.0
Weedy check	8.8 (77)	8.7 (76)	10.5 (109)	10.7 (113)	7.2 (52)	7.5 (56)	15.4 (238)	15.7 (245)	4.6 (21)	6.6 (44)		
LSD (p=0.05)	0.49	0.47	0.45	0.54	0.64	0.49	0.45	0.50	0.32	0.41		

BLW, broad-leaf weeds; WCE, weed control efficiency; values in parenthesis are original and outside are transformed $\sqrt{x+0.5}$

bispyribac-sodium resulted in longer (24.4 cm in 2015 and 24.1 cm in 2016) and heavier panicles (3.1 and 3.8 g/panicle, respectively) followed by premix and tank mix of pretilachlor+pyrazosulfuron, whereas the weedy check produced shorter and lighter panicles (21.7 and 21.5 cm, 2.9 and 2.8 g/ panicle, respectively). Moreover, the filled grains/ panicle were higher with twice hand weeding (167 and 156, respectively), followed by pyrazosulfuron *fb* bispyribac-sodium (161 and 148, respectively), whereas the weedy check had fewer grains/panicle (84 and 77, respectively). Overall, other weed management practices were better in terms of yield attributes than the weedy check. The weedy check had higher chaffy grains (20–22 grains/panicle) than the other treatments.

Crop yield

The highest grain yield was obtained under twice hand weeding in 2015 (7.45 t/ha), whereas pyrazosulfuron *fb* bispyribac-sodium showed the highest yield in 2016 (6.58 t/ha). The premix of pretilachlor + pyrazosulfuron followed by pendimethalin *fb* bispyribac-sodium was the next best treatment, which gave a significantly higher rice grain yield than other treatments. These provided an extended weed–free environment, which allows rice plants to utilize available resources such as water, nutrients, sunlight and space. It promoted the production of higher LAI, leading to increased photosynthesis, translocation to different plant parts, and ultimately, higher total dry matter production, longer and heavier panicles, more filled grains, and fewer chaffy grains (**Table 4**), leading to higher grain and straw yield in rice. These findings are consistent with earlier studies by Teja *et al.* (2016), Kumar *et al.* (2018), and Singh *et al.* (2018). Similarly, Walia *et al.* (2008) reported that the application of pendimethalin 0.75 kg/ha *fb* bispyribac-sodium 25 g/ha resulted in 372% more rice grain yield due to better weed control over the weedy check. Weedy check had the lowest grain yields (3.62 and 3.61 t/ha, respectively) due to severe weed competition, leading to reduced yield characters, growth, nutrient uptake, and yield

Table 3. Growth parameters and yield attributes as influenced by different treatments in transplanted rice

Treatment	Tillers (no./m^2)		Leaf area index		Panicle length (cm)		Panicle weight (g/panicle)		Filled grain (no./panicle)		Chaffy grain (no./panicle)	
	2015	2016	2015	2016	2015	2016	2015	2016	2015	2016	2015	2016
Pyrazosulfuron 20 g/ha 2 DAT *fb* bispyribac-sodium 25 g/ha (25 DAT)	450.0	463.3	3.03	2.81	23.5	23.2	3.34	3.22	161.0	148.0	10.5	12.0
Fenoxaprop + 2,4-D (TM) 60 + 500 g/ha (25 DAT)	350.0	355.0	1.93	1.77	22.7	22.6	3.03	2.99	117.8	106.8	14.7	16.7
Pretilachlor + pyrazosulfuron (PM) 615 g/ha (6 DAT)	383.3	390.0	2.64	2.52	22.4	22.6	3.44	3.40	152.8	140.8	11.0	12.0
Pretilachlor + pyrazosulfuron (TM) 600+15 g/ha (6 DAT)	366.7	353.3	2.41	2.20	23.7	23.5	3.61	3.57	117.1	107.1	13.6	15.6
Bispyribac-sodium + 2,4-D (TM) 25 + 500 g/ha (25 DAT)	396.7	380.0	2.93	2.67	23.7	23.5	3.48	3.39	125.1	114.1	12.6	13.6
Fenoxaprop + chlorimuron + metsulfuron (TM) 60 + 4 g/ha (25 DAT)	366.7	345.0	2.50	2.27	23.2	23.3	3.70	3.66	101.3	89.3	15.2	17.2
Pendimethalin 1000 (2 DAT) *fb* bispyribac-sodium 25 g/ha (25 DAT)	435.0	413.3	3.12	2.81	24.4	24.1	3.81	3.79	150.6	140.6	11.5	13.5
Bispyribac-sodium 25 g/ha (25 DAT)	420.0	400.0	2.85	2.59	22.7	22.8	3.13	3.08	133.0	121.0	12.3	14.8
Pyrazosulfuron 20 g/ha (2 DAT)	395.0	393.9	2.68	2.53	23.3	23.1	3.38	3.32	133.0	122.0	16.3	17.3
Fenoxaprop 60 g/ha (25 DAT)	358.3	356.7	2.12	1.95	23.4	23.2	3.23	3.18	98.9	88.9	19.7	20.7
Hand weeding at 20 and 40 DAT	472.2	447.8	2.93	2.81	23.3	23.2	3.57	3.52	166.6	155.6	8.4	8.9
Weedy check	300.0	293.3	1.89	1.69	21.7	21.5	2.90	2.82	83.7	76.7	20.9	21.9
LSD (p=0.05)	72.73	75.63	0.75	0.72	1.55	1.51	0.47	0.48	20.00	20.00	6.93	6.94

Table 4. Grain, straw and biological yield as influenced by different treatments in transplanted rice

Treatment	Grain yield (t/ha)		Straw yield (t/ha)		Biological yield (t/ha)		Yield loss (%)	
	2015	2016	2015	2016	2015	2016	2015	2016
Pyrazosulfuron 20 g/ha 2 DAT *fb* bispyribac-sodium 25 g/ha (25 DAT)	7.17	6.58	8.05	7.84	15.22	14.43	3.8	-3.9
Fenoxaprop + 2,4-D (tank mix) 60 + 500 g/ha (25 DAT)	5.34	5.25	5.57	7.21	10.92	12.46	27.4	16.9
Pretilachlor + pyrazosulfuron (premix) 615 g/ha (6 DAT)	7.03	6.22	7.43	6.39	14.47	12.61	5.1	1.6
Pretilachlor + pyrazosulfuron (tank mix) 600+15 g/ha (6 DAT)	5.59	6.01	5.90	7.60	11.49	13.61	25.0	5.2
Bispyribac-sodium + 2,4-D (tank mix) 25 + 500 g/ha (25 DAT)	5.72	6.20	6.81	7.75	12.52	13.95	22.3	2.1
Fenoxaprop + chlorimuron + metsulfuron (tank mix) 60 + 4 g/ha (25 DAT)	4.80	5.65	5.20	7.70	10.00	13.36	35.6	10.5
Pendimethalin 1000 (2 DAT) *fb* bispyribac-sodium 25 g/ha (25 DAT)	6.92	6.00	7.06	7.37	13.97	13.37	6.7	5.1
Bispyribac-sodium 25 g/ha (25 DAT)	6.02	6.06	6.84	6.84	12.86	12.90	19.2	4.2
Pyrazosulfuron 20 g/ha (2 DAT)	4.56	5.77	4.90	6.59	9.46	12.37	38.6	9.0
Fenoxaprop 60 g/ha (25 DAT)	4.43	4.95	4.77	6.48	9.20	11.43	40.3	21.7
Hand weeding at 20 and 40 DAT	7.45	6.35	9.24	6.56	16.69	12.91	0.0	0.0
Weedy check	3.62	3.61	4.55	4.75	8.17	8.36	51.1	42.8
LSD (p=0.05)	1.16	0.62	0.91	0.75	1.26	1.37		

parameters of the crop (Nagarjun *et al.* 2019). The trend for straw yield followed a similar pattern, with the highest yield observed in 2015 with twice hand weeding (9.24 t/ha) and in 2016 with pyrazosulfuron *fb* bispyribac-sodium (7.84 t/ha). The lowest straw yield was obtained in weedy check (4.55 and 4.75 t/ha, respectively). Biological yield also followed the same trend. Yield loss in rice was the highest in weedy check, ranging between 43–51%, although the loss was higher in 2015 than in 2016. The relationship between grain yield and weed density (at 45 DAT) followed a quadratic relationship with a coefficient of determination (R^2) of 0.75 in 2015 and 0.54 in 2016 (**Figure 1a**). Similarly, rice grain yield had a quadratic relationship with weed biomass following R^2 of 0.86 in both years (**Figure 1b**). At 75 DAT, rice grain yield followed the quadratic relationship with weed density (R^2, 0.75 and 0.83, respectively) (**Figure 2a**) and weed biomass (R^2, 0.93 and 0.83, respectively) **(Figure 2b**).

Economics

The economic parameters were significantly affected by the weed management practices adopted in the study (**Table 5**). The highest cost of production was observed with twice hand weeding (₹ 41560/ha) due to requirement of a greater number of manual labourers for weed removal, followed by pendimethalin *fb* bispyribac-sodium (₹ 31660/ha), while the lowest cost was incurred in the weedy check (₹ 29160/ha). With regard to gross returns, twice hand weeding showed the highest value in 2015, whereas pyrazosulfuron *fb* bispyribac-sodium showed the highest value in 2016. However, in terms of net returns (₹ 66157-69153/ha) and B: C (2.13–2.23), the highest values were observed with pyrazosulfuron *fb* bispyribac-sodium in both years, followed by premix of pretilachlor + pyrazosulfuron, which could be due to the lesser cost of cultivation and higher grain yield (Nagarjun *et al.* 2019). Herbicide-based weed management in rice has been reported as an alternative option for selective and economic weed management, supporting better growth, competitive superiority, higher yields, and economic viability (Singh *et al.* 2016, Yogananda *et al.* 2017). The lowest net returns and B: C values were obtained in the weedy check.

Conclusions

Based on the experimental results, it was found that the use of pre-emergence herbicide such as pyrazosulfuron or pendimethalin in combination with

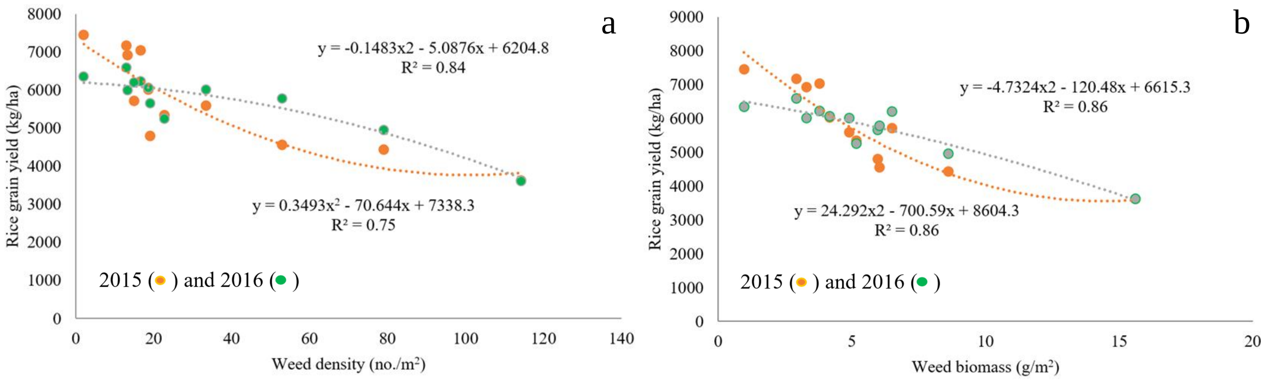

Figure 1. Effect of herbicide-based weed management practices at 45 DAT on a) weed density (m^2) and b) weed biomass (g/m^2) during 2015 and 2016

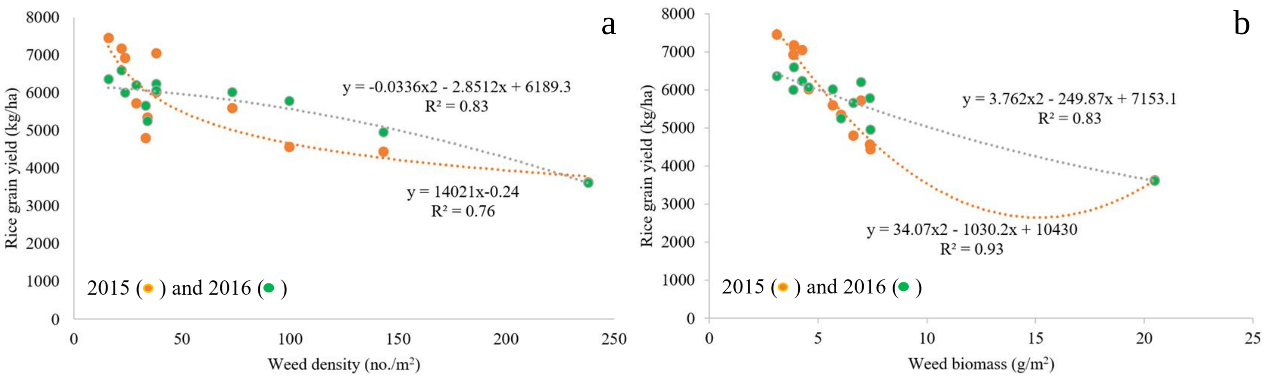

Figure 2. Effect of herbicide-based weed management practices at 75 DAT on a) weed density (per m^2) and b) weed biomass (g/m^2) during 2015 and 2016

Table 5. Economics of rice cultivation as influenced by different treatments in transplanted rice

Treatment	Cost of cultivation ($x10^3$ `/ha)	Gross returns ($x10^3$ `/ha)		Net returns ($x10^3$ `/ha)		B:C	
		2015	2015	2015	2016	2015	2016
Pyrazosulfuron 20 g/ha 2 DAT *fb* bispyribac-sodium 25 g/ha (25 DAT)	31.03	97.19	97.19	66.16	69.15	2.13	2.23
Fenoxaprop + 2,4-D (tank mix) 60 + 500 g/ha (25 DAT)	30.99	72.23	72.23	41.24	49.46	1.33	1.60
Pretilachlor + pyrazosulfuron (premix) 615 g/ha (6 DAT)	31.16	95.15	95.15	63.99	62.89	2.05	2.02
Pretilachlor + pyrazosulfuron (tank mix) 600+15 g/ha (6 DAT)	30.38	75.64	75.64	45.26	61.30	1.49	2.02
Bispyribac-sodium + 2,4-D (tank mix) 25 + 500 g/ha (25 DAT)	30.85	77.72	77.72	46.87	63.76	1.52	2.07
Fenoxaprop + chlorimuron + metsulfuron (tank mix) 60 + 4 g/ha (25 DAT)	31.05	65.00	65.00	33.95	55.57	1.09	1.79
Pendimethalin 1000 (2 DAT) *fb* bispyribac-sodium 25 g/ha (25 DAT)	31.66	93.45	93.45	61.79	59.76	1.95	1.89
Bispyribac-sodium 25 g/ha (25 DAT)	30.56	81.64	81.64	51.08	61.38	1.67	2.01
Pyrazosulfuron 20 g/ha (2 DAT)	29.63	61.71	61.71	32.07	58.06	1.08	1.96
Fenoxaprop 60 g/ha (25 DAT)	30.70	60.02	60.02	29.32	44.97	0.95	1.46
Hand weeding at 20 and 40 DAT	41.56	101.47	101.47	59.91	54.41	1.44	1.31
Weedy check	29.16	49.29	49.29	20.13	26.11	0.69	0.90
LSD (p=0.05)				14.96	9.45	0.48	0.30

(1US$=72 Indian Rupees at the time of study)

bispyribac-sodium in transplanted rice leads to better weed control for a longer duration, resulting in higher productivity and profitability. Moreover, the sequential application of herbicides helps in achieving higher net returns and B: C.

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