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ORIGINAL ARTICLE

Standardization of agrotechniques for weed management in aerobic rice (*Oryza sativa* L.)

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Abstract

This weed management investigation was carried out at the Zonal Agricultural Research Station (ZARS), Bangalore, during the summers of 2017 and 2018 to standardize agrotechniques for weed management of rice grown under aerobic conditions. The experiment was laid out in a randomized complete block design with eleven treatments replicated thrice. It consisted of two pre-emergence herbicides and one early post-emergence herbicide, the stale seedbed technique, mulching, hand weeding and intercultivation which was compared to the weedy check. The results showed that pyrazosulfuron ethyl 10% wettable powder (WP) at 35 active ingredient (a.i.) g · ha^{-1} as PE *fb* bispyribac sodium 10% SC at 30 ml · ha^{-1} a.i. as an early post-emergence herbicide performed better in terms of rice grain and straw yield (5,800 and 9,786 kg · ha^{-1}, respectively), plant height (58.42 cm), rice total dry matter production (149.84 g · plant^{-1}), productive tillers · hill^{-1} (40.32), panicle length (24.53 cm), 1000 grain weight (25.35 g), net returns (Rs. 62424), higher B : C ratio (2.59) and lower total weed density, weed dry weight at different stages of rice and weed index (3.80%) as well as higher weed control efficiency (90.52%). This practice could be recommended to farmers growing aerobic rice under these climatic conditions.

Keywords: benefit, bispyribac, herbicide, mulching, stale seedbed

Introduction

Weeds are common in crops and are also a perpetual problem on farms because of their dynamic nature. Their composition and competition depend on soil, climate, crop and management factors. Even with modern management practices intended for weed suppression, weeds continue to be a ubiquitous and persistent menace for crop production due to their ability to shift in response to management practices and environmental conditions. Due to the diversity and plasticity of weed communities, weed management should include various tactics and be seen as a continuous process. Physical, cultural, and biological weed management were the only weed control strategies till 1940 (Rashanth *et al.* 2016). Since the introduction of herbicides, their amazing performance led to the belief that herbicides would solve the weed problem forever (Vaishali *et al.* 2018). But concern over the escalating problems of herbicide persistence and resistance in weeds and herbicide toxicity to crops has reinforced the need for alternative approaches (Anwar *et al.* 2013). Herbicides are often blamed for environmental pollution and impoverishment of the natural flora and fauna in agro ecosystems. Long term efficacy and sustainability issues are also the driving forces behind the reconsideration of herbicide dependent weed management.

In response to the aforesaid problems, rice farming has been challenged to adopt a weed management strategy more respectful of the environment (Anwar *et al.* 2012a). Weed management continues to be a huge challenge in aerobic rice which is highly vulnerable to weed infestation because of dry ploughing and aerobic soil conditions (Juraimi *et al.* 2013). Proper weed management is considered to be a fundamental tool to ensure satisfactory yields of rice. High weed pressure in direct seeded rice lowers the economic return, and in extreme cases rice cultivation becomes a losing concern. This demands the reappearance of physical, cultural, and biological weed management combined with judicious application of herbicides based on a thorough understanding of the crop-weed ecology, known as integrated weed management (IWM) (Jabran *et al.* 2012).

Integrated agrotechniques involve the integration of effective, environmentally safe, and socially acceptable control strategies that lessen weed interference below the economic injury level. They are more beneficial hence, selection of such appropriate and cost-effective methods is very important. Different agrotechniques such as the stale seedbed technique, different kinds of mulching, intercultivation, hand weeding, application of pre- and post-emergent herbicides have been attempted. Stale or false seedbed technique is a preventive method of weed management (Sindhu *et al.* 2010). This technique involves soil preparation of a seedbed to promote germination of weeds, a number of days or weeks before the actual sowing or planting of the crop. This depletes the weed seed bank in the surface layer of soil and reduces the subsequent emergence of weeds. Following emergence, weeds are killed either by a non-selective herbicide or by light tillage prior to the sowing of rice. Stale seedbed can also be implemented by submergence of a rice field 7 and 14 days after weed emergence (Singh and Singh 2012). Mulching is a practice used to reduce weed problems in direct seeded unpuddled rice. Mulching helps to maintain optimum surface soil moisture for germination and rooting of the crop protects seeds from birds and it helps control weeds. Organic mulch provides stronger mechanical barriers to all kinds of germinating weeds. Rice straw was tried in this research. Co-culturing dhaincha and rice is a common practice throughout the world, but co-culturing horsegram may not have been tested so far. Both of them were tried since they help smother the weeds by suppressing the growth of associated weed plants, thereby conserving moisture and adding a good amount of nitrogen into soil without adding much to the cost of production. The above live-mulching crops suppress weeds and can potentially intercept incident radiation reaching the soil surface. Some cultivars with a prostrate, vining and dense crop canopy, suppress weed emergence and growth, thus reducing the frequency of weeding the rice crop and the labour costs involved (Ansari *et al.* 2017). These co-culturing techniques result in efficient land utilization and improved yields (Mahey *et al.* 1986; Mashingaidze *et al.* 2000).

According to Jayadeva *et al.* (2011), integration of different agrotechniques can be successfully implemented in aerobic rice. None of the control measures alone can provide acceptable levels of weed control, and therefore, various components need to be integrated in a logical manner.

There is very little information on the standardization of the above-mentioned technologies in aerobic rice production. Therefore, keeping this lack of research in mind, an experiment was planned to study the standardization of agrotechniques for weed management in aerobic rice (*Oryza sativa* L.).

Materials and Methods

The experimental site was red sandy loam. The local climate was located in a dry land zone with little rainfall. During the experimental period, the average maximum air temperature during the experiment ranged from 27.3°C and 27.4°C in January to 35.1°C and 33.1°C in April 2017 and 2018, respectively. The mean minimum air temperature was 13.5°C in February 2017 and 14.7°C in January 2018. The mean monthly relative humidity (RH) ranged from 82.7% in March to 91.2% in August 2017 and 78.3 in March up to 91.9% in July 2018. The mean monthly maximum hours of sunshine were the highest in February 2017 (10.1 h) and February 2018 (9.54 h) during the cropping period. The mean wind speed was maximum during June 2017 ($10.6 \text{ km} \cdot \text{h}^{-1}$) and June 2018 ($9.24 \text{ km} \cdot \text{h}^{-1}$). Lower wind speeds were recorded in March 2017 ($6.9 \text{ km} \cdot \text{h}^{-1}$) and May 2018 ($5.06 \text{ km} \cdot \text{h}^{-1}$). The mean pan evaporation ranged from 3.5 mm in January to 4.6 mm in April and June 2017 and 4.3 mm in June to 7.8 mm $\cdot$ day^{-1} in March 2018.

The experiment was laid out in Randomized Completely Block Design (RCBD) with 11 treatments and three replications. The treatments consisted of: the stale seedbed technique *fb* two intercultivations (IC) at 15 and 30 days after seeding (DAS) (T_1), the stale seed bed technique *fb* bispyribac sodium 10% SC at 30 ml $\cdot$ ha^{-1} a.i. as early post-emergent spray (T_2), the stale seed bed technique *fb* bispyribac sodium 10% SC at 30 ml $\cdot$ ha^{-1} a.i. as early post-emergent (PoE) + one IC at 40 DAS (T_3), straw mulch at 6 t $\cdot$ ha^{-1} *fb* bispyribac sodium 10% SC at 30 ml $\cdot$ ha^{-1} a.i. as PoE (T_4), live mulch with dhaincha at 25 kg $\cdot$ ha^{-1} (T_5), live mulch with horsegram at 30 kg $\cdot$ ha^{-1} (T_6), pendimethalin 30% EC at 1.5 l $\cdot$ ha^{-1}as PE *fb* bispyribac sodium 10% SC at 30 ml $\cdot$ ha^{-1} a.i. as early PoE (T_7), pyrazosulfuron ethyl 10% WP at 35 g $\cdot$ ha^{-1} a.i. as PE *fb* bispyribac sodium 10% SC at 30 ml $\cdot$ ha^{-1} a.i. as early PoE (T_8), pyrazosulfuron ethyl 10% WP at 35 g $\cdot$ ha^{-1} a.i. as PE + one IC as per package of practice (T_9), weed-free check (T_{10})

and weedy check (T_{11}). The weed-free plots were maintained through manual weeding whenever necessary. In weedy-checks, no weeding operations were done.

Various agrotechniques were tested in this study to create more competitive conditions in favor of rice and hence to achieve higher weed control efficiency and a lower weed index. Timing of pre-and post-emergence herbicide applications, live-mulching, intercultivation and manual weeding were adjusted to match the predetermined critical period of weed control of 25–60 DAS at minimum yield loss level.

In the stale seedbed technique, weeds were allowed to emerge for at least 3 weeks before being killed by light cultivation. Weed emergence was stimulated by light irrigation or after rainfall which served to maintain enough soil moisture for weeds to germinate. When the soil conditions were suitable for sowing, the rice crop was sown without further tillage operations.

For live mulching, fast growing cover crops namely dhaincha (*Sesbania bispinos*a) and horsegram (*Macrotyloma uniflorum*) were sown by the broadcasting method in the same lines of paddy in order to suppress the weeds. These cover crops were cut off at 30 DAS and placed in interrows of a rice crop to manage the weeds.

Hand weeding was done manually with the aid of Kurpi or varvari at 15 and 30 DAS (18th March, 3rd April, 15th January, 6th February, 2017 and 2018, respectively) in T_1, T_3, T_9 and T_{10} and weeds were allowed to grow under weedy condition treatments.

Intercultivation was performed by using a small hand tool called a rotary weeder at 15–30 DAS in the following treatments: T_1, T_3, T_9 and T_{10}.

Spraying of pre-emergent herbicides like pyrazosulfuron ethyl (in T_8 and T_9) and pendimethalin 30% EC (in T_7) in aerobic rice was done 1 DAS (5th March, 28th January, 2017 and 2018, respectively), whereas, it was done 21 DAS (24th March and 17th February, 2017 and 2018, respectively) for early post-emergent herbicide bispyribac sodium (in T_2, T_3, T_4, T_7 and T_8). The quantity of herbicides per treatment was calculated according to the following formula and were dissolved in water at the rate of 750 and 500 l of water for pre-emergent and early post-emergent herbicides, respectively and sprayed onto the plots uniformly using a knapsack sprayer. The soil was ensured with sufficient moisture during the pre-emergent herbicidal spraying.

$$F = \frac{R \times 100}{\text{Purity [\%]}} \times \frac{A}{10{,}000} \quad \text{(Rana and Rana 2016)},$$

where: F – formulated product required [kg, l · ha^{-1}], R – active ingredients (a.i.) kg · ha^{-1} to be sprayed (recommended rate), A – area [m^2].

The land was dry-ploughed, harrowed and unpuddled during its preparation. The planting material of aerobic rice variety was MAS 946-1, which is a high yielding, semi-tall plant (100–105 cm), tolerant to drought and blast disease. Rice seeds were directly dry-seeded at 2 cm depth in rows with 25 cm interrow and intrarow spacing at the rate of 7 kg · ha^{-1} seeds. Each plot was 4.25 m long and 3.5 m wide. The recommended dose of farm yard manure (FYM) at the dose of 10 t · ha^{-1} was applied 15 days prior to sowing and the land was fertilized with single super phosphate (SSP) and muriate of potash (MoP) at the rate of 50 kg · ha^{-1} P and 50 kg · ha^{-1} K, respectively, as the basal dose during final land preparation. Urea was top dressed at the rate of 100 kg · ha^{-1} N applied at the dosage of 50% applied as basal dose and the remaining 50% was applied at two different times i.e. at tillering and panicle initiation stages.

Soil moisture was maintained under aerobic conditions throughout cropping since irrigation facilities were available at the site and supplemental drip irrigation was given when hair-like cracks appeared on the soil surface. Plant protection measures were carried out according to the package of practices established by a concerning research body of this agroclimatic zone.

The 0.5 m × 0.5 m quadrate was randomly placed lengthwise at one spot in each plot for recording weed data at 30, 60, 90 DAS and at harvest. Weed plants were clipped to ground level, identified and counted by group, and separately oven dried at 65°C for 48 h. Weed density and weed dry weight were expressed as number (no.) · m^{-2} and g · m^{-2}, respectively.

Weed control efficiency (*WCE*) of different herbicide treatments was calculated (Hasanuzzaman *et al.* 2008) as follows:

$$WCE = \frac{DMC - DMT}{DMC} \times 100\,[\%],$$

where: DMC – dry matter of weeds in weedy check plot [g], DMT – dry matter of weeds in treated plots [g].

At maturity, yield attributing parameters were recorded from five randomly selected hills to have a sufficient number of samples. All the panicles of sample hills were counted and converted to panicles · m^{-2}. Sample panicles were hand threshed and 1,000 grain weight in grams was taken. Net plot size of each plot was hand-harvested by cutting the whole rice plants from 2 cm above ground to record grain yield (kg · ha^{-1}). Grain yield and 1,000 grain weight were adjusted to 14% moisture content by sun drying the grains for 5 days.

Weed index (*WI*) or per cent relative yield loss due to weeds was calculated as follows:

$$WI = \frac{\text{weed-free plots yield} - \text{weedy plots yield}}{\text{weed-free plots yield}} \times 100[\%].$$

Economic analysis is essential since farmers are often interested in profits and costs of a newly developed technology. They also want to know about the risks involved in the adoption of new practices. Pooled data were economically analysed with respect to the net economic return (Indian rupees) and benefit cost ratio.

The square root transformation of original data of weeds was done for statistical analyses as described by Cochran and Cox (1957) and all other data were subjected to ANOVA by using statistical software package (OPSTAT).

Results and Discussion

Total weed density, total weed dry weight and weed control efficiency

The trial was carried out under naturally occurring mixed weed flora. The site of investigation was infested mainly by broadleaf weeds accounting for 65.21%, grasses – 30.38% and sedges – 4.34%. All the treatments resulted in a significant reduction of total weed density and total weed dry weight compared to the weedy check during the course of the experiment (Table 1).

Both, total weed dry weight and total weed density were significantly influenced by weed management practices on all sampling dates (Table 1). At all growth stages, the plots received stale seedbed technique *fb* bispyribac sodium 10% SC at 30 ml · ha^{-1} a.i. as early PoE + one IC at 40 DAS, straw mulch at 6 t · ha^{-1} *fb* bispyribac sodium 10% SC at 30 ml · ha^{-1} a.i. as PoE at 30 DAS and the ones treated with pre-emergence herbicides followed by post-emergence herbicides produced lower weed dry weight and total density compared to weedy check. Stale seedbed technique *fb* bispyribac sodium 10% SC at 30 ml · ha^{-1} a.i. as early PoE + one IC at 40 DAS recorded significantly total lower weed count and lower weed dry weight at 30 DAS (11.50 and 0.53 g · m^{-2}), at 60 DAS (31.33 and 8.61 g · m^{-2}) and at 90 DAS (38.33 and 28.0 g · m^{-2}) followed by straw mulch at 6 t · ha^{-1} *fb* bispyribac sodium 10% SC at 30 ml · ha^{-1} a.i. as PoE at 30 DAS (15.67 and 0.71 g · m^{-2}), at 60 DAS (35.33 and 9.86 g · m^{-2}) and at 90 DAS (42.17and 30 g · m^{-2}).

Significantly lower numbers of total weeds and total weed dry weights were due to efficient control of the weeds at all stages of crop growth. The weedy check had a significantly higher total weed population and total dry weight. The results are in conformity with the findings of Jaya *et al.* (2011), Anwar *et al.* (2012b), Prashanth *et al.* (2016) and Chakraborti *et al.* (2017). The WCE based on the weed dry weight at harvest varied significantly from the weed control treatments. All the weed management practices showed more than 80 per cent WCE. The stale seedbed technique *fb* bispyribac sodium 10% SC at 30 ml · ha^{-1} a.i. as early PoE + one IC at 40 DAS achieved the highest weed control efficiency (91.91 per cent). It was lower (0 per cent) in the weedy check and 82.20 per cent in live mulch with dhaincha at 25 kg · ha^{-1} (Table 1). The lower weed control efficiency was due to the poor control of weeds that resulted a higher weed population and higher weed dry weight. Weed control efficiency was eventually translated into grain yield. All the weed control treatments significantly out-yielded the weedy check and some performed as well as the weed-free check because of their high WCE. In contrast, weed management practices with low WCE resulted in reduced yield. The WCE is also reflected in the weed index. As evident from this study, the higher the WCE the lower the weed index. In fact, weed removal reduces interspecific competition for resources and enables crops to utilize available resources more efficiently than weeds which eventually results in higher yield. The increase in rice grain yield by increasing WCE has also been reported by Jaya *et al.* (2011), Anwar *et al.* (2012a), Yaduraju and Rao (2013), Prashanth *et al.* (2016) and Chandu *et al.* (2018).

Rice yield, growth and yield attributes

Grain yield of MAS 946-1 varied significantly due to the weed management practices (Table 2). All the treatments resulted in significantly higher grain yield than the weedy check and several treatments generated yields as high as the weed-free check plot's yield. The stale seedbed technique *fb* bispyribac sodium 10% SC at 30 ml · ha^{-1} a.i. as early PoE + one IC at 40 DAS, straw mulch at 6 t · ha^{-1} *fb* bispyribac sodium 10% SC at 30 ml · ha^{-1} a.i. as PoE, pendimethalin 30% EC at 1.5 l · ha^{-1} as PE *fb* bispyribac sodium 10% SC at 30 ml · ha^{-1} a.i. as early PoE, pyrazosulfuron ethyl 10% WP at 35 g · ha^{-1} a.i. as PE *fb* bispyribac sodium 10% SC at 30 ml · ha^{-1} a.i. as early PoE and pyrazosulfuron ethyl 10% WP at 35 g · ha^{-1} a.i. as PE + one IC according to a package of practices performed excellently in terms of rice grain and straw yield (ranging from 5,699 to 5,838 kg · ha^{-1} for grain yield and 9,853 to 9,904 kg · ha^{-1} for straw yield, respectively) which were statistically similar to that obtained from the weed-free check (6,068 and 9,973 kg · ha^{-1}, respectively).

All the attributes attained their highest values in the weed-free check and lowest values in the weedy check. In general, the stale seedbed technique *fb* bispyribac sodium 10% SC at 30 ml · ha^{-1} a.i. as early PoE + one IC at 40 DAS, straw mulch at 6 t · ha^{-1} *fb*

Table 1. Total weed density and weed dry weight at different stages and weed control efficiency (*WCE*) at harvest in rice as influenced by weed management practices, pooled data 2017 and 2018

Treatments	30 DAS		60 DAS		90 DAS		*WCE* [%]
	weed density [no. · m^{-2}]	weed dry weight [g · m^{-2}]	weed density [no. · m^{-2}]	weed dry weight [g · m^{-2}]	weed density [no. · m^{-2}]	weed dry weight [g · m^{-2}]	
T_1	6.51 (42.00)	1.37 (1.37)	8.15 (66.17)	5.52 (30.00)	9.31 (86.17)	6.69 (44.3)	85.36
T_2	6.78 (46.17)	1.44 (1.59)	8.61 (73.83)	5.69 (31.86)	9.75 (95.00)	7.15 (50.7)	84.47
T_3	3.42 (11.50)	1.02 (0.53)	5.63 (31.33)	3.02 (8.61)	6.23 (38.33)	5.34 (28.0)	91.61
T_4	4.00 (15.67)	1.11 (0.74)	5.98 (35.33)	3.21 (9.86)	6.49 (42.17)	5.53 (30.0)	90.93
T_5	7.85 (61.83)	1.62 (2.14)	9.67 (93.83)	6.20 (37.91)	10.56 (111.5)	7.51 (56.0)	82.20
T_6	7.54 (56.33)	1.54 (1.88)	8.86 (78.17)	5.99 (35.43)	9.48 (91.00)	7.31 (53.0)	83.35
T_7	5.21(26.67)	1.23 (1.00)	7.32 (53.17)	3.38 (10.92)	7.73 (59.33)	5.61 (31.0)	90.40
T_8	4.47 (19.67)	1.18 (0.89)	6.52 (42.00)	3.28 (10.26)	6.99 (48.67)	5.57 (30.6)	90.52
T_9	5.50 (30.17)	1.27 (1.10)	7.38 (54.00)	3.46 (11.48)	8.30 (68.83)	5.71 (32.1)	89.08
T_{10}	0.71 (0.00)	0.71 (0.00)	0.71 (0.00)	0.71 (0.00)	0.71 (0.00)	0.71 (0.0)	100.00
T_{11}	8.26 (67.83)	2.22 (4.43)	20.48 (419.50)	10.42 (108.22)	22.56 (508.8)	17.35 (300.8)	0.00
SEM	0.04	0.01	0.08	0.04	0.12	0.08	NA
CD at 5%	0.13	0.03	0.25	0.13	0.38	0.23	NA

DAS – days after seeding

Values in parentheses are original values; data analyzed using transformation -$\sqrt{x}$ + 0.5, NA – not analyzed; stale seedbed technique *fb* two IC at 15 and 30 DAS (T_1); stale seedbed technique *fb* bispyribac sodium 10% SC at 30 ml · ha^{-1} a.i. as early post-emergent spray (T_2); stale seedbed technique *fb* bispyribac sodium 10% SC at 30 ml · ha^{-1} a.i. as early PoE + one IC at 40 DAS (T_3); straw mulch at 6 t · ha^{-1} *fb* bispyribac sodium 10% SC at 30 ml · ha^{-1} a.i. as PoE (T_4); live mulch with dhaincha at 25 kg · ha^{-1} (T_5); live mulch with horsegram at 30 kg · ha^{-1} (T_6); pendimethalin 30% EC at 1.5 l · ha^{-1} as PE *fb* bispyribac sodium 10% SC at 30 ml · ha^{-1} a.i. as early PoE (T_7); pyrazosulfuron ethyl 10% WP at 35 g · ha^{-1} a.i. as PE *fb* bispyribac sodium 10% SC at 30 ml · ha^{-1} a.i. [1] as early PoE (T_8); pyrazosulfuron ethyl 10% WP at 35 g · ha^{-1} a.i. as PE + one IC as per package of practice (PoP) (T_9); weed free (T_{10}) and weedy-check (T_{11}); SEM – standard error of the mean; CD – critical difference

Table 2. Growth, yield attributes, yield, weed index (*WI*) and economics of aerobic rice as influenced by different weed management practices, pooled data 2017 and 2018

Treatments	Plant height at harvest [cm]	TDM at harvest [g · plant^{-1}]	Productive tillers · hill^{-1}	Panicle length [cm]	1,000 grain weight [g]	Grain yield [kg · ha^{-1}]	Straw yield [kg · ha^{-1}]	*WI* [%]	Net returns [Rs. · ha^{-1}]	B : C ratio
T_1	55.38	125.53	23.40	20.50	21.80	4,625	8,242	23.78	41,819	2.05
T_2	54.93	120.89	21.92	19.43	21.00	4,583	8,123	24.48	42,158	2.09
T_3	59.17	151.30	41.58	24.98	26.12	5,838	9,904	3.80	61,782	2.54
T_4	58.98	150.39	40.75	24.70	25.58	5,817	9,842	4.14	58,448	2.34
T_5	53.97	109.86	20.83	17.43	19.74	4,235	8,014	30.21	36,525	1.94
T_6	54.40	110.10	21.75	18.15	20.15	4,312	8,056	28.93	38,415	2.00
T_7	57.99	149.79	40.15	24.23	25.12	5,781	9,802	4.73	61,801	2.56
T_8	58.42	149.84	40.32	24.53	25.35	5,800	9,786	4.41	62,424	2.59
T_9	57.58	149.60	39.45	23.78	24.41	5,699	9,853	6.09	61,654	2.53
T_{10}	60.18	154.37	42.55	25.42	26.83	6,068	9,973	0.00	35,265	1.86
T_{11}	30.05	39.16	1.62	10.28	16.25	430	805	92.91	–29,854	0.20
SEM	0.98	1.76	0.52	0.38	0.55	71.02	145.60	NA	NA	NA
CD at 5%	2.90	5.21	1.55	1.13	NS	209.53	429.54	NA	NA	NA

Stale seedbed technique *fb* two IC at 15 and 30 DAS (T_1); stale seedbed technique *fb* bispyribac sodium 10% SC at 30 ml · ha^{-1} a.i. as early post-emergent spray (T_2); stale seedbed technique *fb* bispyribac sodium 10% SC at 30 ml · ha^{-1} a.i. as early PoE + one IC at 40 DAS (T_3); straw mulch at 6 t · ha^{-1} *fb* bispyribac sodium 10% SC at 30 ml · ha^{-1} a.i. as PoE (T_4); live mulch with dhaincha at 25 kg · ha^{-1} (T_5); live mulch with horsegram at 30 kg · ha^{-1} (T_6); pendimethalin 30% EC at 1.5 l · ha^{-1} as PE *fb* bispyribac sodium 10% SC at 30 ml · ha^{-1} a.i. as early PoE (T_7); pyrazosulfuron ethyl 10% WP at 35 g · ha^{-1} a.i. as PE *fb* bispyribac sodium 10% SC at 30 ml · ha^{-1} a.i. as early PoE (T_8); pyrazosulfuron ethyl 10% WP at 35 g · ha^{-1} a.i. as PE + one IC as per package of practice (PoP) (T_9); weed free (T_{10}) and weedy-check (T_{11}). NA – not analyzed, B : C – benefit cost; TDM – total dry matter; SEM – standard error of the mean; CD – critical difference bispyribac sodium 10% SC at 30 ml · ha^{-1} a.i. as PoE, pendimethalin 30% EC at 1.5 l · ha^{-1} as PE *fb* bispyribac sodium 10% SC at 30 ml · ha^{-1} a.i. as early PoE, pyrazosulfuron ethyl 10% WP at 35 g · ha^{-1} a.i. as PE *fb* bispyribac sodium 10% SC at 30 ml · ha^{-1} a.i. as early PoE and pyrazosulfuron ethyl 10% WP at 35 g · ha^{-1} a.i. as PE + one IC performed best in terms of growth and yield attributes. From these practices, plant height varied from 57.58 to 59.17 cm, rice total dry matter production ranged from 149.60 to 151.30 g · plant^{-1}, number of productive tillers · hill^{-1} ranged from 39.45 to 41.58, panicle length (23.78 to 24.98 cm) and 1000 grain weight (24.41 to 26.12 g).

The weed index or relative yield loss due to weed varied widely between the tested weed management practices (from 3.80 to 30.21%). Understandably, the weedy check allowed a maximum *WI* as high as 92.91% due to high crop-weed competition (Table 2). The stale seedbed technique *fb* bispyribac sodium 10% SC at 30 ml · ha^{-1} a.i. as early PoE + one IC at 40 DAS allowed the least yield loss of only 3.8% closely followed by straw mulch at 6 t · ha^{-1} *fb* bispyribac sodium 10% SC at 30 ml · ha^{-1} a.i. as PoE (4.14%), pyrazosulfuron ethyl 10% WP at 35 g · ha^{-1} a.i. as PE *fb* bispyribac sodium 10% SC at 30 ml · ha^{-1} a.i. as early PoE (4.41%), pendimethalin 30% EC at 1.5 l · ha^{-1} as PE *fb* bispyribac sodium 10% SC at 30 ml · ha^{-1} a.i. as early PoE (4.73%) and pyrazosulfuron ethyl 10% WP at 35 g · ha^{-1} a.i. as PE + one IC as per package of practice (6.09%), all these might be due to their high *WCE*. The remaining weed management practices allowed moderate weed indexes ranging between 23.78 and 30.21%.

Superior growth and yield attributes with the stale seedbed technique *fb* bispyribac sodium 10% SC at 30 ml · ha^{-1} a.i. as early PoE + one IC at 40 DAS was attributed to efficient and well-timed weed management which reduced the total weed population and the dry weight which led to higher weed control efficiency during early stages of crop growth and facilitated the crop to have sufficient space, light, nutrients and moisture which ultimately resulted in increased grain and straw yield and yield attributes. Lower grain and straw yield were noticed in a weedy check owing to severe crop-weed competition which resulted in the reduction of growth and yield attributes of rice. These results are in conformity with the findings of Sunil *et al.* (2010), Anwar *et al.* (2012a) and Vaishali *et al.* (2018).

Economic analysis

Weed management practices showed a wide range of net economic return and benefit cost ratio (Table 2). Cost analysis revealed that the highest net return of Indian rupees and benefit cost ratio (Rs. 62,424 ha^{-1} and 2.59, respectively) was recorded with application of pyrazosulfuron ethyl 10% WP at 35 g · ha^{-1} a.i. as PE *fb* bispyribac sodium 10% SC at 30 ml · ha^{-1} a.i. as early PoE closely followed by pendimethalin 30% EC at 1.5 l · ha^{-1} as PE *fb* bispyribac sodium 10% SC at 30 ml · ha^{-1} a.i. as early PoE (Rs. 61,801 ha^{-1} and 2.56, respectively), the stale seedbed technique *fb* bispyribac sodium 10% SC at 30 ml · ha^{-1} a.i. as early PoE + one IC at 40 DAS (Rs. 61,782 ha^{-1} and 2.54, respectively) and pyrazosulfuron ethyl 10% WP at 35 g · ha^{-1} a.i. as PE +one IC as per package of practice (Rs. 61,654 ha^{-1} and 2.53, respectively). The highest gross return registered in weed-free check plots resulted in very low net return and benefit cost ratio (Rs. 35,265 ha^{-1} and 1.86, respectively) because of high cost involvement in manual weeding. The increase in net returns in the above-mentioned treatments was attributed to higher grain yield and straw yield, lower cost of weed management and better management of weeds throughout the crop growth period. There was a net loss in the weedy check (Rs. 29,854) due to lower grain and straw yield as a result of greater crop-weed competition. Similar observations were also made by Wibawa *et al.* (2011), Anwar *et al.* (2012b) and Chakraborti *et al.* (2017).

Conclusions

The higher competitive cropping system in favor of aerobic rice as a consequence of the combined use of different agrotechnique practices such as stale seedbed, mulching, use of pre and post emergence herbicides is evident from this investigation. It was reflected in lower weed pressure, higher weed control efficiency, better yield and higher returns. Weed management only during the critical period of competition is also justified as some weed management practices gave yields similar to the weed-free check plot's yield. From an economic point of view, application of pre-emergence followed by post-emergence herbicides used in this experiment: pyrazosulfuron ethyl 10% WP at 35 g · ha^{-1} a.i. as PE *fb* bispyribac sodium 10% SC at 30 ml · ha^{-1} a.i. as early PoE and pendimethalin 30% EC at 1.5 l · ha^{-1} as PE *fb* bispyribac sodium 10% SC at 30 ml · ha^{-1} a.i. as early PoE could be recommended for aerobic rice growers under these particular agroclimatic conditions. For the sustainability of weed management for long-lasting periods, the stale seedbed technique practiced before sowing to reduce the weed seed bank in the experimental site followed by bispyribac sodium 10% SC at 30 ml · ha^{-1} a.i. as early post emergence herbicide spray + one intercultivation at 40 DAS could be done.

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