Indian Journal of Agronomy **67** (1): 12—19 (March 2022)

Research Paper

Performance of sequential application of pre and post-emergence herbicides for management of weeds in aerobic rice (*Oryza sativa*)

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Received: November 2020; Revised accepted: February 2022

ABSTRACT

A field experiment was conducted during the rainy (*kharif*) season of 2014 and 2015 at Zonal Agricultural Research Station, V.C. Farm, Mandya, Karnataka, India, to study the performance of sequential application of herbicides in aerobic rice (*Oryza sativa* L.). Among the weed-management practices, hand-weeding at 20, 40 and 60 days after sowing (DAS) resulted in significantly lower density and dry weight of all categories of weeds, ensuing higher grain yield (5.57 and 5.42 t/ha, respectively); this was closely followed by pre-emergence application of pyrazosulfuron ethyl @ 25 g/ha and by post-emergence application of bispyribac-sodium @ 25 g/ha at 20 days after sowing (5.20 and 5.12 t/ha, respectively) during both the years. However, the higher net returns (₹48,210 and 47,040/ha, respectively) and benefit: cost ratio (2.62 and 2.58, respectively), during both the years were obtained from sequential application of herbicide treatment. Uncontrolled weed growth caused about 51% reduction in grain yield of aerobic rice during 2014 and 2015.

***Key words*:** Aerobic rice, Bispyribac-sodium, Pyrazosulfuron ethyl, Sequential application, Yield

Rice (*Oryza sativa* L.) is a predominant dietary energy source for 17 countries of Asia Pacific, 9 countries in America and 8 countries in Africa. It is known as the grain of life and is synonymous with food for Asians. It is a semi-aquatic annual grass native to tropical Asia, especially to India and is the world's single most important food crop and a primary source of food for more than one-third of world's population. In India, rice is the staple food crop grown in an area of 43.79 million ha (m ha) with a production of 112.91 million tonnes (mt) and productivity of 2,578 kg/ha (MA&FW, 2018). In Karnataka it is cultivated in an area of 1.01 m ha, producing about 2.54 mt with a productivity of 2,522 kg/ha (MA&FW, 2017). Cauvery Command area occupies an area of 88,657 ha, with a production of 2,66,775 tonnes and productivity of 3,143 kg/ha.

Now-a-days, water is the most critical input in agriculture and future estimate revealed that, scarcity of water will become more severe as the share of water to other sector will increase. Water requirement for rice is very high, particularly for puddling operation. Therefore new cultivation system, *i.e.* aerobic rice should be tested, as it requires very less amount of water to reduce future water-scarcity problem. The reality is that rice production needs to produce more rice with less water, *i.e.* more crop per drop. In aerobic rice, crop is subjected to greater weed competition than transplanted one. Weeds are one of the major constraints to aerobic rice-production systems, as dry tillage, alternate wetting and drying condition are conductive to germination, growth of weeds causing grain yield losses of 50–90% (Mishra and Singh, 2007). This constraint also causes in the way of wider adoption of aerobic rice, as weeds and rice seeds germinate at the same time causing serious crop-weed competition (Mewada *et al.,* 2016).

Weed control through use of chemicals is one of the potential options to solve this problem. Pre-plant incorporation, pre-emergence and post-emergence application of the herbicides control weeds effectively. The abundance of some weed species is likely to be strongly influenced by environmental and cultural conditions and its infestation could be more efficiently managed by proper selection of herbicides (Jaybhay *et al.,* 2018). Now-a-days, the use of herbicides is gaining popularity in rice fields owing to their rapid effects and the lower costs compared with the traditional methods. But, continuous use of herbicides alone at higher dose may lead to the problems of residual toxicity, besides causing a shift in weed flora. Dependence on manual weed control alone is time consuming and costly.

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Hence, integrated weed management practice or sequential application of pre and post-emergence herbicides offers most practical and cost-effective means of reducing weed competition in aerobic rice (Mahajan and Chauhan, 2013). Considering the above facts, present study was carried out to explore sequential application of herbicides on weed management in aerobic rice.

MATERIALS AND METHODS

A field experiment was conducted during the rainy (*kharif*) season of 2014 and 2015 at Zonal Agricultural Research Station, V. C. Farm, Mandya (12° 34.3' N, 76° 49.8' E, 697 m above mean-sea level), under the jurisdiction of University of Agricultural Sciences, Bengaluru, Karnataka, India. The soil was red sandy loams classified as Alfisols, with bulk density and particle density of 1.15 g/cc and 2.65 g/cc, respectively, at a soil depth of 30 cm. The soil had *p*H 6.56 (neutral in reaction), electrical conductivity 0.358 dS/m and organic matter content 0.385%. It was low in available nitrogen (225 kg/ha), phosphorus (28 kg/ha) and potassium (126 kg/ha). Rainfall during the both *kharif* 2014 and 2015 was 502.0 mm and 366.0 mm, respectively.

The experiment was laid out in a randomized complete block design with 3 replications, containing alone and combined application of 2 pre-emergence and 1 post-emergence herbicides along with 1 intercultivation at 40 days after sowing (DAS). Eight treatments, viz. pyrazosulfuron-ethyl @ 25 g/ha (pre) + 1 intercultivation at 40 DAS, pendimethalin @ 1 kg/ha (pre) + 1 intercultivation at 40 DAS, pyrazosulfuron ethyl @ 25 g/ha (pre) followed by *(fb)* bispyribac-sodium @ 25 g/ha (post), pendimethalin @ 1 kg/ha (pre) *fb* bispyribacsodium @ 25 g/ha (post), bispyribac-sodium @ 25 g/ha (post). The post-emergence herbicides were applied when the weeds are 3–4-leaf stage. These were compared with hand-weeding thrice at 20, 40 and 60 DAS, weedy and weed-free check with 5 hand-weedings.

All other agronomic and plant protection measures were adopted as per the recommended packages of the University of Agricultural Sciences, Bengaluru, for raising a good crop. Medium-duration (130–135 days) rice variety 'IR 30864' was sown by hand dibbling with a row-to-row spacing of 20 cm and plant-to-plant spacing of 10 cm on leveled field in August 2014 and 2015 with a seed rate of 5.0 kg/ha. The crop was fertilized with 100-50-50-20 kg N-P_2O_5-K_2O-$ZnSO_4$/ha and 50% nitrogen, entire dose of phosphorus, potassium and Zn was applied basal. Remaining 50% of the nitrogen was top dressed at 2 equal splits– at tillering and panicle-initiation stage. The gross plot size was 5.0 m × 3.0 m. The pre-emergence herbicides were sprayed at 5 DAS using knapsack sprayer fitted with deflector nozzle mixed with water @ 750 litres/ha. The post-emergence herbicides were sprayed at 3–4 leaf stage of weeds with a spray solution of 500 litres/ha. Intercultivation was carried out at 40 DAS as per the treatments. Hand-weeding was carried out as per the treatment schedule.

The efficacy of herbicides were tested by taking the observation on category -wise weeds, viz. grasses, sedges and broad-leaf weeds, weed density and weed dry weight at 30 and 60 days after sowing of the crop by using a quadrate (0.5 m × 0.5 m) randomly in each plot and their subsequent effect on growth and yield of aerobic rice. The weeds were uprooted from 1 m^2 area selected at random, and were oven-dried to a constant weight at 65°C and dry weight of weeds in each treatment was recorded and expressed as g/m^2. Weed-control efficiency (WCE) denotes the magnitude of weed reduction due to the weed- control treatment. The weed control efficiency was calculated by using the formula given by Mani *et al.* (1973).

Weed index is the reduction in crop yield due to the presence of weeds in comparison with weed free plot expressed as percentage (Gill and Vijayakumar, 1969).

Data on growth parameters like plant height (cm) and number of tillers at harvesting and yield parameters like grain weight/panicle (g), 100-seed weight (g), per cent chaffiness and yield (kg/plot) of aerobic rice was recorded at harvesting. The per cent choppiness was worked out by using the following formula.

$$\text{Per cent chaffiness} = \frac{\text{Number of unfilled grains/panicle}}{\text{Total number of grains/panicle}} \times 100$$

The data collected from the experiment at different growth stages were subjected to statistical analysis as described by Panse and Sukhatme (1967). The normality of distribution was not seen in case of observation on weeds hence, the values were subjected to square-root transformation ($\sqrt{x + 0.5}$) prior to statistical analysis to normalize their distribution. Statistical analysis was carried out based on mean values obtained. The level of significance used in 'F' and 't' test was P= 0.05. Critical difference values were calculated wherever 'F' test was significant as per the procedure given by Gomez and Gomez (1984).

RESULTS AND DISCUSSION

Weed flora

The major weed flora observed in the experimental field in association with the aerobic rice, *viz.* Bermuda grass [*Cynodon dactylon* (L.) Pers.], awnless barnyard grass [*Echinochloa colona* (L.) Link], quack grass, (*Panicum repens* L.), crab grass [*Digitaria sanguinalis* (L.) Scop.], viper grass *[Dinebra retroflexa (Vahl) Pahz.],* crowfoot grass [*Dactyloctenum aegyptinum* (L.) Willd.] among grasses; Benghal dayflower (*Commelina benghalensis* L.), carpet weed (*Mollugo disticha* (L.) Ser.], chick weed (*Ageratum conyzoides*), (False amaranth), *Digera arvensis Forsck.* native gooseberry (*Physalis minima* L.), garden spurge (*Euphorbia hirta*), spiderflower (*Cleome viscosa* L.), Stonebreaker *(Phyllanthus niruri* L.), Common purslane (*Portulaca olearaceae* L.), (horse purslane) *Trianthema portulacastrum* L. among broad-leaf weeds (BLW); Purple nut sedge (*Cyperus rotundus* L.) and Small flower umbrella sedge (*Cyperus difformis* L.) among sedges.

Among different category of weeds, density and dry weight of broad-leaf weeds (BLWs) (57.7%) was more, followed by grasses (35.4%) and sedges (6.9%). Sunil *et al.* (2010) also reported similar weeds species in aerobic rice.

Weed density

The density of grasses, BLWs, sedges and total weeds varied significantly due to weed-management practices in aerobic rice at 30 DAS during both the years. Weed-free check showed the lowest density of grasses, BLWs, sedges and total weeds during both the years, while, the highest density of grasses, BLWs, sedges and total weeds were recorded in weedy check during both the years (Table 1). Among the weed-management practices, significantly lower density of grasses, BLWs sedges and total weeds was observed in hand-weeding at 20, 40 and 60 DAS during both the years. However, it was on a par with pyrazosulfuron ethyl @ 25 g/ha (pre) *fb* bispyribac-sodium @ 25 g/ha (post).

At 60 DAS, weed-free check recorded the lowest density of grasses, BLWs, sedges and total weeds, while the highest density of grasses, BLWs, sedges and total weeds were recorded in weedy check during both the years. Among the weed-management practices, significantly lower density of grasses, BLWs, sedges and total weeds was observed in hand weeding at 20, 40 and 60 DAS during both the years. However, it was on a par with pyrazosulfuron ethyl @ 25 g/ha (pre) *fb* bispyribac sodium @ 25 g/ha (post) during both the years (Table 2).

This was due to effective control of the first flush of weeds by pre-emergence herbicide up to 20 days. Our results are similar to those of Mewada *et al.* (2016), and later emerging weeds were effectively controlled by bispyribac sodium @ 25 g/ha. Among the 3 categories of weeds, BLWs were dominant and bispyribac-sodium @ 25 g/ha was found effective in controlling of BLWs. Hence, this treatment exhibited significantly lower density of weeds and dry-matter production. However, pendimethalin @ 1 kg/ha (pre) *fb* 1 intercultivation at 40 DAS, pendimethalin @ 1 kg/ha *fb* bispyribac-sodium @ 25 g/ha (post) and bispyribac-sodium @ 25 g/ha (early post) could not control weeds because of higher weed pressure.

Weed dry weight

The lowest dry weight of grasses, BLWs, sedges and

Table 1. Effect of weed-management practices on density of weeds (no./m^2) in aerobic rice at 30 days after sowing during 2014 and 2015

Treatment	Grasses		Broad-leaf weeds		Sedges		Total	
	2014	2015	2014	2015	2014	2015	2014	2015
Pyrazosulfuron ethyl @ 25 g/ha (pre) *fb* 1 intercultivation at 40 DAS	3.57 (12.25)	3.69 (13.14)	3.84 (14.29)	3.95 (15.14)	1.83 (2.86)	1.91 (3.16)	5.46 (29.40)	5.65 (31.44)
Pendimethalin @ 1 kg/ha (pre) *fb* 1 intercultivation at 40 DAS	4.15 (16.76)	4.23 (17.39)	4.79 (22.43)	4.87 (23.27)	2.17 (4.24)	2.27 (4.66)	6.62 (43.42)	6.77 (45.33)
Pyrazosulfuron ethyl @ 25 g/ha (pre) *fb* bispyribac sodium @ 25 g/ha (post)	2.94 (8.17)	3.03 (8.72)	3.45 (11.43)	3.51 (11.79)	1.70 (2.39)	1.75 (2.57)	4.74 (21.99)	4.86 (23.08)
Pendimethalin @ 1 kg/ha (pre) *fb* bispyribac sodium @ 25 g/ha (post)	3.94 (15.21)	4.02 (15.84)	4.24 (17.52)	4.29 (17.96)	2.02 (3.57)	2.05 (3.71)	6.06 (36.30)	6.16 (37.51)
Bispyribac sodium @ 25 g/ha (early post)	4.80 (22.59)	4.83 (22.94)	5.79 (33.06)	5.85 (33.76)	2.68 (6.75)	2.80 (7.41)	7.93 (62.40)	8.04 (64.11)
Hand-weeding at 20, 40 and 60 DAS	1.88 (3.09)	1.97 (3.44)	2.97 (8.35)	3.09 (9.07)	1.17 (0.86)	1.24 (1.04)	3.58 (12.31)	3.75 (13.55)
Weed-free check	0.71	0.71	0.71	0.71	0.71	0.71	0.71	0.71
Weedy check	5.87 (33.96)	5.97 (35.18)	8.05 (64.76)	8.19 (67.05)	3.09 (9.12)	3.29 (10.38)	10.40 (107.8)	10.63 (112.6)
SEm±	0.16	0.17	0.19	0.19	0.10	0.09	0.14	0.16
CD (P=0.05)	0.50	0.52	0.56	0.57	0.29	0.26	0.44	0.50

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

Table 2. Influenc of weed-management practices on density of weeds (no. /m^2) in aerobic rice at 60 days after sowing during 2014 and 2015

Treatment	Grasses		Broad-leaf weeds		Sedges		Total	
	2014	2015	2014	2015	2014	2015	2014	2015
Pyrazosulfuron ethyl @ 25 g/ha (pre) *fb* 1 intercultivation at 40 DAS	*4.14 (16.61)	4.24 (17.48)	4.71 (21.68)	4.82 (22.76)	1.86 (3.00)	1.93 (3.24)	6.46 (41.29)	6.63 (43.5)
Pendimethalin @ 1 kg/ha (pre) *fb* 1 intercultivation at 40 DAS	5.00 (24.56)	5.20 (26.54)	5.15 (26.06)	5.19 (26.50)	2.17 (4.21)	2.24 (4.51)	7.44 (54.83)	7.62 (57.5)
Pyrazosulfuron ethyl @ 25 g/ha (pre) *fb* bispyribac sodium @ 25 g/ha (post)	3.76 (13.70)	3.91 (14.81)	4.20 (17.41)	4.29 (18.16)	1.72 (2.47)	1.78 (2.65)	5.82 (33.58)	5.99 (35.6)
Pendimethalin @ 1 kg/ha (pre) *fb* bispyribac sodium @ 25 g/ha (post)	4.62 (20.90)	4.78 (22.37)	4.66 (21.27)	4.74 (22.07)	1.88 (3.05)	1.95 (3.33)	6.76 (45.22)	6.94 (47.8)
Bispyribac sodium @ 25 g/ha (early post)	5.19 (26.43)	5.26 (27.24)	6.27 (39.00)	6.46 (41.41)	2.37 (5.14)	2.48 (5.69)	8.42 (70.57)	8.64 (74.3)
Hand-weeding at 20, 40 and 60 DAS	2.93 (8.09)	3.09 (9.06)	3.55 (12.10)	3.60 (12.49)	1.28 (1.14)	1.38 (1.41)	4.67 (21.33)	4.84 (23.0)
Weed-free check	0.71	0.71	0.71	0.71	0.71	0.71	0.71	0.71
Weedy check	6.73 (45.00)	6.88 (47.03)	8.64 (74.15)	8.76 (76.27)	2.80 (7.37)	2.97 (8.32)	11.27 (126.5)	11.49 (131.6)
SEm±	0.17	0.17	0.18	0.19	0.09	0.08	0.19	0.20
CD (P=0.05)	0.51	0.51	0.56	0.58	0.26	0.25	0.58	0.61

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

total weeds was observed in weed-free check at 30 DAS during both the years, while, the highest dry weight in weedy check during both the years (Table 3). Among the weed-management practices, significantly lower dry

Table 3. Dry weight of weeds and weed-control efficiency (WCE) (g/m^2) as influenced by weed-management practices in aerobic rice at 30 days after sowing during 2014 and 2015

Treatment	Grasses		Broad-leaf weeds		Sedges		Total		WCE (%)	
	2014	2015	2014	2015	2014	2015	2014	2015	2014	2015
Pyrazosulfuron ethyl @ 25 g/ha (pre) *fb* 1 intercultivation at 40 DAS	*1.66 (2.26)	1.69 (2.35)	1.45 (1.62)	1.52 (1.81)	1.35 (1.32)	1.42 (1.51)	2.39 (5.20)	2.48 (5.67)	72	70
Pendimethalin @ 1 kg/ha (pre) *fb* 1 intercultivation at 40 DAS	1.83 (2.85)	1.89 (3.08)	1.73 (2.48)	1.80 (2.72)	1.48 (1.71)	1.54 (1.89)	2.74 (7.04)	2.86 (7.69)	61	60
Pyrazosulfuron ethyl @ 25 g/ha (pre) *fb* bispyribac sodium @ 25 g/ha (post)	1.52 (1.81)	1.57 (1.95)	1.23 (1.03)	1.29 (1.16)	0.91 (0.33)	0.99 (0.47)	1.91 (3.17)	2.02 (3.59)	83	81
Pendimethalin @ 1 kg/ha (pre) *fb* bispyribac sodium @ 25 g/ha (post)	1.72 (2.47)	1.77 (2.65)	1.50 (1.77)	1.56 (1.93)	0.96 (0.42)	0.95 (0.42)	2.27 (4.66)	2.34 (5.00)	74	74
Bispyribac sodium @ 25 g/ha (early post)	2.38 (5.17)	2.40 (5.30)	1.86 (2.98)	1.91 (3.17)	1.89 (3.07)	1.88 (3.02)	3.42 (11.22)	3.46 (11.49)	38	40
Hand-weeding at 20, 40 and 60 DAS	1.33 (1.28)	1.37 (1.39)	0.95 (0.40)	0.99 (0.48)	1.05 (0.61)	1.09 (0.69)	1.67 (2.29)	1.74 (2.56)	87	86
Weed-free check	0.71	0.71	0.71	0.71	0.71	0.71	0.71	0.71	100	100
Weedy check	2.77 (7.22)	2.81 (7.43)	2.73 (6.98)	2.82 (7.47)	2.11 (3.99)	2.17 (4.24)	4.32 (18.19)	4.43 (19.14)	0.0	0.0
SEm±	0.06	0.06	0.08	0.07	0.06	0.06	0.06	0.06	–	–
CD (P=0.05)	0.17	0.17	0.24	0.21	0.17	0.19	0.19	0.19	–	–

*Square-root (X+0.5)-transformed values; values in the parentheses are original values; DAS, days after sowing weight of grasses, BLWs, sedges and total weeds was observed in hand-weeding at 20, 40 and 60 DAS during both the years (Table 3). However, it was on a par with pyrazosulfuron ethyl @ 25 g/ha (pre) *fb* bispyribac sodium @ 25 g/ha (post) during both the years (Table 3).

The lowest dry weight of grasses, BLWs, sedges and total weeds were observed in weed-free check at 60 DAS during both the years, while the highest in weedy check during both the years (Table 4). Among the weed-management practices, significantly lower dry weight of grasses, BLWs, sedges and total weeds was observed in hand-weeding at 20, 40 and 60 DAS during both the years. However, it was on par with pyrazosulfuron ethyl @ 25 g/ha (pre) *fb* bispyribac sodium @ 25 g/ha (post) during both the years (Table 4).

This was mainly due to better control of weed growth even up to harvesting, resulting in lower dry weight of weeds. Our results confirm the findings of Singh *et al.* (2005) and Sunil *et al.* (2010). There was a considerable reduction in weed emergence at the initial crop-growth stage due to pre-emergence application of herbicides, resulting in vigorous seedling establishment, However, the later emerging weeds were effectively controlled by bispyribac-sodium (post). The initially vigorous crop stand provided spatial advantage to crop in suppressing the weeds below threshold level even at later stages Dhanapal *et al.* (2018).

Weed-control efficiency

The crop yield is directly proportional to weed-control efficiency (WCE) and with different weed-management practices in aerobic rice. The WCE at 30 and 60 DAS was the maximum in hand-weed thrice at 20, 40 and 60 DAS and this was closely followed by pyrazosulfuron ethyl @ 25 g/ha (pre) *fb* bispyribac sodium @ 25 g/ha (post) in 2014 and 2015, and this was the best treatment among the herbicides in terms of higher WCE (Tables 3 and 4). Our results support the findings of Dhanapal *et al*. (2018) and Ramesha *et al*. (2019). The pre-emergence application of herbicides followed by 1 hand-weeding at 40 DAS were failed to control the all types of weeds due to weed growth during critical period of crop growth (Yogananda *et al.* 2019).

Phytotoxicity

Among the herbicides tested, pendimethalin was found toxic and hindered the germination of rice seeds, led to reduced plant population. The toxicity was mainly due to leaching of herbicides to the seed zone due to maintenance of saturation. A similar phytotoxic effect caused by

Table 4. Dry-weight of weeds (g/m^2) and weed-control efficiency (WCE) as influenced by weed-management practices in aerobic rice at 60 days after sowing during 2014 and 2015

Treatment	Grasses		Broad-leaf weeds		Sedges		Total		WCE (%)	
	2014	2015	2014	2015	2014	2015	2014	2015	2014	2015
Pyrazosulfuron ethyl @ 25 g/ha (pre) *fb* 1 intercultivation at 40 DAS	1.84 (2.88)	1.88 (3.05)	2.01 (3.55)	2.06 (3.75)	1.66 (2.27)	1.74 (2.54)	3.03 (8.70)	3.14 (9.34)	74	73
Pendimethalin @ 1 kg/ha (pre) *fb* 1 intercultivation at 40 DAS	2.08 (3.83)	2.12 (4.01)	2.25 (4.56)	2.34 (4.99)	1.73 (2.50)	1.82 (2.80)	3.37 (10.89)	3.51 (11.80)	67	66
Pyrazosulfuron ethyl @ 25 g/ha (pre) *fb* bispyribac sodium @ 25 g/ha (post)	1.76 (2.62)	1.87 (2.99)	1.74 (2.55)	1.82 (2.80)	1.35 (1.33)	1.41 (1.48)	2.64 (6.49)	2.79 (7.27)	80	79
Pendimethalin @ 1 kg/ha (pre) *fb* bispyribac sodium @ 25 g/ha (post)	1.98 (3.45)	2.04 (3.68)	2.13 (4.03)	2.25 (4.59)	1.46 (1.63)	1.51 (1.80)	3.10 (9.11)	3.25 (10.07)	72	71
Bispyribac sodium @ 25 g/ha (early post)	2.44 (5.48)	2.52 (5.87)	3.20 (9.98)	3.29 (10.58)	2.28 (4.70)	2.33 (4.96)	4.54 (20.16)	4.67 (21.42)	39	39
Hand-weeding at 20, 40 and 60 DAS	1.52 (1.82)	1.57 (1.96)	1.41 (1.50)	1.44 (1.58)	1.57 (1.98)	1.63 (2.15)	2.41 (5.30)	2.49 (5.69)	84	84
Weed-free check	0.71	0.71	0.71	0.71	0.71	0.71	0.71	0.71	100	100
Weedy check	3.31 (10.46)	3.43 (11.27)	3.81 (14.05)	3.92 (14.86)	3.01 (8.62)	3.10 (9.12)	5.80 (33.13)	5.98 (35.25)	0.0	0.0
SEm±	0.07	0.07	0.14	0.15	0.07	0.06	0.10	0.09	–	–
CD (P=0.05)	0.20	0.22	0.42	0.44	0.22	0.19	0.30	0.28	–	–

Square root (X+0.5)-transformed values; values in the parentheses are original values; DAS, days after sowing pendimethalin on rice crop was observed by Rana *et al.* (2016). Application of pre-emergence herbicide *fb* 1 intercultivation failed to control the all types of weeds due to continuous rainfall, which resulted in re-establishment of weeds.

Growth and yield of aerobic rice

The data pertaining to plant height (cm), number of tillers, grain weight/panicle (g), 100-seed weight (g), per cent chaffiness, grain yield (t/ha) and weed index (%) varied significantly among the weed-management practices (Table 5 and 6). All the herbicide treatments resulted in significantly higher grain yield than to weedy check. Unweeded check showed 51 and 52% reduction in grain yield during 2014 and 2015, respectively, due to severe competition offered by uncontrolled weeds for nutrients, soil moisture, space and light (Jaybhay *et al.* 2018). Among the weed-control treatments, significantly higher grain yield (5.58 and 5.62 t/ha in 2014 and 2015 respectively) was obtained with season-long weed-free check than weedy check. However, it was at par with pyrazosulfuron ethyl @ 25 g/ha (pre) *fb* bispyribac sodium @ 25 g/ha (post) (5.20 and 5.12 t/ha in 2014 and 2015 respectively) and hand-weeding thrice at 20, 40 and 60 DAS (5.57 and 5.42 t/ha in 2014 and 2015, respectively). The superior performance of these treatments were mainly attributed to enhanced yield parameters, viz. number of tillers/plant, grain weight/panicle and 100-seed weight (Table 5). The increase in rice grain yield over weedy check owing to different treatments was attributed to the reduced density and biomass of weeds at all stages of crop growth, which resulted in increased dry matter of rice and number of panicles/m^2. These results confirm the findings of Dhanapal *et al.* (2018) and Sunil *et al.* (2010), who reported 50–75% increase in grain yield of rice owing to sequential application of pre- and post-emergence herbicides as compared to unweeded check. Reduced competition for moisture, space, light and nutrients between crop and weeds along with effective suppression of weeds by combination of herbicides has helped in obtaining higher yield in both the years, as also reported by Upasani *et al*. (2012). Unweeded control gave the lowest rice grain yield due to severe competition from all types of weeds. Similar trend was noticed with respect to weed index. These results are in line with Dhanapal *et al.* (2018), who also reported 50–55% reduction in grain yield of rice due to season-long weed infestation.

All the weed-control treatments substantially reduced the competition offered by weeds for various resources, resulting in lower weed index (John Daniel *et al.,* 2012). Pre-emergence application of pyrazosulfuron ethyl @ 25 g/ha *fb* post-emergence application of bispyribac sodium @ 25 g/ha (7.1 and 9.0% respectively) and hand-weeding thrice at 20, 40 and 60 DAS (0.2 and 3.6% respectively) recorded lower weed index during both the years (Table 6).

Economics of weed-management

Application of pyrazosulfuron ethyl @ 25 g/ha (pre) *fb* bispyribac-sodium @ 25 g/ha (post) recorded higher net returns (₹48,210 and 47,040/ha, respectively) and benefit: cost (2.62 and 2.58 respectively) during both the years (Table 6). This was closely followed by pyrazosulfuron

Table 5. Effect of weed-management practices on growth and yield parameters of aerobic rice during 2014 and 2015

Treatment	Plant height at harvesting (cm)		Tillers at harvesting		Grain weight /panicle (g)		100-seed weight (g)		Per cent chaffiness	
	2014	2015	2014	2015	2014	2015	2014	2015	2014	2015
Pyrazosulfuron ethyl @ 25 g/ha (pre) *fb* 1 intercultivation at 40 DAS	57.5	56.2	13.5	13.2	2.51	2.29	1.66	1.62	16.4	18.6
Pendimethalin @ 1 kg/ha (pre) *fb* 1 intercultivation at 40 DAS	47.7	47.5	11.3	10.6	1.50	1.38	1.07	1.09	23.6	26.2
Pyrazosulfuron ethyl @ 25 g/ha (pre) *fb* bispyribac sodium @ 25 g/ha (post)	61.0	59.9	14.1	13.5	2.53	2.64	1.73	1.66	14.5	16.4
Pendimethalin @ 1 kg/ha (pre) *fb* bispyribac sodium @ 25 g/ha (post)	53.1	52.1	11.4	11.0	1.52	1.64	0.96	0.95	22.3	23.0
Bispyribac sodium @ 25 g/ha (early post)	52.0	50.7	11.0	10.8	1.59	1.54	1.03	1.03	25.7	26.0
Hand-weeding at 20, 40 and 60 DAS	64.0	63.3	15.0	14.8	2.79	2.86	1.85	1.90	10.3	11.3
Weed-free check	64.6	65.0	15.8	15.3	2.83	2.80	1.88	1.84	9.60	10.5
Weedy check	42.9	42.2	8.55	8.33	1.59	1.50	1.00	1.02	50.1	60.4
SEm±	2.43	2.46	0.62	0.53	0.10	0.12	0.07	0.09	1.00	5.00
CD (P=0.05)	7.37	7.47	1.87	1.60	0.30	0.36	0.22	0.28	3.00	15.3

DAS, days after sowing

Table 6. Effect of weed management practices yield and economics of aerobic rice on during 2014 and 2015

Treatment	Grain yield (t/ha)		Weed index (%)		Net returns (× 10³ ₹/ha)		Benefit: cost ratio	
	2014	2015	2014	2015	2014	2015	2014	2015
Pyrazosulfuron ethyl @ 25 g/ha (pre) *fb* 1 intercultivation at 40 DAS	5.15	5.11	7.70	9.10	46.41	45.84	2.51	2.49
Pendimethalin @ 1 kg/ha (pre) *fb* 1 intercultivation at 40 DAS	2.89	2.91	48.2	48.3	15.99	15.43	1.52	1.52
Pyrazosulfuron ethyl @ 25 g/ha (pre) *fb* bispyribac sodium @ 25 g/ha (post)	5.20	5.12	7.10	9.00	48.21	47.04	2.62	2.58
Pendimethalin @ 1 kg/ha (pre) *fb* bispyribac sodium @ 25 g/ha (post)	3.35	3.23	39.8	42.5	20.47	18.70	1.69	1.63
Bispyribac sodium @ 25 g/ha (early post)	3.10	3.04	44.3	45.9	19.66	18.70	1.73	1.70
Hand-weeding at 20, 40 and 60 DAS	5.57	5.42	0.20	3.60	46.60	44.27	2.26	2.20
Weed-free check	5.58	5.62	0	0	40.73	41.33	1.95	1.96
Weedy check	2.73	2.72	51.0	51.6	12.69	11.75	1.51	1.47
SEm±	0.17	0.15	3.0	2.7	–	–	–	–
CD (P=0.05)	0.51	0.51	9.0	8.2	–	–	–	–

DAS, Days after sowing

ethyl 25 g/ha (pre) *fb* 1 intercultivation. The lowest net returns and B: C were observed in the unweeded check during both the years (Table 6). This result was obtained owing to effective weed management at critical stages by integration of effective pre and post-emergence herbicides which resulted in higher grain yield with reduced cost of cultivation. Prameela *et al*. (2014), Dhanapal *et al.* (2018) and Sanodiya and Singh (2019) also reported similar results, such results would play an important role in areas where labour is too expensive and time is a constraint (Sunil *et al.* 2010).

It was concluded that pyrazosulfuron ethyl @ 25 g/ha (pre) *fb* bispyribac sodium @ 25 g/ha (post) was found the most suitable weed-management practice for achieving higher weed-control efficiency and grain yield by reducing the weed growth throughout the crop critical period in aerobic rice in Cauvery Command area of Karnataka.

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