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**Research Paper**

# Herbicide options for controlling weeds in transplanted rice (*Oryza sativa*) under North Eastern Plains Zone

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## ABSTRACT

A field experiment was conducted during the rainy seasons of 2012 and 2013 at research farm of Regional Station, Indian Agricultural Research Institute, Pusa, Samastipur, Bihar, to evaluate suitable herbicide options for controlling weeds in transplanted aromatic rice (*Oryza sativa* L.). The experiment comprised 8 treatments, viz. pendimethalin 30 EC pre-emergence (PE) @ 1.0 kg a.i./ha, butachlor 50 EC (PE) @ 1.5 kg a.i./ha, oxydiargyl 80 WP (PE) @ 0.10 kg a.i./ha, bispyribac-sodium 10 SC post-emergence (PoE) @ 0.025 kg a.i./ha, ethoxysulfuron 15 WDG (PoE) @ 0.018 kg a.i./ha, pendimethalin (PE) @ 0.75 kg a.i./ha followed by (fb) bispyribac-sodium 10 SC (PoE) @ 0.025 kg a.i./ha, weed free and a weedy check. Sequential application of pendimethalin (PE) fb bispyribac-sodium (PoE) was observed to reduce the Jungle rice [*Echinochloa colona* (L.) Link] density by 87.6 and 82.7% as compared to weedy check at 30 and 90 days after transplanting (DAT) of crop respectively. At the same time, the density of bermuda grass [*Cynodon dactylon* (L.) Pers.], false daisy [*Eclipta alba* (L.) Hassk.] and barnyard grass [(*Echinochloa crussgalli* (L.) Beauv] were also reduced significantly by this treatment. Single application of ethoxysulfuron (PoE) significantly reduced the population of smallflower umbrella sedge (*Cyperus difformis* L.) at all growth stages of rice as compared to the other herbicide used. Among the herbicide treatments, significant higher weed-control efficiency (WCE) was recorded with the sequential application of pendimethalin (PE) fb bispyribac-sodium (PoE) to the tune 92.4 and 88.2%, respectively as compared to weedy check at 30 and 90 DAT of crop. Minimum total weed dry biomass (21.1 g/m$^2$) and highest weed-control efficiency (84.8%) were also recorded with application of pendimethalin (PE) fb bispyribac-sodium (PoE). Sequential application of pre- and post-emergence herbicide had significant effect on yield and yield attributes of aromatic rice as compared to single application of pre- or post-emergence herbicides.

***Key words*** : Aromatic rice, Herbicide, Jungle rice, Weed-control efficiency, Weed-control index, Weed flora

Rice plays a vital role in food and livelihood security for almost every household, particularly to the farmers of North Eastern Plains Zone (NEPZ) of India. Rice production in north-east India is playing a crucial role in the food sufficiency of this region. At the current rate of population growth (1.55%) in India, the rice requirement by 2020 would be around 120-135 million tonnes. To safeguard the food security in India, it is quite important to raise the productivity levels of rice. The states of Bihar, Eastern Uttar Pradesh, West Bengal and Jharkhand of the NEPZ are major contributors of area and production of rice but with the lower productivity of rice. Weeds pose a major problem in rice production, as they not only compete with crop but also hinder the quality. Yadav *et al*. (2009) reported reduction in yield of transplanted rice by about 28–45%. Therefore, timely weed control has become one of the crucial factors for realizing desired level of productivity. Accordingly, an efficient and economic weed-management programme is necessary to control different types of weeds occurring throughout the cropping period. Manual weeding is common in India, but its use is decreasing because of labour scarcity at the critical time of weeding due to the implementation of the Mahatma Gandhi National Rural Employment Guarantee Act, 2005 introduced by the Indian government and also due to increasing labour costs.

Some weeds, namely Jungle rice (Das, 2008) and barnyard grass [*Echinochloa crus-galli* (L.) Beauv.], at their early growth stages look similar to rice seedlings, making

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hand-weeding (HW) difficult. Further, many weeds which propagate by vegetative means are becoming dominant due to increased use of tractor and power tiller. Weeds like barnyard grass, Jungle rice and *Sacciolepis sp*. having mimics with rice crop are appearing as major weeds in many rice-growing areas of eastern India. Moreover, shortage of labours, increased wages and lack of suitable weed-control implements have compelled farmers to think for alternative strategies of weed management (Duary *et al.,* 2015). Herbicides offer economic and efficient weed control if applied at proper dose and stage (Prakash *et al.,* 2013). Effective control of weeds at initial stages (0–40 days after transplanting) can help in improving productivity of this crop. Chemical methods of weed control are, therefore, the most practical and cost-efficient without any harmful effect on human health and crop growth, if applied at proper concentration and time. Several pre-emergence (e.g. pendimethalin, oxadiazon, oxdiargyl, and pyrazosulfuron) and post-emergence herbicides (e.g. bispyribac-sodium, azimsulfuron, penoxsulam, fenoxaprop, ethoxysulfuron, and 2, 4-D) are now available in many Asian countries and have been reported to provide effective weed control. The choice of the right herbicide depends on major weed flora and response of weeds to various herbicides. There is a need to use high-efficacy herbicides in combination coupled with broad-spectrum herbicides to control the complex weed flora in transplanted rice (Gnanavel and Anbhazhagan, 2010). Hence a study was carried out to provide suitable weed-control options and to evaluate the efficacy of single and sequential application of pre- and post-emergence herbicides in the NEPZ for transplanted aromatic rice.

## MATERIALS AND METHODS

The field study was conducted during the rainy seasons of 2012 and 2013 at research farm of Regional Station, Indian Agricultural Research Institute, Pusa, Samastipur, Bihar (85.67° E, 25.98° N and 52.0 m above mean sea-level). The soil was sandy loam, with *p*H 8.5, low in organic carbon (0.40 and 0.43%), medium in available phosphorus (18.5 and 18.9 kg/ha) and available potassium (190 and 195 kg/ha). The climate is humid subtropical and received a mean annual precipitation of 1,270 mm. Out of which nearly 88% is received during the monsoon season extending from June to October. The experiment, consisting 8 weed-control treatments, i.e. pendimethalin @ 1.0 kg a.i./ha, butachlor @ 1.5 kg a.i./ha, oxydiargyl 80 WP @ 0.10 kg a.i./ha as pre-emergence (PE), bispyribac-sodium 10 SC @ 0.025 kg a.i./ha, ethoxysulfuron 15 WDG @ 0.018 kg a.i./ha as post-emergence (PoE) and sequential application of pendimethalin @ 0.75 kg a.i./ha followed by (fb) bispyribac-sodium 10 SC @ 0.025 kg a.i./ha including weed free and weedy check, was laid in a randomized complete-block design with 4 replications during both the years.

In both the years, aromatic rice (advanced breeding line ‘Pusa 1176’, a medium-duration aromatic line, with duration of 140 days) was transplanted in the second week of July and harvested in mid November. Field was prepared by a disc harrow-cross cultivation, followed by levelling with a wooden leveller. Thereafter the field was irrigated and maintained 4 cm depth of water for puddling. Seedling of 21 days age were transplanted at 20 cm × 15 cm spacing. Full amount of $P_2O_5$ (60 kg/ha), $K_2O$ (40 kg/ha), $ZnSO_4$ (25 kg/ha) and half N (60 kg/ha) were applied at last puddling. Remaining N (60 kg/ha) was applied in 2 splits 20 and 40 days after transplanting (DAT). Pre-emergence (PE) herbicides were applied at 2 DAT and post-emergence (PoE) herbicides at 20 DAT. Herbicides were applied with knapsack sprayer having a flat-fan nozzle and water was used at 500 L/ha for PE spray and at 350 L/ha for PoE spray.

Species-wise densities of weeds were noted at 30, 60 and 90 DAT, whereas weed biomass was measured at 90 DAT. The weed density was recorded in 3 quadrates (1.0 m × 1.0 m), placed randomly in each plot. Weeds were cut at ground level, washed with tap-water, sun-dried, oven-dried at 66 ± 4 °C for 48 hours, and then weighed. Weed indices like weed-control efficiency (WCE) and weed-control index (WCI) were calculated (Das, 2008) as:

$$WCE = (WDc - WDt)/WDc \times 100$$

where WDc is the weed density (number/m$^2$) in control plot; WDt is the weed density (number/m$^2$) in treated plots.

$$WCI = (WDMc - WDMt)/WDMc \times 100$$

where WDMc is the weed dry biomass (unit/m$^2$) in control plot; WDMt is the weed dry biomass (unit/m$^2$) in treated plots.

Yield variables measured include effective tillers/m$^2$, panicle length, grains/panicle, grain weight (g)/panicle, 1,000-grain weight and grain yield. Grain yield was calculated (on the basis of grain yield of net plot area of 8.0 m$^2$) in the centre of each plot and expressed in t/ha at 14% moisture. The effective tillers were measured by using quadrate. At the same time, 10 plants were randomly selected from each plot to measure panicle length, grains/panicle and grain weight/panicle.

All the data were analyzed statistically using the F-test as per the standard procedure. LSD values at $P$ = 0.05 were used to determine the significance of difference between treatment means. Weed density data were transformed with square-root transformation [$\sqrt{(x + 1.0)}$] before analysis. The non-transformed weed density and dry biomass data are reported with the interpretation based on transformed data. The relationship between grain yield with weed density and weed dry biomass were assessed with the use of linear correlation.

## RESULTS AND DISCUSSION

### *Weed density*

The experiment plots infested with many weed species like Jungle rice [*Echinochloa colona* (L.) Link], smallflower umbrella sedge (*Cyperus difformis* L.), purple nutsedge (*Cyperus rotundus* L.), Bermuda grass [*Cynodon dactylon* (L.) Pers.], false daisy (*Eclipta alba* Hassk.), barnyard grass [*Echinochloa crussgalli* (L.) P. Beauv.] and flatsedge or yellowsedge (*Cyperus iria* L.) etc. However, species-wise results are presented for the first 5 weeds only, as they were dominant in the samples.

*Jungle rice:* All the herbicide treatments significantly reduced the density of Jungle rice compared with the weedy check. Pre-emergence application of pendimethalin fb post-emergence application of bispyribac-sodium significantly reduced the mean weed density of Jungle rice as compared the remaining treatments except weed-free check at 30 and 90 DAT of rice (Table 1). The single application of pendimethalin, butachlor and oxydiargyl as pre-emergence and bispyribac-sodium and ethoxysulfuron as post-emergence were found at par in reducing the weed density of Jungle rice at 30 and 90 DAT of rice except ethoxysulfuron at 90 DAT, where effectiveness of ethoxysulfuron reduced as compared to the other herbicides used. The lowest weed density of this weed was observed with following sequential application of pendimethalin (PE) fb bispyribac-sodium (PoE), which revealed 87.6 and 82.7% reduction in Jungle rice density compared with weedy check (non-treated control) at 30 and 90 DAT of crop respectively. Jungle rice was the predominant weed associated with crop, which thrives well under flooded situation and considered as a major weed of rice. Chauhan and Seth (2012) reported effect of bispyribac-sodium on seedling survival of Jungle rice at different stages of their growth (4, 6 and 8 leaves stage) and found most effective in controlling this weed as compared to fenoxaprop-p-ethyl + ethoxysulfuron and penoxsulam + cyhalofop.

*Smallflower umbrella sedge*: Smallflower umbrella sedge was observed as a dominating species among sedges under this study. Different herbicide treatments significantly influenced the density of this weed (Table 1). Single application of ethoxysulfuron (PoE) significantly reduces the population of smallflower umbrella sedge at all the growth stages of rice as compared to the other herbicidal treatments. This herbicide reduced the mean weed density to tune of 1.6 and 1.6 as compared to 6.3 and 6.6 in weedy check presented in numbers per meter square at 30 and 90 DAT of rice respectively. All the herbicidal treatments except ethoxysulfuron (PoE), were at par in reducing the density of this weed and remained significantly superior to the weedy check. Reddy *et al*. (2000) reported that ethoxysulfuron provided a 100% control of smallflower umbrella sedge in transplanted rice.

*Purple nutsedge:* The density of the second most important sedge, purple nutsedge, was significantly influenced by the treatments (Table 1). An application of ethoxysulfuron (PoE) significantly reduced the density of this weed as compared to the single application of pendimethalin, butachlor and oxydiargyl as pre-emergence, bispyribac-sodium as post-emergence and sequential application of pendimethalin (PE) fb post-emergence application of bispyribac-sodium at 30 DAT of rice. However, the effectiveness of all herbicides become non-sig-

**Table 1.** Effect of herbicidal treatments on weed density (numbers/$m^2$) at 30 and 90 days after transplanting (DAT) of rice (mean data of 2 years)

| Treatment | Wild rice | | Smallflower umbrella sedge | | Purple nutsedge | |
|---|---|---|---|---|---|---|
| | 30 DAT | 90 DAT | 30 DAT | 90 DAT | 30 DAT | 90 DAT |
| Pendimethalin (PE) @ 1.0 kg/ha | 2.5 (5.5) | 2.7 (6.3) | 2.2 (4.0) | 2.4 (4.8) | 2.7 (6.3) | 2.4 (5.0) |
| Butachlor (PE) @ 1.5 kg/ha | 2.7 (6.5) | 3.5 (11.3) | 2.4 (5.0) | 3.1 (8.5) | 2.8 (7.5) | 2.7 (6.5) |
| Oxydiargyl (PE) @ 0.10 kg/ha | 2.5 (5.3) | 3.2 (9.5) | 2.3 (4.5) | 3.4 (11.0) | 2.9 (7.3) | 2.1 (5.0) |
| Bispyribac sodium (PoE) @ 0.025 kg/ha | 2.5 (5.5) | 2.6 (6.0) | 2.4 (4.8) | 2.4 (5.0) | 2.7 (6.3) | 2.6 (5.8) |
| Ethoxy sulfuron (PoE) @ 0.018 kg/ha | 2.6 (5.8) | 5.6 (30.5) | 1.6 (1.5) | 1.6 (2.3) | 1.8 (2.5) | 2.0 (3.0) |
| Pendimethalin (PE) @ 1.0 kg/ha fb Bispyribac sodium (PoE) @ 0.025 kg/ha | 1.4 (1.0) | 1.6 (1.5) | 2.1 (3.3) | 2.3 (4.5) | 2.5 (5.3) | 2.2 (4.5) |
| Weed-free check | 1.0 (0) | 1.0 (0) | 1.0 (0) | 1.0 (0) | 1.0 (0) | 1.0 (0) |
| Weedy check | 11.3 (129.3) | 9.3 (87.5) | 6.3 (38.5) | 6.6 (42.0) | 3.7 (12.8) | 2.9 (8.0) |
| SEm ± | 0.3 | 0.3 | 0.1 | 0.2 | 0.2 | 0.4 |
| CD (P=0.05) | 1.0 | 0.9 | 0.4 | 0.5 | 0.6 | NS |

PE, Pre-emergence; PoE, post-emergence

nificant at 90 DAT of rice. Purple nutsedge is a perennial, invasive, troublesome and most problematic sedge of the world, its control is very difficult due to long viable tubers formed in chain which easily survive under harsh conditions. Ahmed and Chauhan (2014) reported that sequential application of pyrizosulfuron fb ethoxysulfuron significantly reduced the density of purple nutsedge in Aman rice as compared to single application of pendimethalin fb 1 HW (1 hand-weeding), pyrazosulfuron fb 1 HW and oxadiargyl fb 1 HW.

*Bermuda grass:* Density of Bermuda grass was significantly affected by different herbicidal treatments (Table 2). Application of pendimethalin (PE) fb bispyribac-sodium (PoE) recorded significantly lowest density at all the stages of crop growth as compared to weedy check and other herbicides tested except at 90 DAT where it was non-significant than pendimethalin (PE) or butachlor (PE) treatment. The highest density of this weed was recorded in weedy check. Sequential application of pendimethalin fb bispyribac-sodium significantly reduced the population due to dual time prevention of germination, namely pre-emergence stage and 20 DAT of rice. Singh *et al*., (2016) in farmers' participatory field trials at Taraori rice, in Karnal district of Haryana observed pendimethalin fb bispyribac sodium to be the most suitable treatment in reducing the density of grassy weed (Bermuda grass) as compared to the other treatments.

*False daisy:* False daisy population was significantly influenced by the weed-control treatments (Table 2). The sequential application of pendimethalin (PE) fb bispyribac-sodium (PoE) significantly reduced the density to the tune of 1.3 and 1.3 as compared to single application of pendimethalin, butachlor and oxydiargyl as pre-emergence, ethoxysulfuron and bispyribac-sodium as post-emergence and weedy check at 30 and 90 DAT stage of rice respectively. Similar results were reported by Singh *et al*. (2016).

*Other weeds:* Other weeds like *Echinochloa cruss-galli*, *Cyperus iria* and red sprengletop [*Leptochloa chinensis* (L.) Nees] were observed in small number in the experiment. Total densities of these weeds were significantly influenced by the herbicidal treatments (Table 2). Application of pendimethalin (PE) fb bispyribac-sodium (PoE) significantly reduced the mean density of these weeds as compared to pre-emergence application of pendimethalin, butachlor, oxydiargyl and post-emergence application of bispyribac-sodium and ethoxysulfuron alone and weedy check at 30 and 90 DAT of rice crop. Significant reduction in weed population by sequential application of pendimethalin (PE) fb bispyribac-sodium (PoE) may be due to broad-spectrum control at both pre- and post-emergence stages.

*Total weed density:* All herbicidal treatments reduced the mean density of total weeds as compared to weedy check (Table 3). Total mean weed density recorded under pendimethalin (PE), butachlor( PE), oxydiargyl (PE), bispyribac-sodium (PoE), ethoxysulfuron (PoE) and pendimethalin (PE) fb bispyribac-sodium (POE) treatments were 36, 49.5, 33.5, 35.8, 35.5 and 17.3 plants/m$^2$, respectively, at 30 DAT, as compared to 233.5 plants/m$^2$ in the weedy check. At 90 DAT of rice, the density were 41.3, 67.3, 48.0, 37.8, 70.8 and 20.0 plants/m$^2$, respectively, as compared to 187.8 plants/m$^2$ in the weedy check. The lowest density of weeds were observed with the sequential application of pendimethalin (PE) followed by bispyribac-sodium (PoE). Mahajan and Chauhan (2013) also reported similar response in dry direct-seeded rice under scented rice wheat rotation of western Indo-

**Table 2.** Effect of herbicidal treatments on weed density (numbers/m$^2$) at 30 and 90 days after transplanting (DAT) of rice (mean data of 2 years)

| Treatment | Bermuda grass | | False daisy | | Others | |
|---|---|---|---|---|---|---|
| | 30 DAT | 90 DAT | 30 DAT | 90 DAT | 30 DAT | 90 DAT |
| Pendimethalin (PE) @ 1.0 kg/ha | 2.1 (3.5) | 2.2 (4.3) | 2.1 (3.3) | 2.1 (3.5) | 3.7 (13.5) | 4.3 (17.5) |
| Butachlor (PE) @ 1.5 kg/ha | 2.3 (4.5) | 2.2 (5.5) | 2.2 (3.5) | 2.2 (3.8) | 4.8 (22.5) | 5.7 (31.8) |
| Oxydiargyl (PE) @ 0.10 kg/ha | 2.2 (4.0) | 2.5 (5.5) | 1.9 (2.8) | 1.9 (2.8) | 3.6 (11.8) | 3.9 (14.3) |
| Bispyribac sodium (PoE) @ 0.025 kg/ha | 2.2 (3.8) | 2.3 (4.5) | 1.7 (2.0) | 1.8 (2.3) | 3.8 (13.5) | 3.9 (14.3) |
| Ethoxy sulfuron (PoE) @ 0.018 kg/ha | 2.0 (3.3) | 2.5 (5.3) | 1.9 (2.5) | 1.9 (2.8) | 4.6 (20.0) | 5.3 (27.0) |
| Pendimethalin (PE) @ 0.75 kg/ha fb Bispyribac sodium (PoE) @ 0.025 kg/ha | 1.3 (0.8) | 1.3 (0.8) | 1.3 (0.8) | 1.3 (1.0) | 2.6 (6.3) | 3.0 (8.5) |
| Weed-free check | 1.0 (0) | 1.0 (0) | 1.0 (0) | 1.0 (0) | 1.0 (0) | 1.0 (0) |
| Weedy check | 3.3 (10.3) | 3.3 (10.0) | 2.4 (5.0) | 2.5 (5.3) | 6.2 (37.5) | 6.0 (35.0) |
| SEm ± | 0.2 | 0.3 | 0.1 | 0.1 | 0.3 | 0.2 |
| CD (P=0.05) | 0.6 | 1.0 | 0.3 | 0.4 | 0.9 | 0.6 |

PE, Pre-emergence; PoE, post-emergence

Gangetic Plains of India.

### *Weed-control efficiency, weed dry biomass and weed-control index*

Significant higher weed-control efficiency (WCE) was recorded with the sequential application of pendimethalin (PE) fb bispyribac-sodium (POE) than pre-emergence application of pendimethalin, butachlor, oxydiargyl and post-emergence application of bispyribac-sodium and ethoxysulfuron at 30 and 90 DAT of rice crop respectively (Table 3). The pendimethalin (PE) fb bispyribac-sodium (PoE) treatment remained at par with weed free check for 100% weed-control efficiency at all the measured growth stages.

Total weed dry biomass at harvesting of rice was significantly influenced by the herbicidal treatments (Table 3). A minimum weed dry biomass of weeds was recorded from sequential application of pendimethalin (PE) fb bispyribac-sodium (PoE) as compared to pre-emergence application of pendimethalin, butachlor, oxydiargyl and post-emergence application of bispyribac-sodium and ethoxysulfuron at harvest stage of rice crop, whereas the highest weed dry biomass was recorded under weedy check. Weed-control index was very much influenced by the weed control treatments (Table 3). Among the herbicides, significantly highest WCI was recorded under sequential application of pendimethalin (PE) fb bispyribac-sodium (PoE) as compared to pre-emergence application of pendimethalin, butachlor, oxydiargyl and post-emergence application of bispyribac-sodium and ethoxysulfuron at 90 DAT stage of crop.

### *Yield, yield attributes and economics*

All the herbicidal applications resulted in significantly higher grain yield than weedy check. Of the herbicidal treatments, a significantly highest grain yield was recorded with the sequential application of pendimethalin (PE) fb bispyribac-sodium (PoE), being comparable with the grain yield obtained from weed-free plots (Table 4). A yield reduction of 27.7 and 24.2% was recorded in weedy check plots compared to weed-free treatment and treatment with sequential application of pendimethalin (PE) fb bispyribac-sodium (PoE). As expected, lowest number of effective tillers/ $m^2$ was recorded in weedy-check plot. The maximum numbers of effective tillers per meter square in weed-free check at par with sequential application of pedimethalin (PE) fb bispyribac-sodium treatment were in tern significantly superior to herbicidal treatments i.e. single application of bispyribac-sodium (PoE), pendimethalin (PE), oxydiargyl (PE), butachlor (PE) and ethoxysulfuron (PoE). The panicle length was significantly influenced by the herbicidal treatments (Table 4). Significantly higher panicle length was observed under sequential application of pendimethalin (PE) fb bispyribac-sodium (PoE) compared with single application of pendimethalin (PE), butachlor (PE), oxydiargyl (PE), bispyribac-sodium (PoE) and ethoxysulfuron (PoE) and former treatment remained at par with weed-free check. Herbicidal treatments were observed to initiate more grains per panicle, resulting up to 7.2 to 32.2% increase in grains/panicle as compared to weedy check. The increase in grains/ panicle was more in sequential applications of PE fb PoE herbicide compared to single PE or PoE herbicide. Significantly more grains / panicle was observed owing to herbicidal treatments with the sequential application of pendimethalin (PE) fb bispyribac-sodium (PoE) as compared with single application of pendimethalin (PE), butachlor (PE), oxydiargyl (PE),

**Table 3.** Effect of herbicidal treatments on total weed density (numbers/$m^2$), weed-control efficiency (%), weed biomass and weed-control index (%) at different stage of rice (mean data of 2 years)

| Treatment | Total weed density (Nos./$m^2$) | | WCE (%) | | Total weed dry weight (g/$m^2$) | WCI (%) |
|---|---|---|---|---|---|---|
| | 30 DAT | 90 DAT | 30 DAT | 90 DAT | 90 DAT | 90 DAT |
| Pendimethalin (PE) @ 1.0 kg/ha | 6.0 (36.0) | 6.5 (41.3) | 84.0 | 77.7 | 51.5 | 64.3 |
| Butachlor (PE) @ 1.5 kg/ha | 7.0 (49.5) | 8.2 (67.3) | 78.2 | 64.0 | 64.6 | 55.3 |
| Oxydiargyl (PE) @ 0.10 kg/ha | 5.9 (33.5) | 7.0 (48.0) | 85.2 | 73.5 | 65.4 | 54.7 |
| Bispyribac sodium (PoE) @ 0.025 kg/ha | 6.1 (35.8) | 6.2 (37.8) | 84.2 | 79.6 | 48.5 | 66.7 |
| Ethoxy sulfuron (PoE) @ 0.018 kg/ha | 6.0 (35.5) | 8.5 (70.8) | 84.8 | 62.1 | 72.5 | 50.0 |
| Pendimethalin (PE) @ 0.75 kg/ha fb Bispyribac sodium (PoE) @ 0.025 kg/ha | 4.3 (17.3) | 4.6 (20.8) | 92.6 | 88.2 | 22.1 | 84.8 |
| Weed-free check | 1.0 (0) | 1.0 (0) | 100.0 | 100.0 | 0.0 | 100.0 |
| Weedy check | 15.3 (233.5) | 13.7 (187.8) | 0.0 | 0.0 | 145.8 | 0.0 |
| SEm± | 0.4 | 0.3 | 1.9 | 2.1 | 3.4 | 1.5 |
| CD (P=0.05) | 1.2 | 1.0 | 5.8 | 6.1 | 9.9 | 4.4 |

PE, Pre-emergence; PoE, post-emergence; DAT, days after transplanting

**Table 4.** Effect of herbicidal treatments on yield attributes and yield of transplanted aromatic rice (mean data of 2 years)

| Treatment | Effective tillers/m$^2$ | Panicle length (cm) | Grains/ panicle (Nos.) | Grain weight / panicle (g) | 1,000-grain weight (g) | Grain yield (t/ha) | Straw yield (t/ha) | Harvest index (%) | Cost of cultivation (×10$^3$ ₹/ha) | Gross returns (×10$^3$ ₹/ha) | Benefit: cost ratio |
|---|---|---|---|---|---|---|---|---|---|---|---|
| Pendimethalin (PE) @ 1.0 kg/ha | 302.8 | 25.8 | 140.0 | 3.0 | 19.9 | 3.44 | 6.20 | 35.8 | 30.8 | 63.9 | 1.08 |
| Butachlor (PE) @ 1.5 kg/ha | 289.5 | 25.0 | 126.5 | 2.8 | 19.5 | 3.22 | 5.94 | 35.3 | 29.6 | 60.2 | 1.03 |
| Oxydiargyl (PE) @ 0.10 kg/ha | 293.5 | 25.5 | 136.3 | 2.9 | 19.3 | 3.40 | 6.00 | 35.8 | 32.0 | 62.4 | 0.95 |
| Bispyribac sodium (PoE) @ 0.025 kg/ha | 310.5 | 25.8 | 140.8 | 3.1 | 20.1 | 3.45 | 6.20 | 35.8 | 31.1 | 64.1 | 1.06 |
| Ethoxy sulfuron (PoE) @ 0.018 kg/ha | 280.0 | 24.8 | 133.8 | 2.8 | 19.1 | 3.20 | 5.82 | 35.5 | 29.6 | 59.6 | 1.02 |
| Pendimethalin (PE) @ 0.750 kg/ha fb Bispyribac sodium (PoE) @ 0.025 kg/ha | 343.0 | 27.0 | 156.0 | 3.3 | 21.2 | 3.72 | 6.42 | 36.5 | 31.9 | 68.5 | 1.15 |
| Weed-free check | 362.0 | 27.3 | 162.8 | 3.4 | 21.0 | 3.90 | 6.57 | 37.0 | 31.8 | 71.1 | 1.24 |
| Weedy check | 199.3 | 23.5 | 118.0 | 2.3 | 18.8 | 2.82 | 5.52 | 33.8 | 28.6 | 53.4 | 0.87 |
| SEm± | 10.2 | 0.4 | 4.9 | 0.1 | 0.3 | 0.07 | 0.07 | 0.4 | - | 1.2 | 0.04 |
| CD (P=0.05) | 30.1 | 1.1 | 14.5 | 0.2 | 1.0 | 0.22 | 0.21 | 1.1 | - | 3.6 | 0.12 |

PE, Pre-emergence; PoE, post-emergence

bispyribac-sodium (PoE) and ethoxysulfuron (PoE), but remained at par with weed-free check. Similarly, the grain weight/ panicle was also influenced significantly by the treatments (Table 4). Herbicidal treatments were caused significant differences in more grain weight, resulting in higher 1000-grain weight and grain weight/ panicle. Among the herbicidal treatments, significantly higher grain weight/ panicle (g) and 1,000-grain weight (g) were observed with sequential application of pendimethalin (PE) fb bispyribac-sodium (PoE) than single application of pendimethalin (PE), butachlor (PE), oxydiargyl (PE), bispyribac-sodium (PoE) and ethoxysulfuron (PoE) and remained at par with weed-free check. Straw yield and harvest index (HI) were also influenced by different treatments. Significantly highest straw yield was observed under weed-free check followed by sequential application of pendimethalin (PE) fb bispyribac-sodium (PoE) (6.42 t/ha). These 2 treatments were found at par but significantly superior to single application of pendimethalin (PE), butachlor (PE), oxydiargyl (PE), bispyribac-sodium (POE), ethoxysulfuron (POE) and weedy check. Among the herbicidal treatments, significantly higher HI was recorded under sequential application of pendimethalin (PE) fb bispyribac-sodium (PoE), single application of pendimethalin (PE), oxydiargyl (PE), bispyribac-sodium (PoE) and ethoxysulfuron (PoE)); and remain *at par* among themself but significantly superior to butachlor (PE). The total cost of cultivation of transplanted aromatic rice varied due to differences in herbicide treatments. The highest cost of cultivation was recorded under pre-emergence application of oxydiargyl, followed by sequential application of pendimethalin (PE) fb bispyribac-sodium (PoE) and weed-free check. The gross returns and benefit : cost ratios were significantly higher in weed-free check and remained at par with pendimethalin (PE) fb bispyribac-sodium (PoE) (Table 4). Higher gross returns and benefit : cost ratio in these 2 treatments were mainly owing to higher grain yield.

Weed dry biomass and weed density remained negatively correlated with grain yield at all the stages of crop growth (Table 5), indicating that the weeds had a negative influence on grain yield. In our study, weed dry biomass

**Table 5.** Correlation of weed biomass and weed density with rice grain yield at different stage

| Weed biomass/ density | $R^2$ value[b] |
|---|---|
| Biomass of weeds at 90 DAT | -0.811 |
| Weed densities at 30 DAT | -0.628 |
| Weed densities at 60 DAT | -0.676 |
| Weed densities at 90 DAT | -0.774 |

[b] Significant at 1%; DAT, days after transplanting

was closely correlated followed by weed density at 90, 60 and 30 DAT. Closeness in relationship between dependent variable with independent variables was assessed by calculating $R^2$ values. The closest relationship of grain yield with weed dry biomass was observed with $R^2$ value of -0.811 followed by weed density at 90, 60 and 30 DAT. With above interpretation we can understand that weed dry biomass is more accurate parameter to estimate the reduction in grain yield as compared to densities at different stages. All yield variables and yield of aromatic rice improved in the herbicide-treated plots compared with the weedy check, which was owing to less weed competition with the rice crop. Minimum effective tillers/m$^2$, panicle length (cm), grains/ panicle, grain weight/ panicle and 1,000-grain weight in weedy check plots may be the due to the higher competition among the crop and weeds for nutrient, space, light, and carbondioxide (Tindall *et al.*, 2005). In previous studies, improvement in yield and yield variables in rice were reported in the herbicide-treated plots compared with the non-treated plots (Mahajan *et al.*, 2009). Mahajan and Chauhan (2013) in direct-seeded aromatic rice reported higher grain yield and yield attributes of rice with sequential application of pendimethalin (PE) fb bispyribac-sodium (PoE) and concluded that sequential application of pre- and post-emergence herbicides were quite effective in attaining higher grain yield than single application of pre- or post-emergence herbicides.

The results of this study indicate that pre-emergence application of pendimethalin fb bispyribac-sodium as post-emergence was the best herbicidal treatment for the effective control of Jungle rice, Bermuda grass, false daisy and barnyard grass etc in transplanted aromatic rice. Post-emergence application of ethoxysulfuron was observed most effective to control smallflower umbrella sedge.

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