Original Research

Journal Home page : www.jeb.co.in ★ E-mail : editor@jeb.co.in

Journal of Environmental Biology

JEB™ p-ISSN: 0254-8704
e-ISSN: 2394-0379
CODEN: JEBIDP

DOI : http://doi.org/10.22438/jeb/41/6/SI-264

Weed dynamics, weed control efficiency and yield of aerobic rice as influenced by different weed management practices in eastern U.P.

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Paper received: 13.06.2020 *Revised received*: 03.10.2020 *Accepted*: 30.10.2020

Abstract

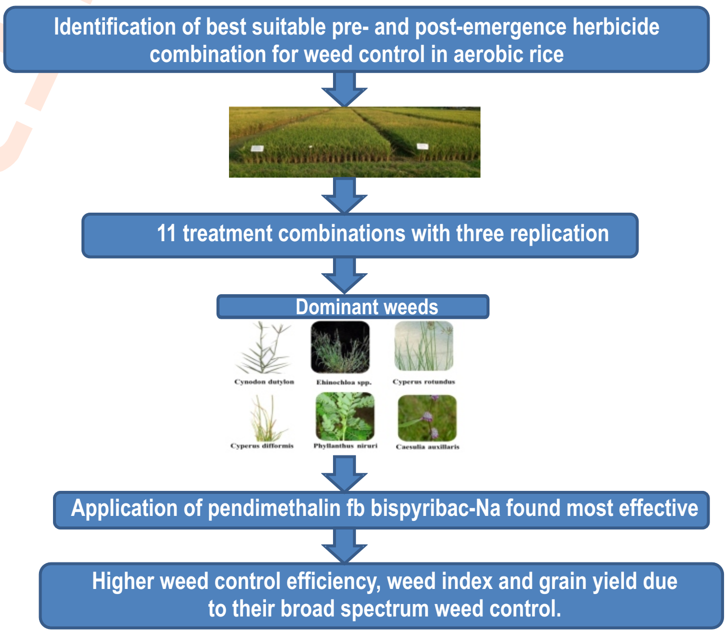
Aim: To identify the best sequence of pre- and post-emergence herbicides for achieving better weed control efficiency in aerobic rice.

Methodology: A field experiment was conducted in Randomized Block Design with eleven treatment combinations, replicated thrice. The dominant weeds in field were *C. dactylon*, *E. colona* and *E. crusgalli* among grasses, *C. rotundus*, *C. difformis* and *F. maliaceae* among sedges and *C. axillaris* and *P. niruri* among broad-leaf weeds. Treatments consisting sequential application of two pre-emergence application [Pendimethalin (30 EC) @ 1.00 kg *a.i.* ha^{-1}; Butachlor (50 EC) @ 1.5 kg *a.i.* ha^{-1}] followed by three post emergence herbicides [Bispyribac-Na (10% SC) @ 35 g *a.i.* ha^{-1}; 2, 4-D Na salt (80 WP) @ 0.06 kg *a.i.* ha^{-1}; Almix (CME + MSM) (20 WP) @ 40 g *a.i.* ha^{-1}] and straw mulching @ 4 t ha^{-1}; Mechanical weeding at 20 and 45 DAS, weed free and unweeded check.

Results: Among herbicidal treatments, pre-emergence application of pendimethalin at 3-4 DAS *fb* Bispyribac-Na at 15-20 DAS as post-emergence was most effective in minimizing weed density (4.81 m^{-2}), biomass (6.20 g m^{-2}), weed index (1.11%) and in enhancing the weed control efficiency (84.50%), grain yield (3.68 t ha^{-1}) and straw yield (4.87 t ha^{-1}) over rest of the treatments.

Interpretation: Sequential application of pendimethalin at 3-4 DAS *fb* bispyribac-Na at 15-20 DAS is prominent in enhancing herbicide efficacy and reducing weed flora abundance resulting in higher weed control efficiency and grain yield due to their broad spectrum weed control.

Key words: Aerobic rice, Grain yield, Weed biomass, Weed dynamics



How to cite : R.K. Parihar, V.K. Srivastava, S. Kumar, V. Kumar and Sanjay-Swami : Weed dynamics, weed control efficiency and yield of aerobic rice as influenced by different weed management practices in eastern U.P. *J. Environ. Biol.*, **41**, 1735-1741 (2020).

Introduction

Rice is the major staple food of Asia and Pacific regions, providing almost 39% of calorie demand (Yaduraju, 2013). In India, it is a mean of livelihood for millions of rural households (Sanjay-Swami and Singh, 2020). Increasing cost of labour and restricted availability of irrigation water has led farmers to shift from traditional practice of conventionally transplanted to aerobic rice. Aerobic rice systems, where the crop is established through direct seeding under unpuddled, non-flooded conditions where plenty of air (oxygen) is present in the rhizosphere as compared to flooded rice which is the most promising approach for saving water and reduce water application by 44% relative to conventionally transplanted systems, by reducing percolation, seepages and evaporative losses, while maintaining yield at an acceptable level (Kumar *et al.*, 2018). Among several factors for low rice productivity in aerobic conditions, the losses due to weeds are one of the most important factors resulting in 50 to 90% yield decrement (Chauhan and Opena, 2012). It is subjected due to much higher weed pressure (Rao *et al.*, 2007), essentially owing to higher weed seed bank in soil along with lack of flood water that enhance seed bank persistence, germination and early establishment of weeds(Nagargade *et al.*, 2018; Raj and Syriac, 2017). Though critical crop-weed competitive period has not been accurately estimated yet; it varied from 0 to 60 days after sowing or some time for entire growth period (Chauhan and Johnson, 2011; Azmi *et al.*, 2007 and Singh, 2008). There is marked shift of weed flora, especially higher population of *L. chinensis, C. dactylon, E. colona and E. crusgalli among grasses, C. rotundus, C. difformis and F. maliaceae among sedges and C. axillaris and P. Niruri* among broad-leaf weeds in aerobic than transplanted rice.

The main challenges in aerobic rice cultivation in India are: reducing/avoiding weed pressure and weed flora shift, combating labour shortages and deep understanding of herbicidal effect in combinations/rotations through intelligent weed management techniques (Rao *et al.*, 2020). Although, weed management through other means are tedious, time consuming and impractical thus; herbicidal use is the smartest and viable options of weed management. Aerobic rice on the other hand, provides eclectic opportunities for same due to close association of weed control with water regimes that provide suitable condition in aerobic rice due to maintenance of moisture levels at field capacity throughout life cycle. For achieving specificity along with less energy requirement herbicidal use are expected to be the main intervention against weeds and are being popular due to their rapid effect, easier application and low cost involvement in comparison to traditional methods (Singh *et al.*, 2006).

Use of pre-emergence herbicide in rice is most popular and its continuous use has created significant weed shift as well herbicidal tolerance (Chauhan and Johnson, 2011). Most of the scientific recommendations rely on single use of only pre/post emergent herbicides in aerobic rice for controlling early flushes of weeds (Mahajan and Chauhan, 2008). It has identified more development of herbicide resistance worldwide even on newly introduced sulfonylureas (Duary *et al.,* 2015; Rajkhowa *et al.*, 2006).

To cope up this situation, there is an urgent need to weigh up different herbicidal combinations. Thus, this study was designed to evaluate the effectiveness of herbicidal combination (pre-emergence and post-emergence) in eastern U.P. This effort is a call to broaden the weed management options and also to conceptualize the effect of herbicide combination approach to enhance the efficacy and crop yield on one hand and with lowers the weed index, biomass and density on other; as compared to weed free aerobic rice.

Materials and Methods

The present investigation was carried out during *kharif* season of 2014 at the Agricultural Research Farm, Institute of Agricultural Sciences, Banaras Hindu University, Varanasi, Uttar Pradesh (India). The cumulative rainfall during the period of investigation in the cropping season 2014 (11 June to 11 November) was recorded 763.3 mm. Soil of the experimental field falls under sandy clay loam in texture and neutral in reaction with low in organic carbon (0.43%), low in nitrogen (202.70 kg ha^{-1}) and medium in available phosphorus (25.60 kg ha^{-1}) and potassium (209.20 kg ha^{-1}).

The experiment was laid out in randomized block design (RBD) with eleven treatment combination and replicated thrice. Pendimethalin (30 EC) @ 1.00 kg *a.i.* ha^{-1} - Bispyribac-Na (10% SC) at 35 g *a.i.* ha^{-1}, Pendimethalin (30 EC) @ 1.00 kg *a.i.* ha^{-1} - 2, 4-D Na salt (80 WP) @ 0.06 kg *a.i.* ha^{-1}, Pendimethalin (30 EC) @ 1.00 kg *a.i.* ha^{-1} - Straw mulching @ 4 t ha^{-1}, Pendimethalin (30 EC) @ 1.00 kg *a.i.* ha^{-1} - Almix (CME + MSM) (20 WP) @ 40 g *a.i.* ha^{-1}, Butachlor (50 EC) at 1.5 kg *a.i.* ha^{-1} - Bispyribac-Na (10% SC) at 35 g *a.i.* ha^{-1}, Butachlor (50 EC) @ 1.5 kg *a.i.* ha^{-1} - 2, 4-D Na salt (80 WP) @ 0.06 kg *a.i.* ha^{-1}, Butachlor (50 EC) @ 1.5 kg *a.i.* ha^{-1} - Straw mulching @ 4 t ha^{-1}, Butachlor (50 EC) @ 1.5 kg *a.i.* ha^{-1} - Almix (CME + MSM) (20 WP) @ 40 g *a.i.* ha^{-1}, Mechanical weeding at 20 and 45 DAS, Weed free and Unweeded check. Pre-emergence (2-3 DAS) and post-emergence (20 DAS) herbicides were applied with the help of a hand-operated knapsack sprayer fitted with flat-fan nozzle and water as a carrier at 500 l ha^{-1}. In the unweeded check, no weeding was done. Rice variety: HUR-3022 was line sown at the row spacing of 20 cm with 35 kg seeds ha^{-1} on 19^{th} July 2014. An uniform dose of 120 kg N + 60 kg P_2O_5 + 60 kg K_2O + 25 kg $ZnSO_4$ ha^{-1} was applied in all the treatments in the form of urea, DAP, MOP and $ZnSO_4$, respectively. Half dose of total N and full dose of P_2O_5, K_2O and $ZnSO_4$ was applied as basal and remaining half-dose of nitrogen was applied in two equal split doses at active tillering and panicle initiation stages. Other agronomic and plant protection measures were adopted as recommended during the crop growth. Density of weeds was recorded in a 0.25 m^2 quadrat at all growth stages of weed. Data on weed biomass was recorded from 0.25 m^2 area by cutting weeds at ground level, washing with tap water, sundry followed by oven drying at 70±2ºC for 48 hr and then weighing. The data on weed density and dry weight for all the categories were subjected to square root (“x+0.5) transformation before statistical analysis to normalize their distribution. However, for better understanding, original values are given in parenthesis. Weed control efficiency and weed index were calculated by the following formulae :

$$\text{WCE (\%)} = \frac{\text{DMC} - \text{DMT}}{\text{DMC}} \times 100$$

Where, DMC is the Dry matter production of weeds in unweeded plot; DMT is the Dry matter production of weeds in treated plot

$$\text{Weed index (\%)} = \frac{\text{Grain yield in hand weeded plot} - \text{Grain yield in treated plot}}{\text{Grain yield in hand weeded plot}} \times 100$$

The data collected were analyzed as per the standard procedure for analysis of variance as described by Gomez and Gomez (1984) and least significance difference ($p \leq 0.05$) was calculated to compare the differences among treatment means.

Results and Discussion

The grassy weeds, which were predominant in trial field were *Cynodon dactylon* (L.) Pers, *Echinochloa colona* (L.) Link and *Echinochloa crusgalli* (L.). Among different herbicidal treatments application of pendimethalin *fb* bispyribac-Na recorded significantly minimum population as well as biomass of grassy weeds, followed by butachlor *fb* bispyribac-Na (Table 1 and 2). The minimum density of grassy weeds was due to selectivity of herbicide and lowest dry biomass of grassy weeds might be due to low density of grasses as compared to non-grassy weeds. Though pendimethalin was applied as pre-emergence herbicide that prevent plant cell division and elongation by blocking microtubule assembly during weeds seed germination but being rainy season crop, it might degraded faster with increase in moisture level thus only manage initial flush of grassy weeds. However, sequential application of bispyribac-Na (after pendimethalin) effectively prolonged the period of effective weed control (Khaliq *et al*., 2012). Bispyribac-Na inhibits acetolactate synthase, an enzyme responsible for branched amino acid biosynthesis in emerged weeds (Rao *et al*., 2007); ultimately declined protein synthesis and growth causing death of grassy weeds (WSSA, 2007).

The sedges which were predominant during the experiment were *Cyperus rotundus* (L.), *Cyperus difformis* and *Fimbristylis maliaceae* (L.). Among different herbicidal treatments application of pendimethalin *fb* bispyribac-Na recorded significantly minimum population and biomass of sedges, this was followed by butachlor fb bispyribac-Na and found significantly superior over other herbicidal treatments (Table 1 and 2). This study revealed sequential application of pendimethalin *fb* bispyribac-Na reduced the sedge biomass (86.8%) and density (86.8%) due to broad-spectrum nature of bispyribac-Na when residual effect of pendimethalin in soil gets exhausted. Similarly, Jabran *et al*. (2012) found reduced sedge population in sequential applications.

Caesulia axillaris (L.) and *Phyllanthus niruri* were dominant broad leaf weeds during investigation period. Pre-emergence application of pendimethalin *fb* post- emergence

Table 1 : Effect of different weed management practices on weed density

Treatments	Density (No. m^{-2})			Total weed density
	Grasses	Sedges	Broad leaf weeds	
Pendimethalin *fb* Bispyribac-Na	2.54 (6.00)	2.48 (5.67)	3.39 (11.00)	4.81(22.67)
Pendimethalin *fb* 2, 4-D Na salt	3.34 (10.67)	4.53 (20.00)	3.03 (8.67)	6.31(39.33)
Pendimethalin *fb* straw mulch	3.63 (12.67)	5.67 (31.67)	5.58 (30.67)	8.69(75.00)
Pendimethalin *fb* Almix	3.24 (10.00)	4.14 (16.67)	2.91 (8.00)	5.93(34.67)
Butachlor *fb* Bispyribac-Na	3.03 (8.67)	4.06 (16.00)	3.72 (13.33)	6.20(38.00)
Butachlor *fb* 2, 4-D Na salt	3.53 (12.00)	4.85 (23.00)	3.53 (12.00)	6.89(47.00)
Butachlor *fb* straw mulch	3.81 (14.00)	5.37 (28.33)	5.99 (35.33)	8.84(77.67)
Butachlor *fb* Almix	3.67 (13.00)	5.05 (25.00)	3.72 (13.33)	7.20(51.33)
Mechanical weeding at 20 & 45 DAS	2.27 (4.67)	2.11 (4.00)	2.04 (3.67)	3.58(12.33)
Weed free	0.71 (0.00)	0.71 (0.00)	0.71 (0.00)	0.71(0.00)
Unweeded	5.21 (26.67)	6.60 (43.00)	8.38 (69.67)	11.83 (139.33)
SE(m) ±	0.08	0.07	0.07	0.07
LSD ($P \leq 0.05$)	0.22	0.20	0.20	0.22

*Data were subjected to square root (“x+0.5) transformation. Data given in parentheses are original value

Table 2 : Effect of different weed management practices on biomass of weeds

Treatments	Biomass ($g\ m^{-2}$)			Total weed biomass
	Grasses	Sedges	Broad leaf weeds	
Pendimethalin *fb* Bispyribac-Na	3.02 (8.64)	3.17 (9.58)	4.49 (19.76)	6.20(37.98)
Pendimethalin *fb* 2, 4-D Na salt	3.99 (15.43)	5.86 (33.87)	4.00 (15.55)	8.08(64.84)
Pendimethalin *fb* straw mulch	4.34 (18.31)	7.35(53.52)	7.44 (54.89)	11.28(126.72)
Pendimethalin *fb* Almix	3.87 (14.50)	5.35 (28.17)	3.85 (14.39)	7.58(57.06)
Butachlor *fb* Bispyribac-Na	3.61 (12.54)	5.24 (27.01)	4.94 (23.90)	7.99(63.44)
Butachlor *fb* 2, 4-D Na salt	4.23 (17.40)	6.27(38.90)	4.69 (21.55)	8.84(77.85)
Butachlor *fb* straw mulch	4.56 (20.29)	6.95 (47.92)	7.98 (63.25)	11.48(131.45)
Butachlor *fb* Almix	4.39 (18.79)	6.53 (42.18)	4.93 (23.83)	9.24(84.80)
Mechanical weeding at 20 & 45 DAS	2.69 (6.77)	2.68 (6.73)	2.65 (6.53)	4.53(20.03)
Weed free	0.71 (0.00)	0.71 (0.00)	0.71 (0.00)	0.71(0.00)
Unweeded	6.25 (38.62)	8.55 (72.70)	11.19 (124.70)	15.37 (236.02)
SE(m) ±	0.10	0.11	0.10	0.13
LSD ($P \leq 0.05$)	0.28	0.31	0.30	0.37

*Data were subjected to square root ("x+0.5) transformation. Data given in parentheses are original value

Table 3 : Effect of different weed management practices on weed control efficiency, weed index, grain and straw yield

Treatments	Weed control efficiency (%)	Weed index (%)	Grain yield ($t\ ha^{-1}$)	Straw yield ($t\ ha^{-1}$)
Pendimethalin *fb* Bispyribac-Na	84.50	1.11	3.68	4.87
Pendimethalin *fb* 2, 4-D Na salt	73.47	24.64	2.80	3.78
Pendimethalin *fb* straw mulch	47.22	30.28	2.60	3.48
Pendimethalin *fb* Almix	76.04	8.71	3.40	4.54
Butachlor *fb* Bispyribac-Na	73.20	5.49	3.52	4.79
Butachlor *fb* 2, 4-D Na salt	67.63	28.85	2.65	3.53
Butachlor *fb* straw mulch	44.55	35.56	2.40	3.33
Butachlor *fb* Almix	64.83	32.79	2.50	3.33
Mechanical weeding at 20 & 45 DAS	91.24	2.00	3.65	4.78
Weed free	100.00	0.00	3.70	4.90
Unweeded	0.00	65.37	1.30	1.74
SE(m) ±	-	-	0.12	0.07
LSD ($P \leq 0.05$)	-	-	0.36	0.21

application of almix was at par with the application of pendimethalin *fb* 2,4-D Na salt followed by pendimethalin *fb* bispyribac-Na and found to be significantly superior treatment which recorded lowest population of broad-leaf weeds over rest of the treatments. In the process of cell division during germination, pendimethalin disrupts the microtubules assembly of broad leaved weeds (Khaliq *et al.*, 2011). Similarly, bispyribac-Na is a member of pyrimidinyl oxybenzoic family that ultimately reduces photoassimilate translocation from source to sink, resulting in poor root and shoot growth of weeds including broad leaved (Darren and Stephen, 2006). These results are in conformity with the findings of Singh and Tewari (2005).

The total density and biomass of weeds were significantly influenced by weed control treatments during the investigation period at 60 DAS (Table 1 and 2). All weed management practices reduced the growth of weeds as compared to control. The lowest total weed density and biomass of weeds was recorded with mechanical weeding followed by pre-emergence application of pendimethalin *fb* bispyribac-Na as post-emergence. Application of pendimethalin *fb* bispyribac-Na registered 77.5%, 86.8%, 84.2% and 83.7% reduction in the densities and 77.6%, 86.8%, 84.1% and 83.9 % reduction in the biomass of grasses, sedges, broad leaf weeds and total weeds, respectively, over weedy check. Total weeds density and biomass is the summation of grasses, sedges and broad leaved weeds. Both pendimethalin and bispyribac-Na, broad spectrum herbicides, thus reduced total density and biomass. Keeping dynamic nature, weeds might shift their abundance but sequential application of pendimethalin and bispyribac-Na found promising in that case also as found lesser total weed count. Similarly, Khaliq *et al.* (2011) reported that application of pendimethalin 1.65 kg ha^{-1} *fb* bispyribac-Na 30 g ha^{-1} was quite effective in reducing weed count and biomass.

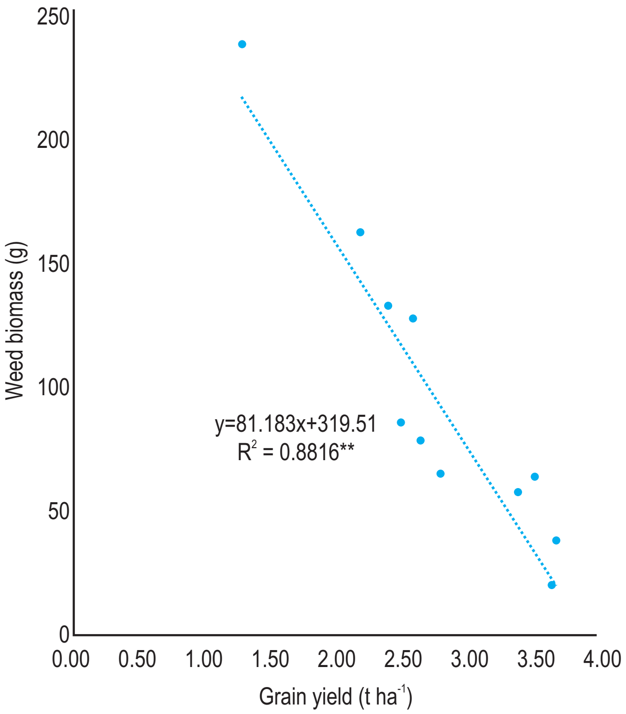


Fig. 1 : Relation between total weed biomass and grain yield (**Significant at P≤0.01).

Weed control efficiency (WCE) of different weed control treatments varied significantly during the observation period at 60 DAS (Table 3). Among herbicidal treatments, pre-emergence application of pendimethalin *fb* bispyribac-Na registered the highest weed control efficiency (84.50%), which was comparable with mechanical weeding (91.24%). The highest weed control efficiency might be attributed to sequential application of two herbicides at proper interval resulting in reduction of weed biomass which was in comparison to weed free check. Chauhan and Johnson (2011) also reported similar results in relation to weed control efficiency due to less dry matter production and population of weeds. Juraimi *et al.* (2013) reported higher selectivity of bispyribac-Na between rice and barnyard grass when applied at 2 to 4 leaf stage. In this study, application of post bispyribac-Na pendimethalin evidenced higher WCE by reducing total weed pressure at early growth stages of crop and later due to bispyribac-Na at standard rates.

Significantly lower values (1.11%) for weed index (Table 3) were recorded with pre-emergence application of pendimethalin *fb* bispyribac-Na, which was comparable with weed free indicating its superiority compared to rest of the weed control treatments, while unweeded check registered the highest weed index (65.37%) among all the weed control treatments. The lowest weed index showed minimum per cent of grain yield reduction due to minimum weed competition. These results were in corroboration with the findings of Nayak *et al.* (2014).

Among herbicidal treatments the maximum grain yield (3.68 t ha^{-1}) was obtained with application of pendimethalin *fb* bispyribac-Na, though it was at par with butachlor *fb* bispyribac-Na, pendimethalin *fb* Almix and mechanical weeding but significantly superior over rest of the treatments. However, these treatments were found numerically different from each other and yield loss was 65%, 63%, 62% and 65% in unweeded plot where weeds were allowed to grow throughout the crop growth period as compared to Pendimethalin *fb* Bispyribac-Na, Butachlor *fb* Bispyribac-Na, Pendimethalin *fb* Almix and Mechanical weeding respectively. Results clearly show that if initial flush of weed is controlled either by chemically or mechanically then better crop can be harvested. The weeds emerged subsequently did not affect the rice yield to that extent as by early weeds. This can be further explained by Fig. 1 in terms of negative correlation between total weed biomass and rice grain yield (R^2 = 0.881). However, weed free plot showed the highest grain yield (3.70 t ha^{-1}) among all the treatments. This study found statistical similar yield of pendimethalin *fb* bispyribac-Na to weed free treatment due to better efficacy and proved to be an important management practice for safeguarding rice yields. No or reduced control of weeds continuously compete with crop for both above and below ground resources. Thus, T_1 showed yield superiority of 183.07% over weedy check. This obtained range corroborates previous studies of Rao *et al.* (2007) and Chauhan and Opena (2012).

Similarly, the maximum straw yield (4.87 t ha^{-1}) was recorded with the application of pendimethalin *fb* bispyribac-Na which was significantly superior to rest of the treatments and remained at par, but numerically different with butachlor *fb* bispyribac-Na and mechanical weeding. Sequential application of pendimethalin *fb* bispyribac-Na at standard rate showed its greater efficacy thus subsequently reduced crop-weed competition for light, water and nutrients that ultimately promoted the growth and its attributes of crop which enhanced straw yield. Kamboj *et al.* (2012) also reported significantly higher grain yield and straw yield with sequential herbicide application as it provides competition-free environment, with larger availability of water, essential nutrients, solar radiation and shade that can ultimately reduce weed competition and enable aerobic rice for better utilization of nutrient and other inputs.

Sequential application of pendimethalin @1.00 kg a.i. ha^{-1} *fb* bispyribac-Na @35 g a.i. ha^{-1} found best for minimizing weed infestation and achieving better weed control efficiency and grain yield for broadening the weed management options in aerobic rice.

Acknowledgment

Authors are grateful to the Department of Agronomy, Institute of Agricultural Sciences, Banaras Hindu University, Varanasi, U.P for funding and providing necessary facilities for research work.

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