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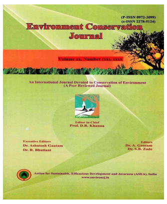

Performance of herbicides for managing weed flora in transplanted *aman* paddy (*Oryza sativa L.*)

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ABSTRACT

A field investigation was performed during the rainy seasons of 2018 and 2019 at the Instructional Farm, Bidhan Chandra Krishi Viswavidyalaya, Jaguli, Nadia, West Bengal, India (22^{0}56'N and 86^{0}48'E, 9.75m above mean sea level) with the aim of determining the comparative effectiveness of different herbicides in controlling various kinds of weeds (grass, sedge and broad-leaf) in the transplanted *aman* paddy. The experiment was laid out in Randomized Block Design having sixteen treatments with three replication, that includes application of either pre-emergence [butachlor, pretilachlor, pyrazosulfuron ethyl and ready mix (RM) of bensulfuron methyl + pretilachlor at 2 days after transplanting (DAT)] or post-emergence [bispyribac sodium and bispyribac sodium + penoxsulum at 20 DAT] herbicides followed by hand weeding at 40 DAT; application of both pre-emergence and post-emergence herbicides; hand weeding at 20 and 40 DAT and weedy check. Hand weeding at 20 and 40 DAT registered significantly lower weed density, weed dry matter and the highest weed control efficiency. Among the herbicidal treatments, ready-mix formulation of bensulfuron methyl 0.6% + pretilachlor 6% (Londax power 6.6%) performed better in controlling weeds of all categories and recorded higher paddy (3.96 t/ha) and straw yield (4.92 t/ha) with the lowest weed index which were statistically at par with the hand weeded treatment. Hence, to fetch the effective suppression of weed, application of Londax power 6.6% @ 0.66 kg a.i./ha as pre-emergence (at 2 DAT) with hand weeding at 40 DAT can easily replace additional one hand weeding at 20 DAT.

Introduction

Paddy (*Oryza sativa* L.) is an essential food grain for majority of the human population of the world, specifically in South East Asia. After wheat, it is the second most widely consumed cereal in the world (Anonymous, 2014a). The world's 112 rice-producing nations cover all seven continents, and 2.5 billion people living in developing nations consume it, with 90% of them residing in Asia and the remaining 10% in Africa, Australia, North and South America and Europe. It contributes roughly 45% of the nation's total grain production and grows on 44.1 million hectares of land, yielding 106.64 million tons of product each year at 2.42 tons/ha of productivity (Bhatt *et al.*, 2017). By 2040, 96 million tons more of milled rice will be required to supply the world's demand for rice than in 2015 (Valera and Belie, 2020). Globally, India ranks first in paddy in terms of acreage and second in terms of production next to China. India accounts for 21% of global rice production from 28% of rice area and West Bengal is the leading state, contributing 13.8% to all India rice production.

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However, weeds are pervasive and insidious oppressor on Earth and are known as important biological obstacles which prevent the yield of paddy with the optimum quality and productivity (Rao & Nagamani, 2013). Thus, weed control at right time is crucial for achieving the desired amount of productivity. One of the major obstacles to effective rice cultivation is heavy weed infestation (Parthipan *et al.*, 2013). They have a significant impact and, on average, lower agricultural productivity by more than 35% (Sattin and Berti, 2003). Under transplanted conditions, unchecked weeds compete with paddy and reduced grain yields by 76% (Mukherjee & Singh, 2005). The efficient control of weeds at early phases [0-40 days after transplanting (DAT)] can help in enhancing the productivity of this crop. Weed removal by manually is labor-intensive, and tiresome. An herbicide is chosen on the basis of type and the extent of weed infestation in the rice field. Herbicides are efficient against different weed species, however the majority of them target a limited number of weed species (Mukherjee and Singh, 2005). Since manual and other weed control procedures are time consuming, cumbersome and expensive, while chemicals are the absolute alternative and indispensable weed management methods. Thus, effective weed management usually calls for a combination of chemical and manual control in order to avoid development of herbicide resistance and lessen the herbicide load in the agro-ecosystem (Rao *et al.*, 2007). Therefore, the present study was carried out to evaluate the efficacy of herbicides with proper dose for broad spectrum control of weed flora and to identify the effective weed management practice which will ensure satisfactory yield of transplanted *aman* rice.

Material and Methods

Experimental Site

A two-year investigation entitled 'Performance of herbicides for managing weed flora in transplanted aman paddy (*Oryza sativa L.*)' was performed during the *kharif* (Aman) period of 2018 and 2019 at the Instructional Farm, Bidhan Chandra Krishi Viswavidyalaya, Jaguli, Nadia, West Bengal, India (22^0 56' N and 86^0 48' E, 9.75m from mean sea level). The investigation was carried out just south of the tropic of cancer under tropical humid climate in fairly uniform topographical condition having sandy clay-loam texture with excellent water retention capacity, neutral in reaction and moderate soil fertility during the months from July to November. The rainfall was distributed throughout the experimental period in both the year. The average maximum temperature for the course of investigation varied from 30 to 33°C and the range of average minimum temperature for the similar time period was 14 to 23°C. Some important meteorological parameters during the time of experiment are presented in the Figure 1.

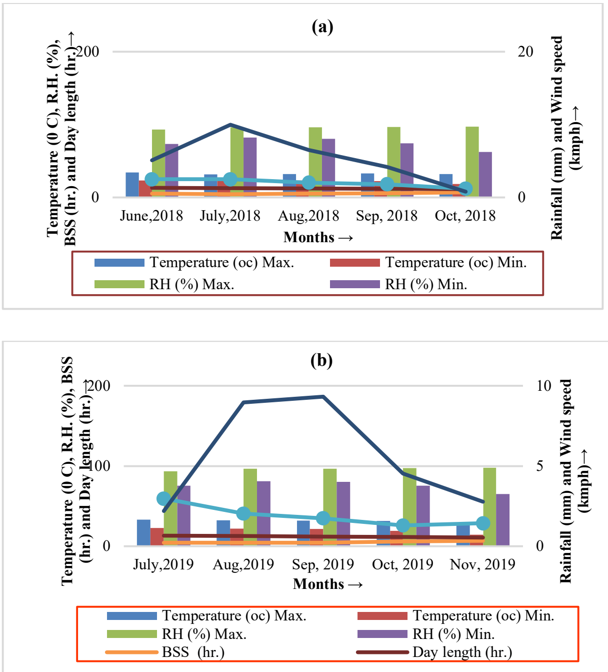

Figure 1: Meteorological observations of (a) 2018 and (b) 2019 during the course of investigation

Experiment details

The semi-dwarf, short duration (110-115 days) and high yielding rice variety Satabdi (IET-4786) was selected and 25 days old seedlings were transplanted with the spacing of 20 cm × 15 cm. Fertilizers used were Urea, Single Super Phosphate and Muriate of Potash with the recommended dosage of N: P_2O_5: K_2O @ 60: 30: 30 kg/ha. Randomized Block Design (RBD) was adopted for the lay out with sixteen treatment combinations (Table 1) replicated three times with the plot size 4 m × 5 m each. Weed control measures include four pre-emergence herbicides (pyrazosulfuron ethyl,

Table 1: Treatment details – herbicide dosage, application time and their combination with hand weeding

Treatment	Herbicide combinations
T_1	Butachlor 50 EC @ 1500 g a.i./ha at 2 DAT + hand weeding at 40 DAT
T_2	Pretilachlor 50 EC @ 750 g a.i./ha at 2 DAT + hand weeding at 40 DAT
T_3	Pyrazosulfuron ethyl 10 WP @ 25 g a.i./ha at 2 DAT + hand weeding at 40 DAT
T_4	Londax power 6.6 % (Bensulfuron methyl + Pretilachlor) [RM] @ 660 g a.i./ha at 2 DAT + hand weeding at 40 DAT
T_5	Bispyribac sodium 10 SC @ 25 g a.i./ha at 20 DAT + hand weeding at 40 DAT
T_6	(Bispyribac sodium 9.5 SC + Penoxsulum 7.8 SC) [RM] @ (23.75 + 19.50) g a.i./ha at 20 DAT + hand weeding at 40 DAT
T_7	Butachlor 50 EC @ 1500 g a.i./ha at 2 DAT + Bispyribac sodium 10 SC @ 25 g a.i./ha at 20 DAT
T_8	Pretilachlor 50 EC @ 750 g a.i./ha at 2 DAT + Bispyribac sodium 10 SC @ 25 g a.i./ha at 20 DAT
T_9	Pyrazosulfuron ethyl 10 WP @ 25 g a.i./ha at 2 DAT + Bispyribac sodium 10 SC @ 25 g a.i./ha at 20 DAT
T_{10}	Londax power 6.6 % [RM] + Bispyribac sodium 10 SC @ 25 g a.i./ha at 20 DAT
T_{11}	Butachlor 50 EC@ 1500 g a.i./ha at 2 DAT + (Bispyribac sodium 9.5 SC + Penoxsulum 7.8 SC) [RM] @ (23.75 + 19.50) g a.i./ha at 20 DAT
T_{12}	Pretilachlor 50 EC @ 750 g a.i./ha at 2 DAT + (Bispyribac sodium 9.5 SC + Penoxsulum 7.8 SC) [RM] @ (23.75 + 19.50) g a.i./ha at 20 DAT
T_{13}	Pyrazosulfuron ethyl 10 WP @ 25 g a.i./ha at 2 DAT + (Bispyribac sodium 9.5 SC + Penoxsulum 7.8 SC) [RM] @ (23.75 + 19.50) g a.i./ha at 20 DAT
T_{14}	Londax power 6.6 % [RM] + (Bispyribac sodium 9.5 SC + Penoxsulum 7.8 SC) [RM] @ (23.75 + 19.50) g a.i./ha at 20 DAT
T_{15}	Hand weeding at 20 and 40 DAT
T_{16}	Weedy check

***DAT: Days after transplanting; EC: Emulsifiable concentrate; WP: Wettable powder; SC: Soluble concentrate**

pretilachlor, butachlor and ready mix (RM) of Bensulfurron methyl + Pretilechlor i.e londax powder. two post-emergence herbicides bispyribac sodium and ready mix (RM) bispyribac sodium + penoxsulum) and hand weeding (HW) at 20 and 40 DAT.

Sampling and measurement on weeds

Weeds appeared in the experimental field were identified and by keeping a quadrate of 0.5 m × 0.5 m size at random places of the experimental plots, weed count or density (number/m^2) and biomass (g/m^2) were collected category wise - grass, sedges and broad leaved at the interval of 15 days (from 30 to 90 DAT). From this, total weed count (number/m^2) and biomass (g/m^2) were worked out. Following are the various weed indices that were calculated using the weed data and standard methods:

Weed control efficiency (WCE):

It was computed using the methodology given by Mani *et al*., (1973) and it is expressed as percentage (%)-

$$\mathbf{WCE} = \frac{(\mathbf{DWC} - \mathbf{DWT})}{\mathbf{DWC}} \times \mathbf{100}$$

Where,
WCE = Weed control efficiency (%)
D_{WC} = Weed dry matter (unit/m^2) in control plot
D_{WT} = Weed dry matter (unit/m^2) in treated plot

Weed index (WI):

Weed index was calculated on the basis of yield drop in comparison to weed-free treatment and expressed in percentage. It was determined utilizing the formula provided by Gill and Kumar (1969).

$$\mathbf{WI} = \frac{\mathbf{X} - \mathbf{Y}}{\mathbf{X}} \times \mathbf{100}$$

Where,
WI = Weed Index (%)
X = Crop yield (t/ha) from weed free plot (hand weeded plot)
Y = Crop yield (t/ha) from treated plot

Yield and harvest index:

The harvesting was done at 94 DAT and 91 DAT during the year 2018 and 2019 respectively with the aid of a sickle. Grain and straw yield (t/ha) yields were documented when the crops were harvested. Harvest index (HI %), given by Donald (1962), was determined using the formula below:

$$\text{HI (\%)} = \frac{\textbf{Economic yield (grain yield)}}{\textbf{Biological yield (grain + straw yield)}} \times 100$$

Statistical analysis

The data were statistically analyzed utilizing Randomized Block Design of Panse & Sukhatme (1985). Data regarding weed count (number/m^2) were analyzed after transforming this using 'Square root transformation (SQRT)' method i.e., $\sqrt{(x + 0.5)}$. Fisher & Snedecor's F-test, with a 5% level of probability, was used to determine the significance of various sources of variation. The Fisher & Yates (1953) statistical table was used for the ascertainment of critical difference (C.D.) at the 5% level of significance. In this tables, mean values were compared with the result of standard error of mean S.Em. (±).

Results and Discussion

Weed flora

The rate of reduction of plant growth and yield mainly depends on the type of weeds prevalent in the field. In both of the experimental years, the field was dominated with mixed weed flora *viz.* grasses, sedges and broad leaved weeds. Eleven (11) species of weeds had been identified in the experimental field among which four (4) species were found to be grassy weed category, three (3) species from sedges and four (4) species from broad leaved category of weeds which were barnyard grass (*Echinochloa crusgalli*), jungle rice (*Echinochloa colonum*), bermuda grass (*Cynodon dactylon)* and southern cut grass (*Leersia hexandra*) among grassy weeds; rice flatsedge (*Cyperus iria*), tall fringe rush (*Fimbristylis miliacea*) and softstem bulrush (*Scirpus juncoides*) among sedge weeds; blistering ammannia (*Ammannia baccifera*)*,* swamp morning-glory (*Ipomea aquatica*)*,* banana plant (*Nymphoides indica*) and pickerel weed (*Pontederia cordata*) among broad leaved weeds which might be due to their seasonal preferences and favourable condition of growth. These outcomes are in agreement with the findings of Ghosh & Ghosh (2005); Mukherjee *et al.* (2008) and Pal *et al.* (2009a) where they observed that the rice fields were seriously infested by similar weed species (like *Echinochloa sp., Cynodon sp., Cyperus sp., Ammannia sp. Fimbristylis sp.* etc.) under lowland condition because of their long emergence profile under ideal soil and climatic condition.

Weed density (number/m^2)

Broad leaved weed population was found to be higher than grassy and sedge weeds for all the weed management methods (Table 2). Increment in weed population was also observed with the advance of growth stages in all weed management techniques, with the exception of twice HW (T_{15}) as the grassy and broad leaved weed counts were decreased in this treatment at 45 DAT and thereafter, it also increased subsequently. The highest weed count was registered in weedy check (T_{16}) and was substantially greater than any other treatments whereas hand weeded plot (T_{15}) registered the lowest count which was at par with the treatment where ready mix (RM) herbicide Londax power (bensulfuron methyl 0.6% + pretilachlor 6%) was used as pre-emergence herbicide followed by one HW (T_4).

Among herbicidal treatments, Londax power [RM] (at 2 DAT) with one HW (at 40 DAT) registered minimum number of total weed population (Table 3) in all the observations (2.82, 3.25, 4.47, 5.6 and 6.83 /m^2 at 30, 45, 60, 75 and 90 DAT, respectively) as it is an acetolactate synthase (ALS) inhibiting herbicide which provides effective solution for weed control in rice by inhibiting the growth of the most important perennial and annual species of weeds and it was statistically at par with pre-emergence application of pretilachlor or pyrazosulfuron ethyl with HW at 40 DAT (T_2 and T_3), these outcomes are in compliance with Shekhra *et al.* (2011) and Mishra (2019). The RM of bispyribac sodium and penoxsulum at 20 DAT with HW at 40 DAT (T_6) showed profound effect in controlling weeds as compared to bispyribac sodium (at 20 DAT) followed by HW at 40 DAT (T_5). Londax power [RM] followed by RM of bispyribac sodium and penoxsulum (T_{14}) performed well as compared to Londax power [RM] followed by only bispyribac sodium (T_{10}). Butachlor at 2 DAT followed by bispyribac sodium at 20 DAT (T_7) recorded the highest total weed density (Table 3).

Weed dry matter (g/m^2)

Hand weeded plot (two HW at 20 and 40 DAT) registered the least dry weight of all categories of

Table 2: Effect of weed control treatments on density (number/m^2) of different categories of weeds in transplanted winter paddy (pooled data over 2018 and 2019)

Treatments	Density of Grassy Weeds (number/m^2)					Density of Sedge Weeds (number/m^2)					Density of Broad leaved Weeds (number/m^2)				
	30DAT	**45DAT**	**60DAT**	**75DAT**	**90DAT**	**30DAT**	**45DAT**	**60DAT**	**75DAT**	**90DAT**	**30DAT**	**45DAT**	**60DAT**	**75DAT**	**90DAT**
T_1	3.28 (10.23)	4.02 (15.63)	4.38 (18.31)	5.66 (31.58)	6.19 (37.86)	2.61 (6.31)	2.83 (7.50)	3.00 (8.51)	4.11 (16.42)	4.63 (20.94)	1.91 (3.14)	2.3 (4.79)	3.07 (8.93)	3.34 (10.68)	3.84 (14.25)
T_2	2.64 (6.45)	3.03 (8.68)	3.65 (12.82)	4.78 (22.34)	5.40 (28.70)	1.93 (3.22)	2.09 (3.86)	2.49 (5.71)	3.28 (10.25)	3.97 (15.23)	1.63 (2.17)	1.92 (3.19)	2.53 (5.91)	2.8 (7.32)	3.47 (11.52)
T_3	3.02 (8.62)	3.65 (12.82)	4.16 (16.82)	5.18 (26.34)	5.79 (32.98)	2.3 (4.79)	2.46 (5.56)	2.71 (6.87)	3.84 (14.26)	4.28 (17.81)	1.84 (2.89)	2.11 (3.94)	2.76 (7.12)	2.94 (8.14)	3.55 (12.13)
T_4	2.17 (4.22)	2.59 (6.21)	3.48 (11.59)	4.31 (18.10)	5.03 (24.80)	1.69 (2.36)	1.59 (2.03)	1.91 (3.15)	2.74 (7.03)	3.38 (10.96)	1.18 (0.89)	1.53 (1.84)	2.3 (4.78)	2.49 (5.71)	3.31 (10.44)
T_5	4.04 (15.79)	4.62 (20.84)	5.30 (27.64)	6.34 (39.65)	6.73 (44.76)	3.09 (9.03)	3.38 (10.94)	3.42 (11.21)	5.33 (27.87)	5.54 (30.20)	2.51 (5.83)	2.84 (7.57)	3.46 (11.54)	3.54 (12.03)	4.17 (16.92)
T_6	3.51 (11.79)	4.16 (16.82)	4.94 (23.92)	6.00 (35.56)	6.36 (39.94)	2.82 (7.47)	3.06 (8.90)	3.21 (9.79)	4.61 (20.73)	4.96 (24.12)	2.17 (4.21)	2.41 (5.31)	3.21 (9.83)	3.36 (10.81)	4.03 (15.78)
T_7	5.19 (26.45)	6.23 (38.32)	7.84 (61.02)	8.41 (70.26)	8.71 (75.39)	4.48 (19.61)	4.72 (21.82)	5.43 (28.97)	6.54 (42.27)	7.27 (52.38)	3.57 (12.23)	4.29 (17.91)	4.51 (19.89)	4.91 (23.67)	5.67 (31.64)
T_8	4.81 (22.67)	5.78 (32.88)	7.31 (52.91)	8.01 (63.68)	8.23 (67.28)	4.13 (16.53)	4.35 (18.45)	4.86 (23.10)	6.35 (39.79)	6.71 (44.58)	3.34 (10.63)	4.05 (15.93)	4.18 (16.98)	4.52 (19.90)	5.01 (24.62)
T_9	5.03 (24.82)	6.01 (35.66)	7.59 (57.05)	8.23 (67.26)	8.45 (70.89)	4.33 (18.25)	4.44 (19.21)	5.09 (25.45)	6.37 (40.11)	6.84 (46.32)	3.47 (11.55)	4.23 (17.38)	4.28 (17.84)	4.68 (21.38)	5.29 (27.48)
T_{10}	4.35 (18.45)	5.18 (26.31)	6.01 (35.66)	6.94 (47.64)	7.13 (50.34)	3.47 (11.57)	3.82 (14.16)	4.04 (15.87)	5.71 (32.14)	6.03 (35.87)	2.84 (7.57)	3.28 (10.28)	3.69 (13.12)	3.92 (14..86)	4.47 (19.45)
T_{11}	4.68 (21.45)	5.67 (31.64)	6.93 (47.56)	8.17 (60.22)	7.92 (62.27)	4.02 (15.68)	4.26 (17.61)	4.68 (21.40)	6.14 (37.17)	6.54 (42.31)	3.23 (9.97)	3.9 (14.68)	4.08 (16.18)	4.45 (19.31)	4.82 (22.74)
T_{12}	4.50 (19.79)	5.30 (27.64)	6.23 (38.32)	7.22 (51.62)	7.40 (54.25)	3.68 (13.02)	4.01 (15.62)	4.34 (18.32)	5.91 (34.43)	6.23 (38.32)	2.96 (8.25)	3.51 (11.82)	3.84 (14.23)	4.14 (16.63)	4.57 (20.38)
T_{13}	4.62 (20.87)	5.55 (30.31)	6.54 (42.23)	7.53 (56.27)	7.67 (58.27)	3.84 (14.28)	4.12 (16.51)	4.47 (19.52)	5.98 (35.29)	6.36 (39.98)	3.09 (9.04)	3.68 (13.02)	4.01 (15.54)	4.22 (17.34)	4.71 (21.69)
T_{14}	4.02 (16.78)	4.81 (23.64)	5.46 (30.31)	6.66 (43.56)	6.75 (47.09)	3.29 (10.31)	3.66 (12.92)	3.91 (14.77)	5.52 (30.02)	5.75 (32.58)	2.68 (6.70)	3.1 (9.11)	3.64 (12.79)	3.66 (12.93)	4.34 (18.34)
T_{15}	1.93 (3.22)	1.18 (0.89)	2.45 (5.52)	3.47 (11.52)	4.11 (16.44)	1.18 (0.89)	0.71 (0)	1.56 (1.92)	2.43 (5.41)	2.95 (8.23)	1.08 (0.67)	0.71 (0)	1.69 (2.37)	2.04 (3.68)	2.73 (6.94)
T_{16}	6.43 (40.81)	7.20 (51.34)	8.85 (77.89)	9.71 (93.79)	11.59 (133.84)	4.89 (23.40)	5.75 (32.57)	6.43 (40.87)	8.29 (68.29)	9.84 (96.38)	4.14 (16.67)	4.59 (20.54)	6.15 (37.33)	6.87 (46.37)	8.31 (68.23)
S. Em. (±)	0.36	0.29	0.32	0.34	0.33	0.14	0.17	0.18	0.21	0.27	0.12	0.13	0.16	0.14	0.15
C.D. at 5 %	1.03	0.84	0.90	0.96	0.95	0.41	0.50	0.53	0.61	0.77	0.34	0.39	0.46	0.41	0.44

Figures in parentheses indicate original values of weed count/ m^2. Square Root transformed data [$\sqrt{(x + 0.5)}$] has been used for analysis.

Table 3. Effect of weed control treatments on total weed density (number/m²) in transplanted winter paddy (pooled data over 2018 and 2019)

Treatment	30 DAT	45 DAT	60 DAT	75 DAT	90 DAT
T_1	4.49 (19.68)	5.33 (27.92)	6.02 (35.75)	7.69 (58.68)	8.58 (73.05)
T_2	3.51 (11.84)	4.02 (15.73)	4.99 (24.44)	6.35 (39.91)	7.48 (55.45)
T_3	4.1 (16.3)	4.77 (22.32)	5.59 (30.81)	7.01 (48.74)	7.96 (62.92)
T_4	2.82 (7.47)	3.25 (10.08)	4.47 (19.52)	5.6 (30.84)	6.83 (46.2)
T_5	5.58 (30.65)	6.31 (39.35)	7.13 (50.39)	8.94 (79.55)	9.61 (91.88)
T_6	4.89 (23.47)	5.61 (31.03)	6.64 (43.54)	8.22 (67.1)	8.96 (79.84)
T_7	7.67 (58.29)	8.86 (78.05)	10.51 (109.88)	11.69 (136.2)	12.64 (159.41)
T_8	7.09 (49.83)	8.23 (67.26)	9.67 (92.99)	11.13 (123.37)	11.7 (136.48)
T_9	7.42 (54.62)	8.53 (72.25)	10.04 (100.34)	11.37 (128.75)	12.05 (144.69)
T_{10}	6.17 (37.59)	7.16 (50.75)	8.07 (64.65)	9.75 (94.64)	10.30 (105.66)
T_{11}	6.9 (47.10)	8.03 (63.93)	9.25 (85.14)	10.82 (116.7)	11.30 (127.32)
T_{12}	6.45 (41.06)	7.45 (55.08)	8.45 (70.87)	10.16 (102.68)	10.65 (112.95)
T_{13}	6.68 (44.19)	7.77 (59.84)	8.82 (77.29)	10.46 (108.9)	10.97 (119.94)
T_{14}	5.85 (33.79)	6.79 (45.67)	7.64 (57.87)	9.33 (86.51)	9.92 (98.01)
T_{15}	2.3 (4.78)	1.18 (0.89)	3.21 (9.81)	4.59 (20.61)	5.92 (34.61)
T_{16}	9.02 (80.88)	10.24 (104.45)	12.51 (156.09)	14.45 (208.45)	17.29 (298.45)
S.Em. (±)	0.25	0.29	0.26	0.31	0.32
CD at 5%	0.72	0.84	0.75	0.88	0.91

Figures in parentheses indicate original values of weed count/m². Square Root transformed data [$\sqrt{(x + 0.5)}$] has been used for analysis.

weeds (Table 4), which, however, was followed by of Londax power [RM] with one HW (T_4) as it is highly selective to most varieties of Indian rice and most of the annual and perennial weed species can effectively be controlled.Increasing trend of total weed biomass with advancement of growth stages had been noticed (Table 5). Whereas, it was decreased at 45 DAT in HW at 20 & 40 DAT (T_{15}), however it has been increased from 60 to 90 DAT due to occurrence, growth and development of several late flushes of weeds in the rice field. The maximum total weed biomass was acquired from weedy check (T_{16}) at all the five observations (21.51, 26.71, 31.03, 35.64 and 41.24 g/m² at 30, 45, 60, 75 & 90 DAT, respectively) that was considerably greater than rest of the treatments. Londax power 6.6% [RM] at 2 DAT with HW at 40 DAT (T_4) recorded the minimum total weed biomass among the herbicidal treated plots which reflect its superiority of controlling weeds than the other herbicides and it was also reported by Singh *et al.* (2010) and Mishra (2019).

Effect on weed control efficiency (WCE, %)

The highest WCE was obtained at 45 DAT, however, it started to decline from 60 DAT onwards and this trend was found in both the years of investigation (Table 5) which might be due to emergence of some new weed species at later by different weeding treatments. Among various weed control practices, HW at 20 and 40 DAT (T_{15}) was the most efficient and registered highest WCE (85.54, 92.18, 85.08, 75.62 and 69.18 % at 30, 45, 60, 75 and 90 DAT, respectively) at all the intervals followed by Londax power at 2 DAT with HW at 40 DAT (T_4) recorded the highest WCE (81.68, 85.02, 80.15, 70.29 and 64.99 % at 60, 75 and 90 DAT, respectively) which confirmed the opinion of

Table 4: Effect of weed control treatments on weed dry matter (g/m^2) of different categories of weeds in transplanted winter paddy (pooled data over 2018 and 2019)

Treatments	Dry weight of Grassy Weeds (g/m^2)					Dry weight of Sedge Weeds (g/m^2)					Dry weight of Broad leaved Weeds (g/m^2)				
	30DAT	45DAT	60DAT	75DAT	90DAT	30DAT	45DAT	60DAT	75DAT	90DAT	30DAT	45DAT	60DAT	75DAT	90DAT
T_1	2.12	2.18	3.21	5.48	7.13	1.62	1.82	2.55	3.76	5.37	1.60	1.88	2.28	3.77	4.84
T_2	1.78	1.83	2.71	4.92	6.88	1.36	1.48	2.07	3.07	4.65	1.38	1.52	1.98	3.12	3.96
T_3	1.95	2.08	2.97	5.00	6.92	1.48	1.66	2.34	3.41	5.05	1.44	1.68	2.14	3.48	4.54
T_4	1.53	1.41	2.48	4.75	6.32	1.25	1.16	1.81	2.90	4.24	1.16	1.43	1.87	2.94	3.88
T_5	2.46	2.54	3.54	5.56	7.43	1.98	2.25	3.33	4.56	5.84	2.05	2.52	2.92	4.21	5.17
T_6	2.24	2.33	3.35	5.41	7.24	1.77	2.02	2.84	3.98	5.51	1.82	2.04	2.54	3.96	4.98
T_7	3.89	4.48	4.82	6.91	9.89	4.01	5.11	6.78	7.86	8.92	3.49	4.32	5.23	6.12	7.64
T_8	3.45	3.91	4.42	6.55	9.20	3.42	4.48	5.86	6.93	7.98	3.18	3.87	4.50	5.41	6.78
T_9	3.64	4.05	4.66	6.77	9.56	3.78	4.82	6.33	7.41	8.23	3.26	4.10	4.94	5.87	7.13
T_{10}	2.84	2.95	3.88	5.95	8.05	2.56	2.73	4.21	5.48	6.72	2.45	2.83	3.32	4.69	5.72
T_{11}	3.38	3.68	4.27	6.43	8.94	3.15	3.94	5.32	6.75	7.71	3.09	3.56	4.29	4.98	6.55
T_{12}	2.98	3.04	3.95	6.09	8.18	2.84	3.04	4.78	5.91	6.96	2.64	3.01	3.68	4.88	5.91
T_{13}	3.13	3.22	4.13	6.36	8.62	2.97	3.37	4.95	6.34	7.35	2.89	3.28	3.95	5.03	6.24
T_{14}	2.75	2.86	3.72	5.85	7.81	2.13	2.42	3.86	4.96	6.23	2.18	2.69	3.11	4.48	5.53
T_{15}	1.22	0.64	1.86	3.73	5.82	0.77	0.58	1.45	2.58	3.44	1.12	0.87	1.32	2.38	3.45
T_{16}	6.96	8.17	9.73	11.58	13.42	8.32	10.43	12.05	13.24	14.98	6.23	8.11	9.25	10.82	12.84
S. Em. (±)	0.12	0.11	0.15	0.21	0.28	0.10	0.11	0.16	0.19	0.21	0.10	0.11	0.13	0.17	0.21
C.D. at 5 %	0.33	0.32	0.44	0.62	0.79	0.28	0.29	0.47	0.54	0.62	0.29	0.32	0.39	0.49	0.62

Table 5. Effect of weed control treatments on total weed biomass (g/m^2) and weed control efficiency (%) in transplanted winter paddy

Treatments	Total weed biomass (g/m^2)					Weed control efficiency (%)				
	30 DAT	45 DAT	60 DAT	75 DAT	90 DAT	30 DAT	45 DAT	60 DAT	75 DAT	90 DAT
T_1	5.34	5.88	8.04	13.01	17.34	75.17	77.99	74.09	63.5	57.95
T_2	4.52	4.83	6.76	11.11	15.49	78.99	81.92	78.21	68.83	62.44
T_3	4.87	5.42	7.45	11.89	16.51	77.36	79.71	75.99	66.64	59.97
T_4	3.94	4	6.16	10.59	14.44	81.68	85.02	80.15	70.29	64.99
T_5	6.49	7.31	9.79	14.33	18.44	69.83	72.63	68.45	59.79	55.29
T_6	5.83	6.39	8.73	13.35	17.73	72.9	76.08	71.87	62.54	57.01
T_7	11.39	13.91	16.83	20.89	26.45	47.05	47.92	45.76	41.39	35.86
T_8	10.05	12.26	14.78	18.89	23.96	53.28	54.1	52.37	47	41.9
T_9	10.68	12.97	15.93	20.05	24.92	50.35	51.44	48.66	43.74	39.57
T_{10}	7.85	8.51	11.41	16.12	20.49	63.51	68.14	63.23	54.77	50.32
T_{11}	9.62	11.18	13.88	18.16	23.20	55.28	58.14	55.27	49.05	43.74
T_{12}	8.46	9.09	12.41	16.88	21.05	60.67	65.97	60.01	52.64	48.96
T_{13}	8.99	9.87	13.03	17.73	22.21	58.21	63.05	58.01	50.25	46.14
T_{14}	7.06	7.97	10.69	15.29	19.57	67.18	70.16	65.55	57.1	52.55
T_{15}	3.11	2.09	4.63	8.69	12.71	85.54	92.18	85.08	75.62	69.18
T_{16}	21.51	26.71	31.03	35.64	41.24	--	--	--	--	--
S. Em. (±)	0.26	0.27	0.36	0.53	0.61	2.30	2.06	2.03	1.70	1.58
C.D. at 5 %	0.74	0.78	1.04	1.52	1.76	6.64	5.96	5.87	4.94	4.61

Mishra (2019) whereas butachlor at 2 DAT followed by bispyribac sodium at 20 DAT (T_7) recorded the lowest (47.05, 47.92, 45.76 , 41.39 and 35.86 % at 30, 45, 60, 75 and 90 DAT, respectively) WCE among the herbicidal plots. Post-emergence herbicidal plots with HW at 40 DAT (T_5 and T_6), registered lower WCE than the pre-emergence herbicidal plots with HW at 40 DAT (T_1, T_2, T_3 and T_4). However, application of pre-emergence herbicide or post-emergence herbicide followed by HW at 40 DAT were recorded higher WCE than the both pre- and post-emergence herbicides treated plots (T_7, T_8, T_9, T_{10}, T_{11}, T_{12}, T_{13} and T_{14}). So, it was evident that application of pre-emergence herbicide with HW at 40 DAT was the effective weed control strategy which might be attributed to lowering down of weed density which ultimately increase the weed control efficiency. This result corroborated the findings of Hasanuzzaman *et al*. (2007 and 2009).

Effect on yield (t/ha), harvest index (%) and weed index (WI, %)

According to study, in weedy check plot, weed infestation led to 47.17 % loss of rice grain yield in comparison to HW at 20 and 40 DAT (Table 6). Similar yield reduction in rainy season rice due to crop-weed competition in lateritic belt of West Bengal was also reported by Duary *et al*. (2009) and Mandal *et al*. (2013). Whereas, HW at 20 and 40 DAT (T_{15}) registered maximum grain as well as straw yield (t/ha) that was proceeded by application of Londax power (RM) with HW at 40 DAT (T_4). This could be due to less crop-weed competition for limited resources which promotes good crop growth and its development resulted into higher number of effective tillers per plant and maximum grain this is in compliance with the result registered by Reddy *et al.* (2012) and Mishra (2019). Harvest index of the rice crop during the experimentation varied between 37.72 to 45.02% and the highest value had been registered from plot with twice HW at 20 and 40 DAT whereas the lowermost was observed in weedy check (Table 6). Among herbicides, the maximum HI (44.59 %) was recorded from Londax power (RM) with single HW (T_4) followed by pretilachlor with HW once (T_2). This is due to higher grain as well as straw yield of rice obtained from T_4 which was statistically at par with the treatment with two HW at 20 and 40 DAT. The least value of Weed Index was recorded under T_4 (1.57 %) followed by T_2, T_3 and T_1 (2.90, 4.22 and 5.88 % respectively) among the herbicides showing a wide range of effectiveness in weed control. The results were in conformity with Partipan *et al*. (2013).

Table 6: Effect of weed control treatments on yields (grain and straw), harvest index and weed index in transplanted winter paddy (pooled data over 2018 and 2019)

Treatment	Grain yield (t/ha)	Straw yield (t/ha)	Harvest index (%)	Weed Index (%)
T_1	3.77	4.72	44.41	5.88
T_2	3.9	4.86	44.52	2.90
T_3	3.84	4.8	44.44	4.22
T_4	3.96	4.92	44.59	1.57
T_5	3.51	4.55	43.55	10.64
T_6	3.62	4.62	43.93	8.65
T_7	2.71	3.77	41.82	28.12
T_8	2.91	3.99	42.17	23.47
T_9	2.8	3.87	41.98	26.02
T_{10}	3.31	4.36	43.16	14.95
T_{11}	3.02	4.1	42.42	21.04
T_{12}	3.18	4.25	42.80	17.61
T_{13}	3.09	4.17	42.56	19.49
T_{14}	3.41	4.46	43.33	12.74
T_{15}	4.07	4.97	45.02	0.0
T_{16}	2.15	3.55	37.72	36.75
S.Em. (±)	0.17	0.30	---	2.88
CD at 5%	0.48	0.87	---	8.31

Conclusion

The outcomes of our research showed that even though highest WCE and yield was recorded from treatment with HW at 20 and 40 DAT however, it was laborious and time consuming while use of chemicals or herbicides for weed management was both highly effective and lucrative. The aforementioned experimental out comes indicated that pre-emergence application of Londax power (bensulfuron methyl 0.6% + pretilachlor 6%) [RM] @ 0.66 kg a.i./ ha at 2 DAT with HW at 40 DAT can one of substitute of one HW. The granular formulation of Londax Power gives farmers an additional benefit of easy hand dispersal in the puddled rice field. This low dose herbicide has the potentiality to replace other voluminous and costly herbicides (like butachlor 50 EC @ 1.5 kg a.i./ha and bispyribac sodium 10 SC @ 25 g a.i./ha). This is a newly introduced herbicide and control weeds very effectively than the older herbicides which are used for long time repeatedly. Hence, application of bensulfuron methyl 0.6% + pretilachlor 6% (RM) @ 0.66 kg a.i./ha (2 DAT) with HW at 40 DAT may be suggested for better weed control with higher productivity which can easily replace the tedious and lingering HW (twice) practice. Also, farmers have to follow the rotational use of herbicide followed by hand weeding at 40 DAT to avoid any selection pressure towards weeds.

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Conflict of interest

The authors declare that they have no conflict of interest.

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