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Response of direct seeded rice (*Oryza sativa* L.) Across diverse tillage system and weed control practices

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ABSTRACT

A field experiment was carried out to evaluate the performance of direct seeded upland rice and to determine the most efficient and cost-effective approach under different tillage and weed management techniques during the kharif seasons of 2021 and 2022 at School of Agricultural Sciences (SAS), Nagaland University, Medziphema. Treatments were laid out in split plot design (SPD) and replicated thrice with three tillage system in the main plot and six weed management techniques in the sub-plot. Results revealed that broad-leaved weeds (BLWs) were reported to be the most dominant weeds accounting 72.79% of the total weed density at 60 DAS as compared to grasses and sedges accounting only 25.5% and 1.62%. Tillage system and weed management techniques showed differential effect recording the lowest density and biomass of grasses, sedges and broad-leaved weeds (BLWs) and weed index under conventional tillage system with sequential application of pendimethalin @ 1 kg ha^{-1} (PE) fb bispyribac sodium @ 25 g ha^{-1} (PoE) at 25 DAS. Significantly maximum plant height, number of panicles m^{-2}, number of filled grains panicle^{-1} and straw yield were noticed under conventional tillage with pre-emergence application of pendimethalin @ 1 kg ha^{-1} (PE) fb bispyribac sodium @ 25 g ha^{-1} (PoE) at 25 DAS. However, the maximum net returns and B:C ratio were recorded under zero tillage system and application of pendimethalin @ 1 kg ha^{-1} (PE) fb bispyribac sodium @ 25 g ha^{-1} (PoE) at 25 DAS.

Keywords: Conventional tillage, Bispyribac-sodium, Pendimethalin, Weed Index, Zero tillage

INTRODUCTION

Rice (*Oryza sativa* L.), the vital food grain is grown globally in 165.04 million hectares in more than 100 nations with production of 513 million metric tons (Anonymous, 2022). India ranks second in rice production next to China in the world, occupying an area of 47.00 mha, production of 132.00 million tonnes and national productivity of 4.20 tonnes per hectare (Anonymous, 2023-24). Conventionally, rice transplanting is a popular cultivating method. This method is usually associated with various obstacles which include high labour and energy requirement, high field water use (1000-2000 mm) which is 2-3 times as compared to other cereal crops (Materu *et al.* 2018). Here, direct seeded rice becomes a new devise approach to overcome all these difficulties. It excludes various operations like nursery bed preparation, seeding, seedling care, removing, bundling, transferring, and transplanting (Nagargade *et al.* 2018). It can also lower the production inputs, cost of production, decrease the number of labour use by 42% (Devkota *et al.* 2020). Additionally, it requires less water (35-57%) and less labour (67%) compared to transplanting method (Verma *et al.* 2023). Direct seeded rice can be sown by conventional tillage, minimum or zero tillage operations. Tillage practices are a crucial part of crop husbandry in attaining a favourable environment for better crop establishment. It has substantial impact on crop productivity as it influences the vertical distribution of weed seeds, emergence and relative abundance of weed species in the field. The effectiveness of the direct seeded rice technique is significantly hampered by heavy weed infestation (Zia-Ul-Haq *et al.* 2019). The intensity of weed competition is more in direct seeded rice than that of flooded rice cultivation and reach its climax between 14- 41 days after sowing. Hence, timely control of weed during the critical period is most essential to overcome the crop-weed competition and amplify the better utilization of available growth resources such as

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available nutrients, water, solar energy and space for increasing crop growth and productivity. There are various weed control techniques, of which herbicide/ chemical method has become preferable due to easily availability, quick results, easy to use and less expensive (Patel *et al.* 2018). Herbicides offer more convenient, economical, easy accessibility, timelier and appropriate weed management method in contrast to more expensive, time consuming, labour intensive and lesser efficacy methods (Sen *et al.* 2020). Single use of herbicide may not be possible to control the overall weed flora in DSR and hence sequential application of pre and post emergence herbicide along with cultural method such as stale seed bed will effectively control the diverse weed flora. Therefore, the present investigation was conducted to devise the efficacy of different weed management techniques on weed density, biomass, crop growth, yield and economics of direct seeded rice under different tillage system.

MATERIALS AND METHODS

Studies were conducted for two consecutive years in the experimental farm of the department of Agronomy, School of Agricultural Sciences (SAS), Nagaland University, Medziphema campus during the ***Kharif*** rainy seasons of 2021and 2022. Geographically, the site is located at 25˚ 45' 43" N latitude and 95˚ 53' 04" E longitude at an altitude of 310 m above the mean sea level (MSL) and falls under sub-tropical climatic zone and is subjected to extreme weather conditions. It receives an average rainfall ranging from 2000-2500 mm annually with mean temperature varying between 21-33˚C in summer and 8˚C in winter due to high atmospheric humidity. The mean weekly maximum and minimum temperature recorded during the period of research was 29.8˚C and 18.4˚C (2021) while 30.1˚C and 17.9˚C (2022) with average weekly rainfall of 22.6 mm and 25.3 mm respectively. Soil of the experimental site was well drained sandy loam and highly acidic soil (pH 4.49 and 4.61), rich in soil organic carbon (1.44 and 1.49%), low soil available nitrogen (264.52 and 257.28 kg ha^{-1}), high phosphorus (39.15 and 39.52 kg ha^{-1}) and medium potassium (147.92 and 147.30 kg ha^{-1}). The treatment consisted of three different tillage system *viz*., zero tillage (T_1), minimum tillage (T_2) and conventional tillage (T_3) in the main plot and six weed management techniques in the sub-plot *viz*., stale seedbed *fb* bispyribac sodium @ 25 g ha^{-1} (PoE) at 25 DAS (W_1), pyrazosulfuron-ethyl @ 0.02 kg ha^{-1} (PE) (W_2), stale seedbed *fb* pyrazosulfuron-ethyl @ 0.02 kg ha^{-1} (PE) *fb* cyhalofop-butyl @ 90 g ha^{-1} (PoE) at 25 DAS (W_3), pendimethalin @ 1 kg ha^{-1} (PE) *fb* bispyribac sodium @ 25 g ha^{-1} (PoE) at 25 DAS (W_4), weed free (W_5) and weedy check (W_6) and were replicated thrice. The treatment was laid out in split-plot design (SPD). No soil disturbance was done in case of zero tillage except opening of furrows for placement of seeds by tractor drawn zero till drill. While ploughing only with disc plough followed by furrow preparation for sowing seeds was done in case of minimum tillage. For conventional tillage, the field was first ploughed with disc plough and followed by 2-3 times harrowing and planking as secondary tillage for seedbed preparation. The recommended dose of the fertilizers (60:40:40 kg ha^{-1} of N, P_2O_5 and K_2O) were applied through urea, single super phosphate and muriate of potash. Complete dose of P and K and 1/3rd of N was applied as basal dose during sowing. The remaining dose of N was split into two equal parts and applied during active tillering and panicle initiation stage of crop period. Direct sowing of rice seed was done maintaining row to row spacing of 20 cm and plant to plant spacing by 10 cm during third week of July at a seed rate of 80 kg ha^{-1}. Application of herbicides was done as per the treatment requirement using flat fan nozzle fitted knapsack sprayer as for pre-emergence at 2-3 DAS and post emergence at 25 DAS. Weed observation was done placing a quadrate of of size 0.5 m × 0.5 m at two spots randomly at each plot, counting and identifying the diverse weed species. The data on weed density and biomass were subjected to square root transformation ($\sqrt{x}$ + 0.5) before statistical analysis to normalize the distribution.

Weed index (WI) was calculated at harvest by using the following formula (Gill and Vijaykumar, 1969):

$$\mathrm{WI}\ (\%) = \frac{Y_{WF} - Y_T}{Y_{WF}} \times 100$$

For crop observations, plant height, yield parameters and yield data were taken from the five tagged plants in each plot. Crop growth rate(CGR) (g m^{-2} day^{-1}) and relative growth rate

(RGR) (g g^{-1} day^{-1}) at 25-50 DAS was calculated by using the dry matter accumulation (g) of plant from each plot at 25 and 50 DAS. Economics of different treatments was worked out as per existing market prices. The collected data for various parameters were statistically analyzed in split plot design using the technique of Analysis of Variance given by Gomez and Gomez (1984). The significant difference between the different treatments and their interactions were compared with critical difference at 5% probability level.

RESULTS AND DISCUSSION

Weed compositions

The study gives important and useful data regarding the floristic diversity of weeds found in the experimental field. A total of 11 weed species were reported belonging to grasses, sedges and broad-leaved weeds. Among all the weed categories, grasses, sedges and BLWs accounted 25.5%, 1.62% and 72.79% of the total weed density at 60 DAS of which BLWs are dominant. The relative density of *Cynadon dactylon* L., *Digitaria sanguinalis* L. and *Eleusine indica* L. were 3.20, 20.23 and 2.16 as grasses; *Cyperus iria* L. was 1.62 as sedge. As for BLWs, *Ageratum conyzoides* L. (17.88), *Alternanthera sessiles* L. (4.50), *Borreria latifolia* (Aubl.) K. Schum. (20.32), *Borreria ocymoides* L. (11.50), *Mollugo pentaphylla* L. (14.61), *Lindernia crustacea* L. (2.16) and *Sida cordifolia* L (1.82).

Table 1: Effect of tillage system and weed management techniques on density (no. m^{-2}) of grasses, sedges and broad leaf weeds 60 DAS

Treatments	Grasses		Sedges		BLW	
	2021	2022	2021	2022	2021	2022
Tillage system (T)						
T_1: Zero tillage	8.78 (95.94)	8.61 (92.61)	2.46 (6.78)	2.41 (6.50)	13.56 (279.89)	13.08 (262.39)
T_2: Minimum tillage	8.25 (85.22)	8.07 (82.22)	2.05 (5.17)	1.93 (4.56)	11.88 (237.72)	11.57 (227.11)
T_3: Conventional tillage	7.52 (73.67)	7.33 (70.33)	1.78 (4.17)	1.73 (3.83)	10.57 (207.17)	10.22 (197.50)
SEm±	0.038	0.056	0.026	0.028	0.052	0.052
CD (p=0.05)	0.148	0.221	0.102	0.110	0.202	0.204
Weed management practices (W)						
W_1: Stale seedbed *fb* bispyribac sodium @ 25 g ha^{-1} at 25 DAS	8.93 (79.78)	8.79 (77.22)	2.43 (5.67)	2.24 (4.78)	11.35 (132.22)	11.00 (124.00)
W_2: Pyrazosulfuron-ethyl @ 0.02 kg ha^{-1}	10.26 (104.89)	10.04 (100.33)	3.31 (10.44)	3.29 (10.11)	15.63 (247.00)	15.08 (229.33)
W_3: Stale seedbed + pyrazosulfuron-ethyl @ 0.02 kg ha^{-1} *fb* cyhalofop-butyl @ 90 g ha^{-1} at 25 DAS	7.77 (60.22)	7.48 (56.00)	1.39 (1.78)	1.42 (1.78)	7.46 (58.67)	7.11 (53.67)
W_4: Pendimethalin @ 1 kg ha^{-1} *fb* bispyribac sodium@ 25 g ha^{-1} at 25 DAS	6.51 (43.22)	6.31 (40.56)	1.00 (0.67)	1.00 (0.56)	5.56 (32.11)	5.21 (28.22)
W_5: Weed free	0.71 (0.00)	0.71 (0.00)	0.71 (0.00)	0.71 (0.00)	0.71 (0.00)	0.71 (0.00)
W_6: Weedy check	14.89 (221.56)	14.71 (216.22)	3.76 (13.67)	3.61 (12.56)	31.30 (979.56)	30.64 (938.78)
SEm±	0.043	0.065	0.036	0.030	0.104	0.047
CD (p=0.05)	0.125	0.189	0.104	0.088	0.301	0.135

Note: Data in parenthesis indicates original values which were subjected to $\sqrt{(x+0.5)}$ transformation

Total density and dry weight of grasses, sedges and BLWs

Tillage system and weed management techniques significantly affect both the density and biomass of grasses, sedges and broad-leaved weeds. Study revealed that significantly maximum density and biomass of grasses were recorded under zero tillage system as shown in Table 1 and 2. While the conventionally tilled plots recorded significantly minimum weed density and biomass of grasses and was

Table 2: Effect of tillage system and weed management techniques on biomass (no. m^{-2}) of grasses, sedges and broad leaf weeds 60 DAS

Treatments	Grasses		Sedges		BLW	
	2021	2022	2021	2022	2021	2022
Tillage system (T)						
T_1: Zero tillage	11.45 (181.00)	11.21 (171.51)	3.55 (13.79)	3.51 (13.43)	11.25 (165.52)	11.04 (159.45)
T_2: Minimum tillage	10.54 (156.83)	10.40 (153.53)	2.94 (10.70)	2.90 (10.38)	9.64 (133.61)	9.54 (131.54)
T_3: Conventional tillage	9.67 (140.68)	9.53 (137.94)	2.43 (8.42)	2.38 (8.01)	8.87 (119.79)	8.77 (117.74)
SEm±	0.090	0.028	0.010	0.008	0.012	0.031
CD (p=0.05)	0.354	0.112	0.040	0.032	0.046	0.121
Weed management practices (W)						
W_1: Stale seedbed *fb* bispyribac sodium @ 25 g ha^{-1} at 25 DAS	10.46 (110.99)	10.36 (108.76)	4.05 (15.94)	3.90 (14.75)	10.76 (117.49)	10.55 (112.70)
W_2: Pyrazosulfuron-ethyl @ 0.02 kg ha^{-1}	13.53 (183.15)	13.37 (179.01)	4.20 (17.17)	4.16 (16.82)	13.71 (188.79)	13.46 (181.95)
W_3: Stale seedbed + pyrazosulfuron-ethyl @ 0.02 kg ha^{-1} *fb* cyhalofop-butyl @ 90 g ha^{-1} at 25 DAS	8.31 (69.13)	8.13 (66.22)	2.78 (9.37)	2.75 (9.17)	8.07 (66.14)	7.96 (64.09)
W_4: Pendimethalin @ 1 kg ha^{-1} *fb* bispyribac sodium@ 25 g ha^{-1} at 25 DAS	6.96 (49.14)	6.77 (46.59)	1.78 (4.95)	1.74 (4.69)	5.50 (34.17)	5.37 (32.75)
W_5: Weed free	0.71 (0.00)	0.71 (0.00)	0.71 (0.00)	0.71 (0.00)	0.71 (0.00)	0.71 (0.00)
W_6: Weedy check	23.34 (544.62)	22.93 (525.37)	4.34 (18.38)	4.32 (18.21)	20.78 (431.25)	20.65 (425.97)
SEm±	0.091	0.052	0.026	0.018	0.082	0.036
CD (p=0.05)	0.263	0.150	0.076	0.051	0.236	0.105

Note: Data in parenthesis indicates original values which were subjected to $\sqrt{(x+0.5)}$ transformation

statistically better in comparison to other tillage system. The probable reason behind this might be due to be due to maximum inversion of surface soil and burial of grasses seeds deeply in the soil. About 25% of the weed seeds are buried in the soil at a depth of 5-10 cm in conventionally tilled plots as reported by Chauhan (2012). Deeply buried seeds require lights for germination which is not possible in case of conventionally tilled soil. This was also reported by Surin *et al.* (2019). The results were similar for sedges and broad-leaved weeds as that of grasses. Among the weed management techniques, sequential application of pendimethalin @ 1 kg ha^{-1} *fb* bispyribac-sodium @ 25 g ha^{-1} at 25 DAS effectively controlled all types of weeds and recorded significantly less density and biomass of grasses, sedges and broad-leaved weeds and was followed by stale seedbed *fb* pyrazosulfuron ethyl @ 0.02 kg ha^{-1} (pre-emergence) *fb* cyhalofop-butyl @ 90 g ha^{-1} at 25 DAS as compared to other treatments. Jat *et al.* (2019) and Pavithra *et al.* (2021) reported that pre- emergence application of pendimethalin @ 1 kg ha^{-1} and post-emergence application of bispyribac-sodium @ 25 g ha^{-1} at 25-30 DAS efficiently controlled complex weed flora of grasses, sedges and broad-leaved weeds. This might be due to the effective controlling of complex weed flora with the combined herbicidal effect of pre and post emergence herbicides where initially emerged grasses and broad-leaved weeds were controlled by pendimethalin by interfering the growth and development shoots and roots while the post emerged weed flora were controlled by bispyribac-sodium by inhibiting the growth enzyme (plant acetolactate synthase enzyme).

Growth parameters

The growth parameters were significantly affected by tillage system and weed management techniques. The information regarding the plant height (harvest), crop growth rate and relative growth rate as impacted by the treatment is shown in Table 3. Conventionally tilled rice showed significantly tallest plant height and was statistically at par with minimum tillage system during both years. It might be due to less

Table 3: Effect of tillage system and weed management techniques on growth parameters

Treatments	Plant height (cm) (Harvest)		CGR (g m^{-2} day^{-1}) 25-50 DAS		RGR (g $g^{-1}$$day^{-1}$) 25-50 DAS	
	2021	2022	2021	2022	2021	2022
Tillage system (T)						
T_1: Zero tillage	75.02	75.30	1.92	1.85	0.015	0.014
T_2: Minimum tillage	76.19	76.99	2.16	2.31	0.016	0.016
T_3: Conventional tillage	77.66	77.95	2.20	2.43	0.016	0.017
SEm±	0.38	0.49	0.112	0.149	0.001	0.001
CD (p=0.05)	1.51	1.92	NS	NS	NS	NS
Weed management practices (W)						
W_1: Stale seedbed *fb* bispyribac sodium @ 25 g ha^{-1} at 25 DAS	75.90	75.84	2.03	2.06	0.016	0.016
W_2: Pyrazosulfuron-ethyl @ 0.02 kg ha^{-1}	73.40	73.84	2.00	1.86	0.018	0.017
W_3: Stale seedbed + pyrazosulfuron-ethyl @ 0.02 kg ha^{-1} *fb* cyhalofop-butyl @ 90 g ha^{-1} at 25 DAS	77.22	77.67	1.82	2.28	0.013	0.015
W_4: Pendimethalin @ 1 kg ha^{-1} *fb* bispyribac sodium@ 25 g ha^{-1} at 25 DAS	78.68	79.09	1.93	2.26	0.012	0.014
W_5: Weed free	81.77	82.75	2.98	3.15	0.017	0.018
W_6: Weedy check	70.75	71.30	1.81	1.58	0.017	0.015
SEm±	0.64	0.67	0.238	0.242	0.002	0.002
CD (p=0.05)	1.85	1.92	0.686	0.698	NS	NS

weed emergence because of intensive inversion of soil and hence burial of weed seeds into deeper layer of soil. This will attribute to lesser weed competition with crops with water, essential nutrients, solar energy, space etc. resulting in better growth of crop. Pandey and Kandel (2020) reported similar results. Different weed control techniques caused significant variation on plant height. Higher plant height was registered with application of pendimethalin @ 1 kg ha^{-1} *fb* bispyribac-sodium @ 25 g ha^{-1} at 25 DAS and followed by stale seedbed *fb* pyrazosulfuron ethyl @ 0.02 kg ha^{-1} (pre-emergence) *fb* cyhalofop-butyl @ 90 g ha^{-1} at 25 DAS. The probable reason behind this might be to due higher efficiency of sequential application pre and post-emergence herbicides that create less weed pressure during critical period of rice-weed competition that allowed more uptake of macro- and micronutrients, water, sunlight, and thus increases photosynthesis process that resulted in higher plant height. Kumari and Kaur (2016) also reported significantly higher plant height with application of pendimethalin *fb* bispyribac-sodium.

Different tillage system showed no significant effect on crop growth rate (CGR) as well as relative growth rate (RGR) during both the years. While significant variation was observed in case of different weed control techniques. Pre emergence application of pendimethalin @ 1 kg ha^{-1} *fb* bispyribac-sodium @ 25 g ha^{-1} at 25 DAS recorded the highest CGR which was at par with stale seedbed *fb* pyrazosulfuron-ethyl @ 0.02 kg ha^{-1} *fb* cyhalofop-butyl @ 90 g ha^{-1} at 25 DAS. The probable reason might be due to higher degree of weed suppression, lesser weed nutrient uptake, more light interception, more photosynthetic rates and increased leaf area index thus resulted in better dry matter accumulation. Hence, resulted in more CGR. The result is similar with the findings of Kumari *et al.* (2023). No significant effect was observed in case of RGR.

Yield attributes, yield of rice and weed index

The data pertaining to yield attributes, yield of rice and weed index as influenced by tillage system and weed control techniques is presented in Table 4. A perusal of the data showed that significantly maximum numbers of panicles/m2 were registered under conventional tillage which was statistically at par with minimum tillage system in both the years. However, a maximum number of filled grains per panicle were recorded under conventionally tilled plots and was statistically at par with minimum tillage system in the first year. Straw yield under conventional tillage was statistically higher

Table 4: Effect of tillage system and weed management techniques on yield parameters, yield and weed index

Treatments	Number of panicles m^{-2}		Number of filled grains $panicle^{-1}$		Straw yield ($kg\ ha^{-1}$)		Weed Index (%)	
	2021	2022	2021	2022	2021	2022	2021	2022
Tillage system (T)								
T_1: Zero tillage	180.11	189.72	64.52	65.84	5612.16	5607.88	17.67	17.75
T_2: Minimum tillage	206.28	210.39	67.11	68.63	5743.64	5738.31	13.83	13.86
T_3: Conventional tillage	213.72	219.73	69.55	72.14	5846.09	5842.20	11.22	11.10
SEm±	4.15	4.89	0.56	0.54	12.66	7.17	0.16	0.18
CD (p=0.05)	16.29	19.21	2.21	2.11	49.70	28.14	0.63	0.69
Weed management practices (W)								
W_1: Stale seedbed *fb* bispyribac sodium @ 25 g ha^{-1} at 25 DAS	182.22	192.33	68.23	69.45	5772.74	5770.85	15.23	15.25
W_2: Pyrazosulfuron-ethyl @ 0.02 kg ha^{-1}	154.89	160.67	62.69	63.50	5420.14	5417.19	25.04	24.82
W_3: Stale seedbed + pyrazosulfuron-ethyl @ 0.02 kg ha^{-1} *fb* cyhalofop-butyl @ 90 g ha^{-1} at 25 DAS	214.00	220.56	72.10	73.04	5990.29	5965.56	8.34	8.39
W_4: Pendimethalin @ 1 kg ha^{-1} *fb* bispyribac sodium@ 25 g ha^{-1} at 25 DAS	232.78	236.56	75.14	76.22	6180.92	6183.52	2.20	2.20
W_5: Weed free	276.33	284.02	78.87	83.48	6082.20	6099.12	0.00	0.00
W_6: Weedy check	140.00	145.56	45.31	47.53	4957.48	4940.52	34.64	34.77
SEm±	7.41	8.87	1.07	0.74	11.93	14.27	0.34	0.24
CD (p=0.05)	21.40	25.63	3.10	2.13	34.46	41.21	0.98	0.69

during both the years. The reason for increased number of panicles/m^2, filled grains per panicle and straw yield under conventional tillage might be due to lesser weed emergence owing to deep burial of weed seeds, allowing lesser competition with crops. Furthermore, conventional tillage is known to increase soil porosity thereby increasing better aeration and air exchange, that promote better root growth resulting in better exploration of available nutrients, water and space and hence led to increased photosynthesis rate, assimilation and translocation of photosynthates to sink that ultimately resulted in increased plant dry matter accumulation, and various growth and yield attributes. Similar findings were reported by El-Din *et al.* (2008), Saini *et al.* (2022) and Bhargaw *et al.* (2023).

Table 5: Effect of tillage system and weed management techniques on net returns and B:C ratio

Treatments	Net returns		B:C ratio	
	2021	2022	2021	2022
T_1W_1	41498.15	41728.38	1.15	1.15
T_1W_2	37617.71	37950.49	1.12	1.13
T_1W_3	42925.08	43147.15	1.17	1.18
T_1W_4	59716.69	59953.71	1.69	1.70
T_1W_5	44584.30	44995.77	0.84	0.85
T_1W_6	31113.93	31129.35	0.95	0.95
T_2W_1	36833.38	37049.38	0.87	0.88
T_2W_2	35808.13	35943.38	0.90	0.91
T_2W_3	52334.88	52578.36	1.23	1.23
T_2W_4	54694.82	54914.78	1.33	1.33
T_2W_5	38895.64	39167.28	0.66	0.67
T_2W_6	26261.49	26315.73	0.68	0.68
T_3W_1	43595.38	43810.73	0.87	0.87
T_3W_2	27750.49	28538.82	0.58	0.60
T_3W_3	44629.60	44738.95	0.88	0.88
T_3W_4	47278.26	47668.51	0.96	0.97
T_3W_5	31146.12	31383.39	0.47	0.47
T_3W_6	18647.60	18740.40	0.40	0.40

While the lowest number of panicles/m^2, filled grains per panicle and straw yield were recorded under zero tillage. With view of weed index, this is a measure of yield loss as compared to weed free plot. Weed index was lowest under conventional tillage system while highest under zero tillage which might be attributed from weed free environment that again resulted in better crop growth and hence higher yield. The results are in close conformity as reported by Chaudhary (2022).

Among the weed control techniques, significantly higher number of panicles/m^2 was recorded with pre-emergence application of pendimethalin @ 1 kg ha^{-1} *fb* bispyribac-sodium @ 25 g ha^{-1} at 25 DAS statistically at par with stale seedbed *fb* pyrazosulfuron-ethyl @ 0.02 kg ha^{-1} *fb* cyhalofop-butyl @ 90 g ha^{-1} at 25 DAS in both the years. While the higher number of filled grains per panicle and straw yield as well as lowest weed index was also registered with sequential application of pendimethalin @ 1 kg ha^{-1} *fb* bispyribac-sodium @ 25 g ha^{-1} at 25 DAS but was not statistically at par with any of the treatments. This might be since application of pendimethalin *fb* bispyribac-sodium resulted in lesser weed intensity and pressure and with highest weed control efficiency, this treatment offered efficient weed control throughout the crop growing season promoting greater tillering, more panicles and higher photosynthate accumulation, which enhanced crop development and increased number of filled grains and straw yield significantly. Similar result was reported by Mahajan and Chauhan (2013), Baghel *et al.* (2018) and Baghel *et al.* (2020).

Economics

Various tillage system and weed control techniques showed significant variation on net monetary returns and benefit -cost ratio. The highest net monetary returns and benefit-cost ratio were incurred under zero tillage system with sequential application of pendimethalin @ 1 kg ha^{-1} *fb* bispyribac-sodium @ 25 g ha^{-1} at 25 DAS during both the year. This was followed by pre-emergence application of pendimethalin @ 1 kg ha^{-1} *fb* bispyribac-sodium @ 25 g ha^{-1} at 25 DAS under minimum tillage system. The high net return and B:C ratio under this treatment might be due to lower cost of cultivation, where zero tillage require less labour, machinery and fuel that lead ultimately to significantly higher net return and effective control of weeds during the critical stage of crop that ultimately create a favourable condition for the crop to flourish the available growth resources thus resulting in more grain and straw yield. While significantly lowest monetary returns and benefit-cost ratio were registered under conventional tillage with weedy check which might be ascribed due to higher cost of cultivation and uncontrolled weed growth that led to high competition with crops for essential nutrients, space water and solar radiation for growth and development thus reducing grain and straw yield. The result is in lined with the findings reported by Mandira (2016), Abbas *et al.* (2019) and Bhargaw and Roy (2020).

From the above investigation, it may be concluded that conventional tillage with sequential application of pendimethalin @ 1 kg ha^{-1} *fb* bispyribac-sodium @ 25 g ha^{-1} at 25 DAS recorded the highest crop growth parameters, yield attributes and lowest weed index. But the highest straw yield and B:C ratio was incurred under zero tillage system with application of pendimethalin @ 1 kg ha^{-1} *fb* bispyribac-sodium @ 25 g ha^{-1} at 25 DAS. Hence application of pendimethalin @ 1 kg ha^{-1} as pre-emergence *fb* bispyribac-sodium @ 25 g ha^{-1} at 25 DAS under zero tillage system will be very effective for efficient weed control along with incurring higher monetary net returns and economically feasible for direct seeded rice cultivation.

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