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Integrated weed management in dry direct-seeded rice: Assessing the impacts on weeds and economics in the sub-montane zone of Maharashtra

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Abstract
Studies revealed that, in comparison to puddled transplanted rice, direct seeded rice system can reduce overall labour requirements by 11-66% and irrigation water needs by 35-57%. Heavy weed infestation is the major problem faced by the farmers in DSR, which in severe cases results in full crop loss and diminishes the economic return. Integrated weed management treatments resulted in significant reduction in weed intensity and dry matter accumulation with higher weed control efficiency as compared to UWC. Among the integrated weed management treatments at 14 DAS, monocot weeds, dicot weeds, and sedges were efficiently controlled by all the integrated weed management treatments. Whereas, pretilachlor 30.7% EC at 0.450 kg/ha at 2-3 DAS (PE) *fb* hoeing at 25 DAS *fb* hand weeding at 40 DAS (T_8) and oxyfluorfen 23. 5% EC at 0.150 kg/ha at 2-3 DAS (PE) *fb* hoeing at 25 DAS *fb* hand weeding at 40 DAS (T_3) indicated the lowest weed intensity than any other treatments at the later stages of the crop up to harvest. Among the integrated weed management treatments, lowest weed dry matter at harvest was observed for pretilachlor 30.7% EC at 0.450 kg/ha at 2-3 DAS (PE) *fb* hoeing at 25 DAS *fb* hand weeding at 40 DAS (T_8) and oxyfluorfen 23. 5% EC at 0.150 kg/ha at 2-3 DAS (PE) *fb* hoeing at 25 DAS *fb* hand weeding at 40 DAS (T_3), whereas the maximum was found with oxyfluorfen 23.5% EC at 0.150 kg/ha at 2-3 DAS (PE) *fb* hoeing at 30 DAS (T_1) and pretilachlor 30.7% EC at 0.450 kg/ha at 2-3 DAS (PE) *fb* hoeing at 30 DAS (T6). Amid the weed species found in the UWC, Alternanthera sessilis (37.7%) and Dinebra retroflexa (34.8%) had the maximum contribution to the weed dry matter observed at harvest.

Keywords: Weed free crop (WFC), unweeded check (UWC)

Introduction

Rice (*Oryza sativa* L.) is one of the world's most important crop, grown widely over 161 million hectares in more than 100 countries, and is a principal source of food for more than half of the world's population. Globally, rice production has reached about 756.74 million tonnes with a productivity of 4.6 tonnes per ha (Anonymous, 2022) [2] and is one of the four crops that account for about half of global primary crop production. Around 90% of the global total rice production is being grown and consumed in Asia (Chauhan *et al.*, 2012) [10], which produces around 670 million tonnes of rice (Anonymous, 2021) [1].

Transplanted puddled rice (TPR) has several constrains that make it unaffordable for many farmers, especially small and marginal farmers in Southeast Asia, which include a huge water demand (1000-2000 mm) for puddling and maintaining continuous flooding, a huge energy requirement ranging between 5630-8448 MJ per ha and almost 15-20% higher labour inputs than direct-seeded rice (DSR) (Shekhawat *et al.*, 2020) [28]. In direct-seeded rice, surface irrigation is done to bring the soil water content up to the field capacity while maintaining the soil moist but not overly wet or saturated. In addition to this, is also having advantages like faster and easier planting, reduced labour and drudgery, earlier crop maturity by 7-10 days, increased water use efficiency and higher tolerance of water deficit, fewer methane emission and often higher profit in the areas with assured water supply (Balasubramanian and Hill, 2002) [7].

Weeds are the major biotic constraint which acts as a shelter for crop pests and competes with agricultural crops for space, light, nutrients, soil moisture, etc., thereby reducing the yield, quality, and economic return.

There are 18 genera and 50 weed species from 22 distinct families that were observed under DSR (Kaur and Singh, 2017) [17]. The yield reduction recorded by grasses, broad-leaved weeds, and sedges was 41, 28, and 10%, respectively (Azmi and Baki, 1955). Another study at IRRI revealed that weeds caused a yield loss of 34 percent in transplanted rice, 45 percent in direct-seeded rain-fed lowland rice and 67 percent in upland rice (Datta, 1981). Chemical weed management is the smartest, most economically viable, and best alternative or supplement to hand weeding. The key elements for efficient weed control and a better crop yield are the selection of suitable herbicide by analysing the dominant weed flora, the correct dose, right time of application by analysing the field condition, and the right method of application. Application of pre-emergence herbicides like pendimethalin, pretilachlor, oxyfluorfen, oxadiazone, etc., provides effective weed control in DSR since the majority of weed seeds still remain in the top 2-3 cm of the soil (Chauhan and Johnson, 2011) [11]. In DSR, it is recommended to apply pre-emergence herbicides within 1-3 days after first flush irrigation in saturated soil without water stagnation (Awan *et al.*, 2016) [5]. Numerous studies have emphasised the significance of pre emergence herbicides in DSR because, in the absence of pre-emergence herbicides, weed management becomes more expensive and challenging since they have a key role in preventing the head-start advantage that weeds have over rice (Awan *et al.*, 2015) [4] and can reduce weed density by 50-82% (Chauhan *et al.*, 2015) [4].

Materials and Methods

One year field experiment was conducted during the *Kharif* season of 2021 at the Agronomy farm, RCSM College of Agriculture, Kolhapur. The field trial was held in plot 22C (Survey No. 359). The site was selected on the basis of the suitability of the soil for raising direct-seeded rice. The soil of the experimental plot was medium black clay (vertisol) with 90 cm depth, low in available N (208.64 kg/ha), medium in available P2O5 (34.05 kg/ha) and high in available K2O (398.50 kg/ha). The status of organic carbon content (0.58%) was medium. The available N, P2O5, K2O, and organic carbon content were classified based on a three-tier system, and the results were interpreted accordingly. The electrical conductivity and pH values were 0.43 dSm^{-1} (normal-low saline) and 7.75 (neutral), respectively.

The experiment was laid out using randomized block design with twelve treatments replicated thrice with treatments *viz*, T_1: Pre emergence application of oxyfluorfen 23.5% EC at 0.150 kg/ha at 2-3 DAS *fb* Hoeing at 30 DAS, T_2: Pre emergence application of oxyfluorfen 23. 5% EC at 0.150 kg/ha at 2-3 DAS *fb* Hand weeding at 30 DAS, T_3: Pre emergence application of oxyfluorfen 23. 5% EC at 0.150 kg/ha at 2-3 DAS *fb* Hoeing at 25 DAS *fb* Hand weeding at 40 DAS, T_4: Pre emergence application of oxyfluorfen 23. 5% EC at 0.150 kg/ha at 2-3 DAS *fb* Post emergence application of metsulfuron-methyl + chlorimuron-ethyl at 0.004 kg/ha at 25 DAS, T_5: Pre emergence application of oxyfluorfen 23. 5% EC at 0.150 kg/ha at 2-3 DAS *fb* Post emergence application of bispyribac sodium 10% at 0.02 kg/ha at 25 DAS, T_6: Pre emergence application of pretilachlor 30.7% EC at 0.450 kg/ha at 2-3 DAS *fb* Hoeing at 30 DAS, T_7: Pre emergence application of pretilachlor 30.7% EC at 0.450 kg/ha at 2-3 DAS *fb* Hand weeding at 30 DAS, T8: Pre emergence application of pretilachlor 30.7% EC at 0.450 kg/ha at 2-3 DAS *fb* Hoeing at 25 DAS *fb* Hand weeding at 40 DAS, T9: Pre emergence application of pretilachlor 30.7% EC at 0.450 kg/ha at 2-3 DAS *fb* Post emergence application of metsulfuron-methyl + chlorimuron-ethyl at 0.004 kg/ha at 25 DAS T10: Pre emergence application of pretilachlor 30.7% EC at 0.450 kg/ha at 2-3 DAS *fb* Post emergence application of bispyribac sodium 10% at 0.02 kg/ha at 25 DAS, T_{11}: Weed free crop, T_{12}: Unweeded check.

Weed dry weight was recorded after drying the weed samples at 70 °C for 48 h. Weed control efficiency was calculated based on the data recorded at 45 and 75 DAS in rice as per standard formula. Yield and yield attributing characters was determined using standard procedures. Finally yield was expressed as q/ha.

Weed Intensity: Weed intensity was calculated using formula

$$\text{Weed Intensity} = \frac{\text{Weed Population}}{\text{Weed Population + Crop Population}} \text{X } 100$$

Weed control efficiency: Weed control efficiency of each treatment was calculated by using the formula given by Mani *et al.* (1973) [22].

$$\text{Weed control efficiency} = \frac{WD_C - WD_T}{WD_T} \text{ X } 100$$

Whereas,

WD_C- Weed density (number per m^2) in control plot

WD_T - Weed density (number per m^2) in treated plot

Weed Index: Weed index of each treatment was calculated by using the formula given by Gill and Vijayakumar (1969) [14].

$$\text{Weed Index (WI)} = \frac{Y_{WF}\ Y_T}{Y_{WF}} \text{X}100$$

Where,

YWF - Crop yield from weed-free plot

YT - Crop yield in treatment for which weed index is to be worked out

Weed persistence index: Weed persistence index of each treatment was calculated by using the formula given by Mishra and Misra (1997) [23].

$$\text{Weed persistence index (WPI)} = \frac{\text{Weed population in control plot}}{\text{Weed population in treated plot}} \text{ X } \frac{\text{Weed dry weight in treated plot}}{\text{Weed dry weight in control plot}}$$

Weed management index: Weed management index of each treatment was calculated by using the formula given by Mishra and Misra (1997) [23].

$$\text{Weed management index (WMI)} = \frac{\text{Per cent crop yield over control}}{\text{Per cent control of weeds}}$$

Results and Discussion

Weed Intensity: A perusal of data on weed intensity presented in Table 2 indicated that weed intensity was influenced significantly due to the different integrated weed management treatments at 70, 84, 98 DAS and at harvest. At 70, 84, 98 DAS and at harvest the lowest intensity of monocot weeds, dicot weeds and sedges were found in WFC and the highest was recorded for UWC. The UWC was found with the dominated weed flora comprising the grass *Dinebra retroflexa*, broad leaved weeds, *Alternanthera sessilis, Ageratum conyzoides*, *Digera arvensis* and *Cyperus rotundus*, the sedge.

At 70 DAS, among the integrated weed management treatments, oxyfluorfen 23.5% EC at 0.150 kg/ha at 2-3 DAS (PE) *fb* hoeing at 25 DAS *fb* hand weeding at 40 DAS (T_3), pretilachlor 30.7% EC at 0.450 kg/ha at 2-3 DAS (PE) *fb* hoeing at 25 DAS *fb* hand weeding at 40 DAS (T_8) and pretilachlor 30.7% EC at 0.450 kg/ha at 2-3 DAS (PE) *fb* bispyribac sodium 10% at 0.02 kg/ha at 25 DAS (POE) (T_{10}) recorded the lowest intensity of monocot and dicot weeds and differences among these treatments were of similar magnitude. Similar findings were reported by Kumar *et al.* (2013) [19], Veeraputhiran and Balasubramanian (2013) [30], Singh *et al*. (2014) [29], Kundu *et al*. (2020) [21] and Saravanane (2020) [26].

At 84 and 98 DAS, pretilachlor 30.7% EC at 0.450 kg/ha at 2-3 DAS (PE) *fb* hoeing at 25 DAS *fb* hand weeding at 40 DAS (T_8), oxyfluorfen 23.5% EC at 0.150 kg/ha at 2-3 DAS (PE) *fb* hoeing at 25 DAS *fb* hand weeding at 40 DAS (T_3), pretilachlor 30.7% EC at 0.450 kg/ha at 2-3 DAS (PE) *fb* bispyribac sodium 10% at 0.02 kg/ha at 25 DAS (POE) (T_{10}) and oxyfluorfen 23. 5% EC at 0.150 kg/ha at 2-3 DAS (PE) *fb* bispyribac sodium 10% at 0.02 kg/ha at 25 DAS (POE) (T_5) recorded the lowest intensity of monocot weeds. In the case of dicot weeds, at 84 DAS, 98 DAS and at harvest all the integrated weed management treatments showed lower weed intensity than UWC. The treatments comprising oxyfluorfen 23.5% EC at 0.150 kg/ha at 2-3 DAS (PE) *fb* hoeing at 25 DAS *fb* hand weeding at 40 DAS (T_3), pretilachlor 30.7% EC at 0.450 kg/ha at 2-3 DAS (PE) *fb* hoeing at 25 DAS *fb* hand weeding at 40 DAS (T_8), pretilachlor 30.7% EC at 0.450 kg/ha at 2-3 DAS (PE) *fb* bispyribac sodium 10% at 0.02 kg/ha at 25 DAS (POE) (T_{10}) and oxyfluorfen 23. 5% EC at 0.150 kg/ha at 2-3 DAS (PE) *fb* bispyribac sodium 10% at 0.02 kg/ha at 25 DAS (POE) (T_5) recorded the lowest weed intensity over the rest of the treatments.

In the case of sedges, similar trend of weed intensity was noted as that in dicot weeds at 84 DAS, 98 DAS and at harvest. The treatments, pretilachlor 30.7% EC at 0.450 kg/ha at 2-3 DAS (PE) *fb* hoeing at 25 DAS *fb* hand weeding at 40 DAS (T_8), oxyfluorfen 23.5% EC at 0.150 kg/ha at 2-3 DAS (PE) *fb* hoeing at 25 DAS *fb* hand weeding at 40 DAS (T_3), pretilachlor 30.7% EC at 0.450 kg/ha at 2-3 DAS (PE) *fb* bispyribac sodium 10% at 0.02 kg/ha at 25 DAS (POE) (T_{10}) and oxyfluorfen 23. 5% EC at 0.150 kg/ha at 2-3 DAS (PE) *fb* bispyribac sodium 10% at 0.02 kg/ha at 25 DAS (POE) (T_5) showed lowest weed intensity than the other treatments except WFC which was significantly superior to all the treatments. The results were in conformity with Anwar *et al.* (2012) [3], Kumar *et al.* (2013) [19], Veeraputhiran and Balasubramanian (2013) [30], Singh *et al.* (2014) [29], Kundu *et al*. (2020) [21] and Saravanane (2020) [26].

Table 1: Weed flora observed in the experimental field

Common name	Botanical name	Family	Habit
Grasses			
Viper grass	*Dinebra retroflexa* (Vahl.) Panz.	Poaceae	Annual or perennial grass
Purple Chloris	*Chloris barbata* Sw.	Poaceae	Annual or short-lived perennial grass
Broad-leaved weeds			
Indian jointvetch	*Aeschynomene indica* L.	Fabaceae	Annual undershrub
Sessile joyweed	*Alternanthera sessilis* (L.) DC	Amaranthaceae	Annual or perennial herb
Cock's comb	*Celosia argentea* L.	Amaranthaceae	Annual herb
False amaranth	*Digera arvensis* Forssk.	Ameranthaceae	Annual herb
Ivy leaf morning glory	*Ipomoea hederacea* (L.) Jacq.	Convolvulaceae	Annual vine
Goat weed	*Ageratum conyzoides* L.	Asteraceae	Annual herb
Parthenium	*Parthenium hysterophorus* L.	Asteraceae	Annual herb
Para cress	*Spilanthes calva* DC.	Asteraceae	Annual herb
Cinderella weed	*Synedrella nodiflora* (L.) Gaertn.	Asteraceae	Annual herb
Sedges			
Purple nutsedge	*Cyperus rotundus* L.	Cyperaceae	Perennial sedge

Weed control efficiency (WCE) and weed index (WI)

Among the different integrated weed management treatments presented in Table 3, pretilachlor 30.7% EC at 0.450 kg/ha at 2-3 DAS (PE) *fb* hoeing at 25 DAS *fb* hand weeding at 40 DAS (T8) recorded the highest WCE (81.7%) and lowest WI (6.6). It was followed by oxyfluorfen 23. 5% EC at 0.150 kg/ha at 2-3 DAS (PE) *fb* hoeing at 25 DAS *fb* hand weeding at 40 DAS (T3; 80.3% and 9.7), pretilachlor 30.7% EC at 0.450 kg/ha at 2-3 DAS (PE) *fb* bispyribac sodium 10% at 0.02 kg/ha at 25 DAS (POE) (T10; 77.8% and 11.6), oxyfluorfen 23. 5% EC at 0.150 kg/ha at 2-3 DAS (PE) *fb* bispyribac sodium 10% at 0.02 kg/ha at 25 DAS (POE) (T5; 76.0% and 13.5), pretilachlor 30.7% EC at 0.450 kg/ha at 2-3 DAS (PE) *fb* metsulfuron-methyl + chlorimuron-ethyl at 0.004 kg/ha at 25 DAS (POE) (T9; 74.5% and 18.4), oxyfluorfen 23. 5% EC at 0.150 kg/ha at 2-3 DAS (PE) *fb* metsulfuron-methyl + chlorimuron-ethyl at 0.004 kg/ha at 25 DAS (POE) (T4; 73.8% and 20.5), pretilachlor 30.7% EC at 0.450 kg/ha at 2-3 DAS (PE) *fb* hand weeding at 30 DAS (T7; 70.9% and 31.1), oxyfluorfen 23. 5% EC at 0.150 kg/ha at 2-3 DAS (PE) *fb* hand weeding at 30 DAS (T2; 68.7% and 33.8), pretilachlor 30.7% EC at 0.450 kg/ha at 2-3 DAS (PE) *fb* hoeing at 30 DAS (T6; 67.3% and 35.2) and oxyfluorfen 23. 5% EC at 0.150 kg/ha at 2-3 DAS (PE) *fb* hoeing at 30 DAS (T1; 63.4% and 36.4) in that order, which were equally beneficial in suppressing the weed growth. These results were in conformity with Gopinath and Kundu (2008) [15], Veeraputhiran and Balasubramanian (2013) [30], Rathika and Ramesh (2019) [25], Guru *et al*. (2020) [16] and Kundu *et al*. (2020) [21].

Table 2: Weed intensity in direct-seeded rice as influenced by integrated weed management treatments at 70, 84, 98 DAS and at harvest

Symbol	Weed intensity (Nos./m^2)			
	70 DAS	84 DAS	98 DAS	Harvest
T1	9.44 (88.7)	10.13(102.3)	10.80(116.7)	11.30(127.3)
T2	8.62 (74.0)	9.64 (92.7)	10.02(100.3)	10.45(109.0)
T3	6.13 (37.3)	7.07 (50.0)	7.76 (60.0)	8.30 (68.7)
T4	8.01 (63.7)	8.72 (76.0)	9.37 (87.3)	9.57 (91.3)
T5	7.03 (49.0)	8.22 (67.3)	8.84 (78.7)	9.14 (83.7)
T6	8.84 (77.7)	9.75 (94.7)	10.38(107.3)	10.70(114.0)
T7	8.55 (73.0)	9.36 (87.30	9.71 (94.3)	10.06(101.3)
T8	6.33 (39.7)	6.96 (48.0)	7.48 (55.7)	8.00 (63.7)
T9	7.67 (58.3)	8.45 (71.0)	9.07 (82.0)	9.44 (88.7)
T10	6.45 (41.3)	7.67 (58.7)	8.24 (67.7)	8.82 (77.3)
T11	0.71 (0.0)	0.71 (0.0)	0.71 (0.0)	0.71 (0.0)
T12	12.25(150.3)	12.98(168.0)	13.84(192.3)	18.68(348.3)
S.Em±	0.29	0.33	0.44	0.45
CD at 5%	0.86	0.98	1.29	1.32
General mean	7.50	8.30	8.85	9.60

*Data were subjected to square root transformation [√ (x + 0.5)]. Figures in parenthesis indicates original values

Weed persistence index (WPI): In Table 4, Weed persistence index gives the idea about the resistance in weeds against the tested treatments and confirms the effectiveness of any herbicides under study. The lowest WPI was recorded by pretilachlor 30.7% EC at 0.450 kg/ha at 2-3 DAS (PE) *fb* hoeing at 25 DAS *fb* hand weeding at 40 DAS (T8; 0.36) and oxyfluorfen 23. 5% EC at 0.150 kg/ha at 2-3 DAS (PE) *fb* hoeing at 25 DAS *fb* hand weeding at 40 DAS (T_3; 0.41) which indicates pre-emergence herbicide spray followed by hoeing and hand weeding were equally effective in controlling the weeds and comparable with WFC.

Herbicide efficiency index (HEI): Highest HEI was observed by pretilachlor 30.7% EC at 0.450 kg/ha at 2-3 DAS (PE) *fb* hoeing at 25 DAS *fb* hand weeding at 40 DAS (T8; 10.39) and oxyfluorfen 23. 5% EC at 0.150 kg/ha at 2-3 DAS (PE) *fb* hoeing at 25 DAS *fb* hand weeding at 40 DAS (T3; 8.57), pretilachlor 30.7% EC at 0.450 kg/ha at 2-3 DAS (PE) *fb* metsulfuron-methyl + chlorimuron-ethyl at 0.004 kg/ha at 25 DAS (POE) (T4; 5.46), this means the combination of treatments was found to be effective in controlling the weeds in an effective way.

Table 3: Weed control efficiency and weed index at harvest as influenced by integrated weed management treatments in direct-seeded rice

Symbol	Weed control efficiency (%)	Weed index (%)
T1	63.4	36.4
T2	68.7	33.8
T3	80.3	9.7
T4	73.8	20.5
T5	76.0	13.5
T6	67.3	35.2
T7	70.9	31.1
T8	81.7	6.6
T9	74.5	18.4
T10	77.8	11.6
T11	100.0	0.0
T12	0.0	73.2

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Weed management index (WMI), agronomic management index (AMI) and integrated weed management index (IWMI)

In the Table 4, Among the different integrated weed management treatments, pretilachlor 30.7% EC at 0.450 kg/ha at 2-3 DAS (PE) *fb* hoeing at 25 DAS *fb* hand weeding at 40 DAS recorded the highest values for WMI (2.67), AMI (1.67), and IWMI (2.17). It was closely followed by oxyfluorfen 23. 5% EC at 0.150 kg/ha at 2-3 DAS (PE) *fb* hoeing at 25 DAS *fb* hand weeding at 40 DAS (T_3; WMI; 2.58, AMI; 1.58, and IWMI; 2.08), followed by pretilachlor 30.7% EC at 0.450 kg/ha at 2-3 DAS (PE) *fb* bispyribac sodium 10% at 0.02 kg/ha at 25 DAS (POE) (T10; WMI; 2.57, AMI; 1.57, and IWMI; 2.07), oxyfluorfen 23. 5% EC at 0.150 kg/ha at 2-3 DAS (PE) *fb* bispyribac sodium 10% at 0.02 kg/ha at 25 DAS (POE) (T5; WMI; 2.53, AMI; 1.53, and IWMI; 2.03), pretilachlor 30.7% EC at 0.450 kg/ha at 2-3 DAS (PE) *fb* metsulfuron-methyl + Chlorimuron-ethyl at 0.004 kg/ha at 25 DAS (POE) (T9; WMI; 2.34, AMI; 1.34, and IWMI; 1.84), oxyfluorfen 23. 5% EC at 0.150 kg/ha at 2-3 DAS (PE) *fb* metsulfuron- methyl + Chlorimuron-ethyl at 0.004 kg/ha at 25 DAS (POE) (T4; WMI; 2.26, AMI; 1.26, and IWMI; 1.76) and pretilachlor 30.7% EC at 0.450 kg/ha at 2-3 DAS (PE) *fb* hand weeding at 30 DAS (T7; WMI; 2.21, AMI; 1.21, and IWMI; 1.71), pretilachlor 30.7% EC at 0.450 kg/ ha at 2-3 DAS (PE) *fb* hoeing at 30 DAS (T6; WMI; 2.10, AMI; 1.10, and IWMI; 1.60), oxyfluorfen 23. 5% EC at 0.150 kg/ha at 2-3 DAS (PE) *fb* hoeing at 30 DAS (T1; WMI; 2.10, AMI; 1.10, and IWMI; 1.60) and oxyfluorfen 23. 5% EC at 0.150 kg/ha at 2-3 DAS (PE) *fb* hand weeding at 30 DAS (T2; WMI; 2.07, AMI; 1.07, and IWMI; 1.57) in that order. This shows that integration of application of pre-and post- emergence herbicide or pre- emergence herbicide application and hoeing and or hand weeding were effective in suppressing weed growth and increasing the crop yield. Suppressing the weed growth during early stage of the crop growth is well documented in decreasing the crop- weed competition resulting in increasing the yield of the crop. These results are in conformity with Sen *et al*. (2020) [27].

Table 4: Weed persistence index (WPI), weed management index (WMI), agronomic management index (AMI), integrated weed management index (IWMI), herbicide efficiency index (HEI)

Symbol	WPI	HEI	WMI	AMI	IWMI
T1	0.95	1.67	2.10	1.10	1.60
T2	0.92	2.05	2.07	1.07	1.57
T3	0.41	8.57	2.58	1.58	2.08
T4	0.48	5.14	2.26	1.26	1.76
T5	0.47	5.96	2.53	1.53	2.03
T6	0.99	1.83	2.10	1.10	1.60
T7	0.99	2.13	2.21	1.21	1.71
T8	0.36	10.39	2.67	1.67	2.17
T9	0.47	5.46	2.34	1.34	1.84
T10	0.47	6.60	2.57	1.57	2.07
T11	0.00	-	-	-	-
T12	1.00	-	-	-	-

Yield Studies

Grain Yield: The data regarding the grain yield, which is presented in Table 5 and graphically depicted in Figure 1, reveals that integrated weed management treatments in direct seeded rice have profoundly influenced the grain yield. The maximum grain yield was recorded in the WFC (59.17 q/ha), pretilachlor 30.7% EC at 0.450 kg/ha at 2-3 DAS (PE) *fb* hoeing at 25 DAS *fb* hand weeding at 40 DAS (T8; 55.24 q/ha) and oxyfluorfen 23. 5% EC at 0.150 kg/ha at 2-3 DAS (PE) *fb* hoeing at 25 DAS *fb* hand weeding at 40 DAS (T3; 53.40 q/ha) and those were on par with each other. This may be due to the lowest values of weed intensity and weed dry matter, higher WCE and lower WI, also the plant growth characters and yield attributes were higher in these treatments.

Table 5: Grain yield, straw yield, biological yield, harvest index as influenced by integrated weed management treatments

	Grain yield (q/ha)	Straw yield (q/ha)	Biological yield (q/ha)	Harvest index (%)
T1	37.94	59.67	97.28	38.85
T2	39.17	63.48	102.66	38.24
T3	53.40	83.39	136.80	39.01
T4	47.06	73.42	120.48	39.02
T5	51.88	77.77	128.98	39.67
T6	38.32	60.65	98.97	38.68
T7	40.74	66.42	107.16	37.98
T8	55.24	85.04	140.28	39.32
T9	48.31	75.43	123.74	39.00
T10	52.30	78.31	130.61	40.00
T11	59.17	88.17	147.33	40.09
T12	15.84	30.07	45.90	34.68
S.Em±	2.34	3.32	5.53	1.83
CD (P=0.05)	6.86	9.73	16.21	NS
General mean	44.95	70.15	115.02	38.71

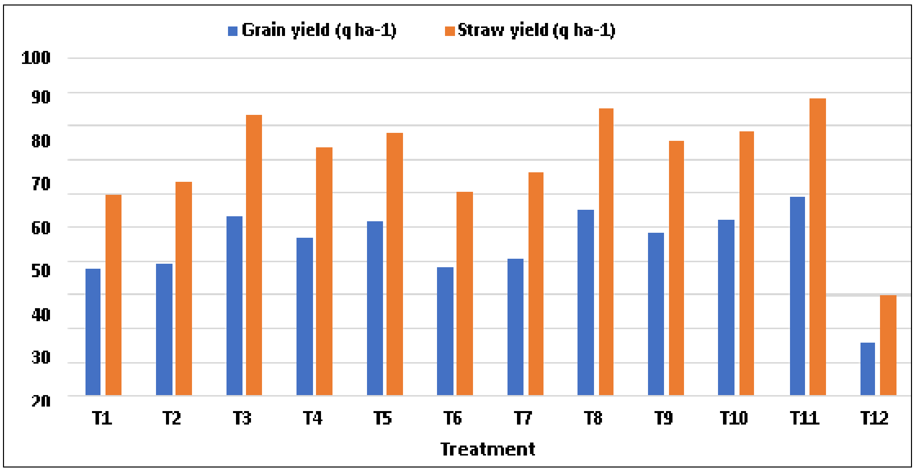

Fig 1: Grain yield (q/ha) and straw yield (q/ha) as influenced by integrated weed management practices in direct-seeded rice

Straw yield: An appraisal of data in Table 5 and graphically depicted in Figure 1 expressed that straw yield was significantly influenced by the different integrated weed management treatments. The higher values of straw yield was observed in the WFC (88.17 q/ha), and it was on par with treatments having integrated weed management treatments such as pretilachlor 30.7% EC at 0.450 kg/ha at 2-3 DAS (PE) *fb* hoeing at 25 DAS *fb* hand weeding at 40 DAS (T8; 85.04 q/ha) and oxyfluorfen 23. 5% EC at 0.150 kg/ha at 2-3 DAS (PE) *fb* hoeing at 25 DAS *fb* hand weeding at 40 DAS (T3; 83.39 q/ha). This might have resulted because of the better plant growth characters and yield attributes achieved by the reduced crop-weed competition in these treatments. It was closely followed by pretilachlor 30.7% EC at 0.450 kg/ha at 2-3 DAS (PE) *fb* bispyribac sodium 10% at 0.02 kg/ha at 25 DAS (POE) (T10; 78.31 q/ha), oxyfluorfen 23. 5% EC at 0.150 kg/ha at 2-3 DAS (PE) *fb* bispyribac sodium 10% at 0.02 kg/ha at 25 DAS (POE) (T5; 77.77 q/ha) and pretilachlor 30.7% EC at 0.450 kg/ha at 2-3 DAS (PE) *fb* metsulfuron-methyl + chlorimuron-ethyl at 0.004 kg/ha^{-1} at 25 DAS (POE) (T9; 75.43 q ha^{-1}).

Biological Yield: The total dry matter produced by a crop, including grain yield and straw yield, is referred to as biological yield. The data presented in Table 5 clearly shows that biological yield followed more or less the same trend as in grain yield and straw yield. The highest biological yield of 147.33 q ha^{-1} was observed in WFC, and it was on par with integrated weed management treatments including pretilachlor 30.7% EC at 0.450 kg/ha at 2-3 DAS (PE) *fb* hoeing at 25 DAS *fb* hand weeding at 40 DAS (T8; 140.28 q/ha) and oxyfluorfen 23. 5% EC at 0.150 kg/ha at 2-3 DAS (PE) *fb* hoeing at 25 DAS *fb* hand weeding at 40 DAS (T3; 136.80 q/ha). It was closely followed by pretilachlor 30.7% EC at 0.450 kg/ha at 2-3 DAS (PE) *fb* bispyribac sodium 10% at 0.02 kg/ha at 25 DAS (POE) (T10; 130.61 q/ha) and oxyfluorfen 23. 5% EC at 0.150 kg/ha at 2-3 DAS (PE) *fb* bispyribac sodium 10% at 0.02 kg/ha at 25 DAS (POE) (T5; 128.98 q/ha). These treatments were on par with pretilachlor 30.7% EC at 0.450 kg/ha at 2-3 DAS (PE) *fb* metsulfuron-methyl + chlorimuron-ethyl at 0.004 kg/ha at 25 DAS (POE) (T9; 123.74 q/ha) and oxyfluorfen 23. 5% EC at 0.150 kg/ha at 2-3 DAS (PE) *fb* metsulfuron-methyl +

chlorimuron-ethyl at 0.004 kg/ha at 25 DAS (POE) (T4; 120.48 q/ha). The treatments pretilachlor 30.7% EC at 0.450 kg/ha at 2-3 DAS (PE) *fb* hand weeding at 30 DAS (T7; 107.16 q/ha), oxyfluorfen 23. 5% EC at 0.150 kg/ha at 2-3 DAS (PE) *fb* hand weeding at 30 DAS (T2; 102.66 q/ha), pretilachlor 30.7% EC at 0.450 kg/ha at 2-3 DAS (PE) *fb* hoeing at 30 DAS (T6; 98.97 q/ha) and oxyfluorfen 23. 5% EC at 0.150 kg/ha at 2-3 DAS (PE) *fb* hoeing at 30 DAS (T1; 97.28 q/ha) noted significantly higher values of biological yield than the UWC (45.90 q/ha).

Harvest index: Harvest index is the proportion of economic yield or grain yield to the biological yield which is expressed in per cent or as a ratio (Donald, 1962). The data related to harvest index presented in Table 5 indicated that there was no significant effect of integrated weed management treatments on harvest index. The highest harvest index was observed in WFC (40.09%) and the lowest was in UWC (34.68%).

Economics

The data presented in Table 6 showed that the highest benefit:cost ratio was obtained for pretilachlor 30.7% EC at 0.450 kg/ha at 2-3 DAS (PE) *fb* bispyribac sodium 10% at 0.02 kg/ha at 25 DAS (POE) (T10; 2.32). It was followed by oxyfluorfen 23. 5% EC at 0.150 kg/ha at 2-3 DAS (PE) *fb* bispyribac sodium 10% at 0.02 kg/ha at 25 DAS (POE) (T5; 2.29), pretilachlor 30.7% EC at 0.450 kg/ha at 2-3 DAS (PE) *fb* metsulfuron-methyl + Chlorimuron-ethyl at 0.004 kg/ha at 25 DAS (POE) (T9; 2.14) and oxyfluorfen 23. 5% EC at 0.150 kg/ha at 2-3 DAS (PE) *fb* metsulfuron-methyl + Chlorimuron-ethyl at 0.004 kg/ha at 25 DAS (POE) (T4; 2.08). These treatments will give more than two rupees as return for every rupee invested. This implies the cost effectiveness of herbicide application rather than the manual weeding. This was followed by pretilachlor 30.7% EC at 0.450 kg/ha at 2-3 DAS (PE) *fb* hoeing at 25 DAS *fb* hand weeding at 40 DAS (T8; 1.90), oxyfluorfen 23. 5% EC at 0.150 kg/ha at 2-3 DAS (PE) *fb* hoeing at 25 DAS *fb* hand weeding at 40 DAS (T3; 1.83), pretilachlor 30.7% EC at 0.450 kg/ha at 2-3 DAS (PE) *fb* hand weeding at 30 DAS (T7; 1.60), oxyfluorfen 23. 5% EC at 0.150 kg/ha at 2-3 DAS (PE) *fb* hand weeding at 30 DAS (T2; 1.53), pretilachlor 30.7% EC at 0.450 kg/ha at 2-3 DAS (PE) *fb* hoeing at 30 DAS (T6; 1.50), WFC (1.50) and oxyfluorfen 23. 5% EC at 0.150 kg/ha at 2-3 DAS (PE) *fb* hoeing at 30 DAS (T1; 1.48), which were showed comparatively low value for B:C ratio might be due to the high cost incurred for manual weeding operations done in these treatments. The lowest B:C ratio was observed in UWC (0.74), which may be because of the lowest yield of crop obtained from UWC. Similar findings were also reported by Khaliq *et al.* (2012) [18], Bhurer *et al.* (2013) [8], Ghosh *et al.* (2016) [13] and Mohapatra *et al.* (2021) [24].

Table 6: Economics of direct-seeded rice as influenced by integrated weed management treatments

	Cost of cultivation (Rs/ha)	Gross monetary returns (Rs/ha)	Net monetary returns (Rs/ha)	B:C Ratio
T1	156773.0	231981.8	75208.8	1.48
T2	156773.0	239898.6	83125.6	1.53
T3	178023.0	326415.1	148392.1	1.83
T4	138483.0	287657.8	149174.8	2.08
T5	138160.5	316438.7	178278.2	2.29
T6	156045.5	234402.1	78356.7	1.50
T7	156045.5	249594.7	93549.2	1.60
T8	177295.5	337399.3	160103.9	1.90
T9	137755.5	295264.7	157509.2	2.14
T10	137433.0	319001.3	181568.4	2.32
T11	241045.5	360800.0	119754.5	1.50
T12	131685.5	97859.4	-33826.1	0.74
S.Em±	-	13662.8	13662.8	-
CD (P=0.05)	-	40071.6	40071.60	-
General mean	-	274726	115933	-

Summary and Conclusion

Integrated weed management treatments resulted in significant reduction in weed intensity and dry matter accumulation with higher weed control efficiency as compared to UWC. Among the integrated weed management treatments at 14 DAS, monocot weeds, dicot weeds, and sedges were efficiently controlled by all the integrated weed management treatments. Whereas, pretilachlor 30.7% EC at 0.450 kg/ha at 2-3 DAS (PE) *fb* hoeing at 25 DAS *fb* hand weeding at 40 DAS (T_8) and oxyfluorfen 23. 5% EC at 0.150 kg/ha at 2-3 DAS (PE) *fb* hoeing at 25 DAS *fb* hand weeding at 40 DAS (T_3) indicated the lowest weed intensity than any other treatments at the later stages of the crop up to harvest.

Based on the current field experiment results, it can be concluded that the integrated weed management treatment, pre-emergence application of pretilachlor 30.7% EC at 0.450 kg/ha at 2-3 DAS *fb* post-emergence application of bispyribac sodium 10% at 0.02 kg/ha at 25 DAS (T_{10}), improved the crop yield and was found to be the most economically-viable integrated weed management approach in the sub-montane zone of Maharashtra.

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