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Crop Establishment and Weed Management in Direct Seeded Rice: A Comprehensive Analysis

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ABSTRACT

Rice (*Oryza sativa* L.) is an important staple crop in India, where it is mainly grown by manual transplanting of seedlings into puddled soil. Recently, however, there is a trend toward dry- direct seeded rice (DSR) because of labour and water scarcity. In DSR, weeds are the main biological constraint. Herbicides are used to manage weeds in DSR systems, but the use of herbicides alone does not provide effective and sustainable weed control. Therefore, field experiment was conducted during rainy season 2008 and 2009to evaluate the effect of crop establishment methods and integrated weed management on weed dynamics, growth and yield of. Rice established by zero-till DSR with anchored residue had minimum density and dry weight of grasses, sedges, broadleaves and maximum weed control efficiency, yield attributes, grain yield (4562 and 4785 kg ha^{-1}), economics and moisture use efficiency. Among weed management methods, application of pendimethalin 1000 gha^{-1} fb azimsulfuron 35 g ha^{-1} at 15-20 DAS + one hand weeding at 40 DAS proved to be the most effective in lowering the weed density and dry weight of grassy and non-grassy weeds, enhancing the weed control efficiency, yield attributes, grain yield (5451 and 5542 $kgha^{-1}$), economics and moisture use efficiency during both the years of experimentation. Although, the result of this trial confirms the effect of different weed management practices on the grain yield of rice, but the findings prove the integration of different crop establishment methods and weed management practices will manage the weeds and enhance the yield of DSR.

***Key words**: Anchored residue, Direct seeded rice, Weed control efficiency, Yield attributes*

Introduction

Rice (*Oryza sativa* L.) is the staple food of more than half of the world's population (Birla *et al*., 2017). Rice accounts for 40% of all global irrigation, and 17% of global groundwater depletion. During the last five years' acreage, production and productivity of rice was found to be 45.5mha, 125.03 million tons and 4.1tons/ha respectively where *Kharif* and *Rabi* rice subsequently contributed 65% and 35% in total production. Water, energy and labor intensive manual or mechanical puddled transplanted rice (PTR) system is still the predominant method of rice establishment leading to soil degradation, environmental pollution, declined water table and increased cost of production (Chaudhary *et al*., 2023). In the last 5 years the area, production and productivity of rice has increased to about 3%, 7% and 4% respectively (Al Mamun *et al*., 2021). Declined water table, labor scarcity and climate change has triggered the need of alternative crop establishment of rice for scientific utilization of natural resources to maintain

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sustainability in Rice-Wheat production system in India.

Rice is a staple food for 65 percent Indian population and contributes nearly 30-50% of agricultural income (Yadav *et al*., 2013). Globally, India has the largest area under rice cultivation (42.56 m ha) and occupies second position in production (95.33 m t) after China with an annual productivity of 2.24 t ha^{-1} (Anonymous, 2011). Cultivation of rice by transplanting is most popular in India; however, it is highly labour intensive, expensive method of cultivation. Moreover, it requires large quantity of water for puddling, transplanting and establishment of rice seedlings. Puddling accounts for 30-40 per cent of total cost of rice cultivation and nearly one–third of total water required for crop production (Kalita *et al*., 2020). Direct Seeded Rice (DSR) may be one of the viable options for crop establishment to address the issues of soil health, environment degradation and climate change with low input demand as compared to puddled transplanted rice (Sandhu *et al*., 2021). As a matter of fact, most of the farmers are marginal, unable to bear the cost in carrying out these operations. In addition, long turn-around time and unpredictable monsoon rain delays the sowing of succeeding crop (Singh and Singh, 2010). Traditionally, rice used to be grown as broadcasted direct seeded rice (DSR) crop. However, this practice became redundant due to heavy weed infestation and non-availability of any appropriate post-emergence herbicide molecule for management of weed flora (Jat *et al*, 2010). Axiomatically, the weed growth in DSR is severe and is one of the serious limiting factors in realizing the yield potential of DSR (Rao *et al*., 2007). In view of water shortages and labor scarcity, farmers are again turning to direct-seeded rice systems, conducive to mechanization, for sustainability of rice production in irrigated ecosystems (Singh *et al*., 2013; Sandhu *et al*, 2021). The success of DSR depends upon the effective weed management.

Zero-till technology is a big boost to resource poor farmers as it advances planting time, save water, and is environmental friendly. A number of herbicides have been available in the Indian market which are selective in action, and have narrow spectrum of weed control. Thus, there is a great need for the use of wide spectrum herbicides, which can provide weed free environment to direct seeded rice (Singh *et al*., 2016). In addition, there is a need to integrate different weed-management strategies to achieve effective and sustainable weed control in conservation agriculture systems (Cordeau, 2022). Herbicides are used to manage either grassy or non-grassy weeds in rice, and none of the herbicide is available to manage both the types of weeds. Further, weeds emerge in direct seeded rice in different flushes, and pre-emergence application of herbicides fails to manage later emerging weeds after 3 weeks due to their short persistence (Saha, 2021). Therefore, the present study was undertaken to evaluate the comparative performance of different crop establishment methods of rice and to evaluate efficacy of herbicides alone or in combination of different herbicides along with hand weeding in different methods of direct-seeded rice establishment on weed density, weed dry weight, weed control efficiency, yield of rice and moisture use efficiency under the irrigated ecosystem of eastern Uttar Pradesh, India.

Materials and Methods

A field experiment was conducted on a sandy clay loam soil (Typic Ustochrept) during rainy season of 2008 and 2009 at the Agricultural Research Farm (25° 182 N latitude and 83° 032 E longitude with mean sea level of 128.9 m) of Banaras Hindu University, Varanasi, Uttar Pradesh, India. The experimental soil had a pH 7.2, organic carbon 0.43%, available N, P, and K contents 198, 24.6 and 210 kg ha^{-1}, respectively. Climatologically, Varanasi district has a subtropical climate and is subjected to extremes of weather conditions, i.e., extremely hot summer and cold winter. This region falls in semi-arid to subhumid type of climate. The total rainfall received during crop season was 1042.8 and 528.4 mm during 2008 and 2009, respectively. Distribution of rainfall was more uniform during first year as compared to second year in crop period. The crop received 2 and 4 irrigations during 2008 and 2009, respectively.

There were 3 crop establishment methods, namely zero-till DSR, zero-till DSR with anchored residues and reduced tillage DSR in main plot and nine weed management treatments (Table 1) in sub plot were tested in split plot design, and replicated thrice. Seeding was done with pre-sowing irrigation by tractor drawn zero- till drill machine in all the crop establishment methods without disturbing the soil, except in reduced till DSR, where two shallow ploughing by a cultivator followed by one planking. Dry seed of rice variety 'Sarjoo-52' was used at 30 kg/ha for seeding by zero-till drill fitted with flatted

roller. Crop was sown and harvested on 19 June on 30 October during both the year of experimentation. An uniform dose of 120 kg N, 60 kg P_2O_5, 60 kg K_2O, 5 kg Znha^{-1} was applied in all the treatments in the form of urea, DAP, MOP and $ZnSO_4$, respectively. Half of total N and full dose of P_2O_5, K_2O and Zn was applied as basal and remaining half dose of N was top dressed in two equal splits at active tillering and panicle initiation stage. Pre-emergence herbicide applied just after sowing whereas, post-emergence herbicide applied as per treatment. Herbicides are applied with the help of a hand-operated knapsack sprayer fitted with flat-fan three boom nozzles and water as a carrier at 600 liters ha^{-1}.

Data on weed density and dry weight were recorded at 40 DAS. For estimation of density, weeds are segregated into grasses, sedges and broad leaved weeds. To determine the effect of crop growth, data on plant height, tillers, plant dry matter accumulation and leaf area index were recorded at 90 DAS. Yield attributes, like panicle count was determined by counting the total number of panicle on five tagged plants and averaging them. A handful of grain was taken without any bias from total grains of the plot, after threshing and winnowing 1000 grains were counted and dried and then weight was recorded treatment wise in gram. The grain yield and straw yield of net plot area was recorded in gram and presented in kg ha^{-1}. Harvest index (HI) was calculated as per formula suggested by Donald (Donald and Hamblin, 1976).

Soil moisture content on weight basis was determined from 0-90 cm depth by gravimetric method (Black, 1965).

For computation of consumptive use of water, the amount of water-use by the crop under different treatments was computed in mm by summing up the value of soil-moisture depletion from the profile and effective rainfall by (Lenka, 1991). Moisture use efficiency (MUE) was calculated as ratio of grain yield to the consumptive use of water in mm and expressed as kgha^{-1}mm^{-1}.

$$MUE = \frac{Y}{CU}$$

Where,

Y refers to yield (seed) in kg ha^{-1} and CU consumptive use in mm.

The economics of different treatments were calculated by considering the prevailing market prices of inputs and outputs. The market price of rice grain was 24 and 22.5 US$ Q^{-1}, rice straw was 0.088 and 0.83 US$ Q^{-1}.

Statistical analysis

The SPSS (18) was used to analyze the data, including analysis of variance (ANOVA) and comparison of means based on a protected LSD procedure. Data on weed density were subjected to square root transformation ($\sqrt{x+0.5}$) before statistical analysis to normalize their distribution at 40 days after sowing. The parametric data was subjected to statistical

Table 1. Details of experimental treatment on rice during *Kharif* season of 2008 and 2009

Treatment details	Abbreviation
Crop establishment methods	
Zero-till dry direct seeded rice	Zero-till DSR
Zero-till dry direct seeded rice with residue	Zero-till DSR with residue
Reduced tillage dry direct seeded rice	Reduced tillage DSR
Weed Managements	
Weedy check	Weedy
Weed free	Weed free
2-Hand weeding (HW) (20 and 40 DAS)	2-HW
Glyphosate 1000 g/ha (PPI) fb pendimethalin 1000 g/ha (PRE) fb 2,4-D EE 500 g/ha (30 DAS)	Glypho *fb* pendi *fb* 2,4-D
Pendimethalin 1000 g/ha (PRE) fb 2, 4-D EE 500 g/ha (25 DAS) fb 1-HW (40 DAS)	Pendi *fb* 2,4-D *fb* 1-HW
Pendimethalin 1000 g/ha (PRE) fb metsulfuron + chlorimuran 4 g/ha (20 DAS) fb 1-HW (40 DAS)	Pendi *fb* Almix *fb* 1-HW
Pendimethalin 1000 g/ha (PRE) fb azimsulfuron 35 g/ha (18 DAS) fb 1-HW (40 DAS).	Pendi *fb* Azim *fb* 1-HW
Fenoxaprop 56 g/ha with safener + ethoxy-sulfuron 18 g/ha (20 DAS) fb 1-HW (40 DAS).	Fenoxa+Ethoxy *fb* 1-HW
Bispyribac 25 g/ha (25 DAS) fb 1-HW (40 DAS).	Bispyri *fb* 1-HW

DAS= Days after sowing, a.i.=active ingredient and fb=followed by

analysis as per the standard procedure given by Cochran and Cox (1957) and the significance was tested by F-test. Treatment mean differences were separated and tested by Fisher's protected least significant difference (LSD) at a significance level of $p \leq 0.05$. Interaction over the years and treatments were not found significantly due to homogeneity (not heterogeneity) of the data of experimentation.

Results and Discussion

During the period of this field investigation, significant variations in the meteorological data as shown in (Fig.1 and Fig.2) were observed. Precipitation during the rice crop seasons were 1042.8 and 528.4 mm in 2008 and 2009, respectively which had a significant influence on irrigation schedules. Similarly, the average temperature during September and October, coinciding with the reproductive stages of the crop, remained milder during the second year than the first year. Mention the predominant weed flora infestation during the crop season.

Effect of Crop Establishment Methods (CEM) and Weed management approaches on Weed Pressure

CEM exhibited significant variation on relative percentage of weed flora (Table 2). Irrespective of CEM grassy weeds contributed maximum percentage followed by sedges and broad-leaved weeds. Highest weed dry weight was recorded under reduced-till DSR which was 25-30 % higher over zero-till with anchored residue. Significantly higher density and dry weight of weeds recorded under reduced till DSR as compared to zero-till and zero-till with anchored residue.

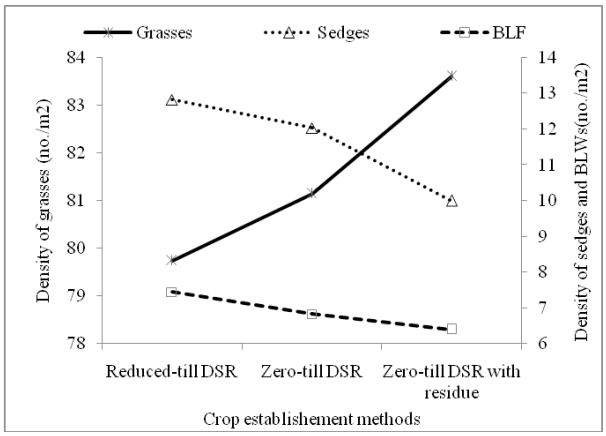

Fig. 2. Effect of crop establishment methods on total weed density and sedges and broad leaved weeds (Mean of two year)

Amongst weed management treatments, pendimethalin fb azimsulfuron + one HW 40 DAS was most effective weed management method in reducing density of weeds and their dry weight. The application of pendimethalin fb azimsulfuron + one HW 40 DAS recorded less number of grasses, sedges and broad-leaved weeds and higher weed control efficiency (77 and 78%) as compared to other weed management methods during both the years. Furthermore, application of only post-emergence herbicides, like Fenoxa+Ethoxy and Bispyri showed significantly higher density grasses and sedges as compared to sequential application of these herbicides where pendimethalin along with 1-HW.

Weed density was less in zero-till with anchored residues than the zero-till DSR and reduced-till DSR. Weed density was less in zero-till with anchored residues due to crop residues are known to modu-

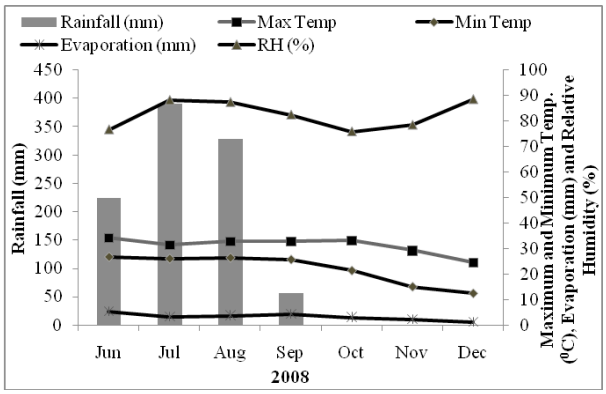

Fig. 1a

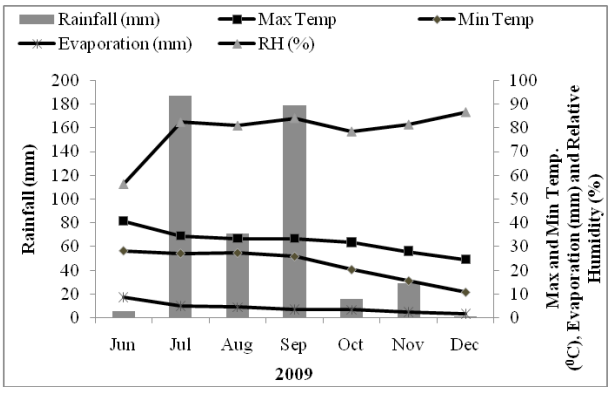

Fig. 1a

Fig. 1a & b. Monthly trends of maximum (max. temp.) and minimum (min. temp.) temperatures, relative humidity (RH), evaporation and rainfall, for the experimental period of year 2008-09.

late soil temperature in the rhizosphere which effects germinations of the weeds besides residues acting as a physical barrier for weeds emergence and growth, Singh *et al*., 2006. Singh *et al*., 2007; Malik and Singh, 1996; Singh *et al*., 2015 have also reported that residue play an important role in weed suppression. Higher weed density obtained under reduced-till DSR was due to favorable soil disturbance. Reduced tillage systems influence vertical weed seed distribution differently in the soil and this distribution of weed seed influence the relative abundance of weed species in the field (Pardo *et al*., 2019; Chauhan *et al*., 2006c; Chauhan and Johnson, 2009b). The application of pendimethalin fb azimsulfuron + one HW 40 DAS recorded less number of grasses, sedges and broad-leaved weeds as compared to other weed management methods during both the years due to the higher efficacy of combination was due to effective control of both narrow and broad-leaved weeds, Singh *et al*. (2010) and Pacanoski and Glatkova (2009). The poor control of weeds with only post-emergence herbicide may be attributed due to its poor efficacy against weeds in this treatment due to the large size of weed plants, which could be difficult to control by the alone application of post-emergence herbicides (Chauhan and Opena, 2012).

Occurrence of more number of weed species and higher density unit^{-1} area due to favourable soil disturbance for weed seed emergence and poor ground cover in absence of residue turned more weed competition, Mobli *et al*., 2022; Singh *et al*. (2007). This

Table 2. Effect of crop establishment methods and weed managements on density, dry weight and control of efficiency of weeds in DSR

Treatments	Grasses density[a] (number/m^2)		Sedges density[a] (number /m^2)		Broadleaf weeds density[a] (number /m^2)		Total weed dry weight[a](g/m^2)		Weed control efficiency (%)[a]	
	2008	2009	2008	2009	2008	2009	2008	2009	2008	2009
Crop establishment methods										
Zero-till DSR	10.25 (131.68)	9.27 (106.63)	4.00 (17.72)	3.84 (16.25)	2.89 (131.68)	2.64 (106.63)	6.35 (46.0)	5.95 (40.38)	58.57	64.49
Zero-till DSR with residue	9.92 (126.13)	8.96 (100.60)	3.72 (15.29)	3.71 (14.94)	2.74 (126.13)	2.48 (100.60)	6.02 (41.1)	5.76 (37.78)	60.67	68.22
Reduced tillage DSR	10.51 (138.25)	9.53 (113.40)	4.14 (19.58)	3.95 (17.38)	2.98 (138.25)	2.73 (113.40)	6.47 (47.7)	6.12 (42.94)	56.57	63.60
LSD (P=0.05)	0.29	0.26	0.11	0.11	0.075	0.068	0.182	0.172	-	-
Weed Managements										
Weedy	22.364 (499.82)	19.81 (392.29)	6.34 (39.89)	5.94 (34.92)	4.84 (499.82)	4.30 (392.29)	10.32 (106.06)	10.10 (101.57)	0.00	0.00
Weed free	0.71 (0.0)	0.71 (0.0)	0.71 (0.0)	0.71 (0.0)	0.71 (0.0)	0.71 (0.0)	0.71 (0.0)	0.71 (0.0)	100.0	100.0
2-HW	10.236 (104.40)	9.48 (89.60)	4.73 (22.61)	4.43 (19.57)	3.06 (104.41)	2.82 (89.60)	6.38 (40.28)	5.97 (35.21)	62.42	69.92
Glypho *fb* pendi *fb* 2,4-D	9.60 (91.90)	8.77 (76.57)	3.60 (12.61)	3.39 (11.09)	3.09 (91.90)	2.83 (76.57)	6.13 (37.19)	5.89 (34.18)	66.18	71.37
Pendi *fb* 2,4-D *fb* 1-HW	8.75 (76.28)	7.96 (62.87)	3.35 (11.18)	3.29 (10.46)	2.74 (76.28)	2.53 (62.87)	5.65 (31.47)	5.45 (29.20)	70.80	76.05
Pendi *fb* Almix *fb* 1-HW	10.89 (118.11)	9.86 (96.80)	4.05 (15.95)	3.87 (14.57)	2.93 (118.11)	2.67 (96.80)	6.73 (44.86)	6.24 (38.49)	64.55	68.27
Pendi *fb* Azim *fb* 1-HW	7.55 (56.64)	6.88 (47.04)	3.94 (15.10)	3.42 (11.28)	2.42 (56.64)	2.22 (47.04)	5.22 (26.76)	4.90 (23.67)	77.60	78.49
Fenoxa+Ethoxy *fb* 1-HW	11.68 (136.02)	10.55 (110.90)	3.59 (12.80)	4.42 (19.07)	3.18 (136.02)	2.89 (110.90)	8.02 (64.11)	7.35 (53.67)	38.17	49.91
Bispyri *fb* 1-HW	10.26 (105.00)	9.28 (85.80)	5.24 (27.59)	5.01 (24.73)	2.88 (105.00)	2.62 (85.80)	7.36 (53.86)	6.91 (47.33)	47.73	56.83
LSD (P=0.05)	0.24	0.21	0.08	0.08	0.062	0.055	0.144	0.136	-	-

Population and biomass figures are transformed to √*x+0.5 and actual figures are given in parenthesis
[a]Data recorded at 40 DAS

resulted in significant increase of weed dry weight under reduced-till DSR. Consequent upon above facts, zero till with anchored residue followed by zero-till resulted in lower weed dry weight. Whereas, pendimethalin fb azimsulfuron + one HW 40 DAS proved to be best control of weeds this may be attributed to more efficacy of the treatment which effectively control the weeds, mainly grassy and sedges weeds which was contributed maximum in total density of weeds. On the other hand, might be due to two-fold action of this combination that affected both narrow and broad-leaved weeds which resulted the lower dry weight of weeds. The poor performance of bispyribacand fenoxaprop + ethoxysulfuron was perhaps due to the fact that field was infected with complex weed flora and only herbicides unable to manage infestation of grassy and broad-leaved weeds properly. Pendimethalin fb azimsulfuron + one HW 40 DAS prove their greater effectiveness on complex weed flora, Singh *et al*., 2014; Singh *et al*. (2013).

Weed control efficiency denotes the relative efficacy of weed control treatments compared to weedy check. Among the weed management methods, pendimethalin fb azimsulfuron + one HW 40 DAS recorded highest weed control efficiency (77 and 78%) which was followed by pendimethalin fb 2,4-D + one HW 40 DAS (70 and 76%) during both the years. However, weed free treatment proved superior over every weed management methods. This was mainly due to weed free plot was kept weed free by hand weeding during crop season. Highest weed control efficiency was associated with pendimethalin fb azimsulfuron + one HW 40 DAS which attributed due to its effective control of complex weed flora *viz*. grasses, sedges and broad-leaved weeds. Alone application of herbicides recorded poor weed control efficiency as compared to sequential application due to control of only one group of weed flora, mainly grassy whereas sequen-

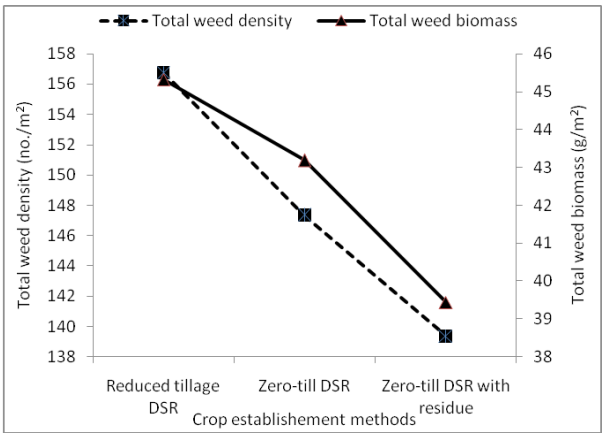

Fig. 3. Effect of crop establishment methods on density of grasses, biomass (Mean of two year)

Table 3. Effect of crop establishment methods and integrated weed management on growth attributes of direct seeded rice at 90 DAS

Treatments	Plant height (cm)		Tillers (m^{-1} row length)		Leaf area index (LAI)		Plant dry matter accumulation (m^{-1} row length in g)	
	2008	2009	2008	2009	2008	2009	2008	2009
Crop establishment methods								
Zero-till DSR	95.29	99.26	45.55	46.44	4.24	4.27	715.77	734.84
Zero-till DSR with residue	96.83	101.01	48.44	48.77	4.31	4.48	756.60	778.27
Reduced tillage DSR	92.31	95.85	46.85	47.71	4.17	4.21	705.92	728.19
LSD (P=0.05)	6.40	6.75	3.16	3.32	0.29	0.30	50.27	51.86
Weed managements								
Weedy	88.46	89.67	29.33	36.56	2.77	2.90	365.02	381.25
Weed free	102.32	107.78	60.78	61.00	4.93	5.22	876.10	911.14
2-HW	92.37	96.63	54.11	43.44	4.38	4.34	739.86	757.36
Glypho *fb* pendi *fb* 2,4-D	93.69	99.96	44.56	44.89	4.54	4.56	758.73	781.49
Pendi *fb* 2,4-D *fb* 1-HW	97.11	101.99	42.89	51.89	4.73	4.65	796.99	823.75
Pendi *fb* Almix *fb* 1-HW	94.44	96.03	47.44	40.56	4.18	4.23	728.36	740.43
Pendi *fb* Azim *fb* 1-HW	101.03	105.08	48.22	56.25	4.85	5.18	858.74	898.61
Fenoxa+Ethoxy *fb* 1-HW	90.42	93.20	48.44	48.44	3.71	3.78	698.19	707.53
Bispyri *fb* 1-HW	93.46	98.04	46.78	45.78	4.07	4.04	712.86	722.34
LSD (P=0.05)	3.90	4.10	1.95	1.92	0.06	0.06	30.40	31.22

tial application of herbicides included one hand weeding managed all the groups of weed flora. The better control of weeds by pre-emergence herbicides in early stages and control of later emerging weeds, particularly sedges and broad-leaved by post-emergence herbicide had been reported by Kumar *et al*., 2018; Bahar and Singh, 2004.

Effect of different crop establishment methods (CEM) and weed management approaches on crop growth and yield

The effect on growth attributes such as plant height, tillers m^{-1}, leaf area index, and dry matter accumulation of rice showed marked variation due to crop establishment methods (Table 2). Significantly taller plant (96 and 101 cm) was recorded under zero-till DSR with anchored residue followed by zero-till DSR (95 and 99 cm) and minimum in reduced-till DSR (92 and 95 cm) during both the years. Among all the weed management methods pendimethalin fb azimsulfuron + one HW 40 DAS recorded maximum (101 and 105 cm) plant height. Number of tillers, LAI and dry matter accumulation were recorded higher in zero-till with anchored residue method followed by zero-till and reduced-till DSR.

The maximum grain yield, biological yield and yield attributes, i.e. panicles $m^{-1}$and 1000-grain weight was recorded in zero till with anchored residue. This was followed by zero till and reduced till DSR establishment methods. Zero-till with anchored residue treatment produced 80% more yield than reduced till DSR. The yields of rice with all weed management methods were higher than that of weedy check (Table 4). Application of pendimethalin fb azimsulfuron + one HW 40 DAS showed greater efficacy in increasing the crop growth, yield attributes, grain and biological yield of DSR in comparison to other weed management treatments. The treatments which had higher weed control efficiency and yield attributing components produced higher grain yield. The minimum grain yield was recorded under weedy check which was attributed due to more weed growth, weed dry weight and poor yield attributing characters.

The effect on growth attributes such as plant height, tillers m^{-1}, leaf area index, and dry matter accumulation of rice showed marked variation due to crop establishment methods. Taller plants, tillers m-1, leaf area index and dry matter accumulation in zero-till with anchored residue field was probably due to lower weed infestation better initial establishment and suitable environment of growth which might have resulted more cell division and cell elongation in the meristematic tissues of plants which led to significant increase in the plant height (Gill *et al*., 2006). On contrary to this, reduced-till DSR method resulted significantly lower LAI and dry matter accumulation due to higher weed competi-

Table 4. Effect of crop establishment methods and integrated weed management on yield attributes,yield and economics of direct seeded rice

Treatments	Panicle count (number/m)		1000- grain weight (g)		Grain yield (q ha^{-1})		Biological yield (q ha^{-1})		Harvest index (%)	
	2008	2009	2008	2009	2008	2009	2008	2009	2008	2009
Crop establishment methods										
Zero-till DSR	236.3	247.6	24.14	24.88	39.2	41.0	100.6	100.5	41.17	41.41
Zero-till DSR with residue	253.6	266.7	26.06	27.27	45.6	47.9	104.8	104.6	41.38	42.05
Reduced tillage DSR	231.6	240.8	24.06	24.62	36.3	37.6	100.6	100.0	41.02	41.21
LSD (P=0.05)	17.0	17.9	1.66	1.72	2.9	3.0	7.1	7.0	2.80	2.81
Weed managements										
Weedy	173.7	179.3	21.85	22.36	20.3	21.9	59.6	59.2	35.74	36.80
Weed free	322.0	335.6	27.31	28.12	56.8	58.5	119.2	119.6	43.66	43.74
2-HW	233.0	244.0	24.19	25.27	40.0	41.7	109.9	109.6	41.71	41.96
Glypho *fb* pendi *fb* 2,4-D	248.7	265.2	25.13	26.04	44.0	45.8	107.1	106.5	42.46	42.53
Pendi *fb* 2,4-D *fb* 1-HW	274.3	298.8	25.43	26.38	47.2	49.3	113.1	113.3	42.77	42.77
Pendi *fb* Almix *fb* 1-HW	225.7	229.4	24.48	25.18	37.4	39.2	95.6	95.7	41.09	41.52
Pendi *fb* Azim *fb* 1-HW	310.0	320.5	26.34	27.52	54.5	55.4	119.3	118.5	43.23	43.33
Fenoxa+Ethoxy *fb* 1-HW	175.0	180.2	23.82	24.54	30.3	32.3	94.4	93.4	39.86	40.44
Bispyri *fb* 1-HW	202.0	212.0	24.23	24.89	32.9	35.2	99.5	99.7	40.20	40.93
LSD (P=0.05)	10.1	10.6	1.01	1.05	1.7	1.8	4.2	4.2	1.69	1.70

tion reduced plant height, tillers m^{-1} row which reflected in term of lesser LAI and dry matter accumulation at each stage. Similar results have been reported by Matloob *et al*., 2015; Tsai *et al.* (1986). Among all the weed management methods pendimethalin fb azimsulfuron + one HW 40 DAS recorded maximum growth attributes due to less weed density and weed dry weight.

The reduction in weed competition in rice by use of weed management practices with crop establishment methods not only favoured the crop plant with abundance availability of moisture, nutrients, light and space but also reduced over all weed interference, facilitating vigorous development of crop plants, Dass *et al*., 2017; Kathirvelan and Vaiyapuri (2004); Singh *et al*. (2009) They reported that the treatment, which had minimum total weed dry weight, produced maximum tillers, LAI and dry matter accumulation.

Maximum grain and biological yield was recorded from zero-till with anchored residue followed by zero-till and reduced-till DSR. Yield attributes, which determine yield, is the resultant of the vegetative development of the plant. Yield attributing characters are the function of growth and development that developed during vegetative phase of the plant. Higher value of yield attributes recorded under zero-till DSR with anchored residue was perhaps due to better partitioning of photosynthates from source to sink as a result of lower crop weed competition and better crop growth which was obtained owing to favourable growing condition in this establishment method. Better partitioning of photosynthates may occur due less crop-weed competition in zero-till in the presence of residue produced a good yield obtained by Alhammad *et al*., 2023; Kandasamy and Chinnusamy (2005). Thus, the result indicated that increase in yield contributing characters in pendimethalin fb azimsulfuron + one HW 40 DAS treatment was owing to low weed growth, minimum weed competition during critical growth period. As a result these conditions enabled the crop to make maximum use of inputs for the crop growth, and thereby for the formation and development of yield attributes. Yaduraju and Mishra, (2004), have also reported that the crop which had minimum weed growth during the critical period of crop growth had better growth and yield attributes. The increased grain and biological yield in zero-till with anchored residue and pendimethalin fb azimsulfuron + one HW 40 DAS treatment was perhaps the result of reduced weed dry weight, better weed control efficiency, and the improvement of yield attributes like number of $panicle^{-1}$ m row and

Table 5. Effect of crop establishment methods and integrated weed management on yield attributes, yield and economics of direct seeded rice

Treatments	Cost of cultivation (US$ ha^{-1})		Net return (US$ ha^{-1})		B: C ratio		Crop profitability (US$ ha^{-1} day^{-1})		Crop productivity (kg ha^{-1} day^{-1})	
	2008	2009	2008	2009	2008	2009	2008	2009	2008	2009
Crop establishment methods										
Zero-till DSR	332.475	311.6953	658.153	658.0019	2.0	2.1	4.91	4.87	29.3	30.4
Zero-till DSR with residue	332.475	311.6953	818.7595	819.1226	2.4	2.6	6.11	6.07	34.0	35.4
Reduced tillage DSR	359.1417	336.6953	557.5556	553.7612	1.5	1.6	4.16	4.10	27.1	27.9
LSD (P=0.05)	22.74118	21.31986	51.06617	50.33259	0.2	0.2	0.38	0.37	1.29	2.24
Weed manazgements										
Weedy	313.5022	293.9083	206.5423	230.1473	0.7	0.8	1.54	1.70	15.2	16.2
Weed free	355.1689	332.9708	1074.179	1045.085	3.0	3.2	8.02	7.74	42.4	43.3
2-HW	341.28	319.95	668.4119	667.3389	2.0	2.1	4.99	4.94	29.9	30.9
Glypho *fb* pendi *fb* 2,4-D	334.4133	313.5125	773.646	769.0875	2.3	2.5	5.77	5.70	32.8	33.9
Pendi *fb* 2,4-D *fb* 1-HW	349.8577	327.9916	839.8726	835.2201	2.4	2.6	6.27	6.19	35.2	36.5
Pendi *fb* Almix *fb* 1-HW	348.1244	326.3666	596.8771	601.964	1.7	1.9	4.45	4.46	27.9	29.0
Pendi *fb* Azim *fb* 1-HW	349.3011	327.4698	1022.628	979.9414	2.9	3.0	7.63	7.26	40.7	41.1
Fenoxa+Ethoxy *fb* 1-HW	340.6115	319.3233	428.3965	447.5853	1.3	1.4	3.20	3.32	22.6	23.9
Bispyri *fb* 1-HW	340.0161	318.7651	492.851	516.2877	1.5	1.6	3.68	3.82	24.5	26.1
LSD (P=0.05)	13.8577	12.99159	30.59341	30.24193	0.1	0.1	0.23	0.22	2.18	1.33

Sale price rice grain =24 and 22.5 US$ Q^{-1}, rice straw = 0.088 and 0.83 US$ Q^{-1} and common cost =304 and 285US$ ha^{-1}, respectively.

1000-grain weight of the crop. The minimum grain and biological yield was recorded under reduced-till DSR. This may be due to higher weed density and their dry weight, crop weed competition and lower yield attributes Kumar *et al*., 2015; Singh *et al.* (2005c), Singh *et al.* (2006a) and Yadav *et al.* (2004).

Weed management methods also influenced the grain and biological yield during both the years. On the other hand, treatments which had higher yield attributing components and weed control efficiency (Table 4) produced higher grain and biological yield. The minimum grain yield was recorded under weedy check which was attributed due to maximum weed density, dry weight and poor yield attributing characters (Chinnusamy *et al*., 2006; Chauhan and Yadav, 2013).

Effect of different crop establishment methods (CEM) and weed management approaches Soil moisture use and moisture use efficiency (MUE)

The high stored soil moisture at sowing and *kharif* rains (277.4 and 284.7 mm during both years) at panicle initiation stage to maturity increase consumptive use of water due to increased availability of soil moisture to plant. Zero till DSR with anchored residue was more moisture use efficiency due to residue increased and conserve the soil moisture. The weed management method increase MUE due to their adequate weed suppression by weed management method. Application of pendimethalin fb azimsulfuron + one HW 40 DAS resulted increase in WUE.

Moisture conservation and moisture use efficiency were higher in zero-till DSR with anchored residue due to residue act as a cover to the soil surface which conserve the moisture and pendimethalin fb azimsulfuron + one HW 40 DAS application maintain less weed occurrence resulted less crop weed competition for moisture.

Economics of different crop establishment methods (CEM) and weed management approaches on growth and performance of crop

Zero-till DSR with anchored residue recorded maximum net returns followed by zero-till DSR, and reduced-till DSR during first and second year, respectively. Similarly, the benefit: cost ratio was higher under zero-till with anchored residue (2.4 and 2.6), than zero-till (2 and 2.1), and reduced-till DSR (1.5 and 1.6) during first and second years, respectively (Tables 4). The data on economics of various crop establishment methods revealed that the higher cost of cultivation 359US$ 336 US$ $ha^{-1}$was recorded under reduced till DSR treatment. Net return (818 and 819 US$ ha^{-1}), benefit: cost ratio (2.4 and 2.6), crop profitability (4.91 and 4.8 US$ $ha^{-1}day^{-1}$ and crop productivity (34.0 and 35.4kg $ha^{-1}day^{-1}$) was maximum in Zero-till DSR with anchored residue and being significantly over zero-till DSR and reduced till DSR.

Table 6. Effect of crop establishment methods and weed managements on moisture use efficiency of direct seeded rice

Treatments	Moisture (mm) on weight basis in (0-90 cm soil profile)				Depletion (mm)		Effective rainfall (mm)		Consumptive use (mm)		Moisture use efficiency ($kgha^{-1}mm^{-1}$)	
	At sowing		At harvest									
	2008	2009	2008	2009	2008	2009	2008	2009	2008	2009	2008	2009
Crop establishmentmethods												
Zero-till DSR	277.4	284.7	177.0	183.0	100.4	101.7	1042.8	528.4	1143.2	630.1	4.0	7.6
Zero-till DSR with residue	277.4	284.7	190.5	194.7	86.9	90.0	1042.8	528.4	1129.7	618.4	3.5	6.6
Reduced tillage DSR	277.4	284.7	178.7	182.6	98.7	102.1	1042.8	528.4	1141.5	630.5	3.2	6.0
LSD (P=0.05)	-	-	12.60	10.80	11.40	10.10	NS	NS	38.00	22.70	1.39	2.97
Weed Managements												
Weedy	277.4	284.7	186.2	192.2	91.2	92.5	1042.8	528.4	1134.0	620.9	1.8	3.5
Weed free	277.4	284.7	182.5	185.0	94.9	99.7	1042.8	528.4	1137.7	628.1	5.0	9.3
2-HW	277.4	284.7	175.4	180.3	102.0	104.4	1042.8	528.4	1144.8	632.8	3.5	6.6
Glypho *fb* pendi *fb* 2,4-D	277.4	284.7	190.4	192.2	87.0	92.5	1042.8	528.4	1129.8	620.9	3.9	7.4
Pendi *fb* 2,4-D *fb* 1-HW	277.4	284.7	182.5	185.0	94.9	99.7	1042.8	528.4	1137.7	628.1	4.2	7.8
Pendi *fb* Almix *fb* 1-HW	277.4	284.7	175.4	181.7	102.0	103.0	1042.8	528.4	1144.8	631.4	3.3	6.2
Pendi *fb* Azim *fb* 1-HW	277.4	284.7	190.4	192.2	87.0	92.5	1042.8	528.4	1129.8	620.9	4.8	8.9
Fenoxa+Ethoxy *fb* 1-HW	277.4	284.7	184.0	189.1	93.4	95.6	1042.8	528.4	1136.2	624.0	2.7	5.2
Bispyri *fb* 1-HW	277.4	284.7	175.4	185.4	102.0	99.3	1042.8	528.4	1144.8	627.7	2.9	5.6
LSD (P=0.05)	-	-	8.90	7.60	9.7	9.1	NS	NS	29.50	16.30	1.07	2.73

Among all the weed management methods was being significantly affected on economics. Higher cost of cultivation (355 and 332 US$ ha^{-1}), net return (1074 and 1045US$ ha^{-1}), benefit: cost ratio (3 and 3.2), crop profitability (8 and 7 US$ ha^{-1}day^{-1}) and crop productivity (42.4 and 43.3 kg ha^{-1}day^{-1}) was obtained under weed free treatment. In pendimethalin fb azimsulfuron + one HW 40 DAS Higher net return (1022 and 979 US$ ha^{-1}), benefit: cost ratio (2.9 and 3.0), crop profitability (7.63 and 7.26 US$ ha^{-1}day^{-1}) and crop productivity (40.7 and 41.1 kg ha^{-1}day^{-1}) during both the years, respectively.

The adoption of any technology in modern agriculture can only be feasible and acceptable to farmers if it is economically viable. Economic viability is a function of gain and loss. The gross return obtained by yield of crop varied markedly due to different treatments, which ultimately influenced the net return and benefit: cost ratio. Zero-till DSR with anchored residue recorded maximum net returns followed by zero-till DSR, and reduced-till DSR. Similarly, the benefit: cost ratio was higher under crop establishment methods zero-till DSR with anchored residue and among weed management methods application of pendimethalin fb azimsulfuron + one HW 40 DAS during first and second years, respectively. This is mainly due to low production cost and higher grain and straw yield under these treatments which led to maximum net return and benefit: cost ratio. In reduced-till DSR, field preparation increased the cost of cultivation in one hand and production of lower grain yield in other hand, which resulted lower net profit as compared to zero-till DSR and Zero-till DSR with anchored residue. Similar views have been expressed by Yadav *et al*., 2021; Singh *et al*., 1999; Budhar and Tamilselvan, 2002.

Conclusion

The study reveals that zero till DSR with anchored residue can be used to achieve the significantly higher growth, yield attributes, yield, moisture use efficiency and better resources utilization with maximum profit followed by zero till DSR with application of pendimethalin fb azimsulfuron + one HW 40 DAS in irrigated condition which provide good control of complex weed flora.

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