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Effect of sequential application of pre and post-emergence herbicides on dynamics of weeds associated with DSR system andrice-growth and sustained yield

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ABSTRACT

The sustained rice yield plays an important role in the country's GDP. The diverse weed flora is a potential biotic threat to the sustained yield in the DSR system. The crop faces severe competition the resources from its beginning (germination of crop seedlings) to the panicle initiation with the diverse weeds flora as it grows quickly in moist conditions, resulting in severe yield losses up to 65 per cent. Thus, an effective and economical weed control strategy in DSR is often required to overcome the losses. In such situations, sequential application of herbicides may provide broad-spectrum weed control in DSR. A field experiment was conducted on silty loam soils to assess the herbicidal effects on weed dynamics and growth & yield productivity of direct-seeded rainy (Kharif) rice at Agronomy Research Farm of Narendra Deva University of Agriculture and Technology, Kumarganj, Ayodhya (U.P.) during the years, 2016 and 2017. The field trial was carried out in Randomized complete block design (RCBD) with three replications and twelve treatments. The treatments consisted of nine pre & post-emergent herbicide combinations along with three distinct controls, i.e. a) Hand weeding (at 20 & 40 DAS), b) Weed Free (weeding at every 15 days interval from seedling to the PI stage), and c) Weedy Check. The results of the field study revealed that the weed-free plots recorded the highest weed control efficiency, and they registered the least weeds density and dry weight of weeds associated with direct seeded rice fields. However, the application of herbicides, namely, pendimethalin (1000 g a.i. ha^{-1}) as pre-emergent and Bispyribac-Na (1000 g a.i. ha^{-1}) as post-emergent coupled with a hand weeding at 40 DAS provided the statistically comparable results to weed-free and is effectively controlled the diverse weed flora by 81.9-84.5 per cent in DSR system. And both the treatments gave significantly better growth (plant height, number of tillers, dry matter, LAI) and yields (grain and straw) of rice as compared to the weedy-check. Among the diverse weeds associated with the DSR fields, sedges were dominant as compared to broad leaves and grasses. The study also recorded the rice-grain yield reduction by 40.9 per cent due to the presence of diverse weed flora in weedy check plot as to weed-free plot.

Keywords: direct-seeded rice, diverse weed flora, effective weed control option, herbicide-tolerant rice, pre & post-emergence herbicides, sequential herbicide application, sustained rice yield, weed-free, weed menace,

INTRODUCTION

Rice (*Oryza sativa* L.) is a staple food for more than half the world's population [1] and more than 90% of Asian populations [2] with high calorific value, and country like India's food security system largely depends on rice productivity as it is grown in a vast area covering 44.1 mha [3]. Rice growers have witnessed that transplanted rice (TPR) with better fertilizer application is a unique system that produces the ever-highest grain yield (106.5 MT) though it requires more water and labour. However, DSR is a good alternative to TPR in changing climate and overwhelming situations of irrigation water shortage and escalating labour shortages coupled with higher wages in agriculture have brought a paradigm swing in rice cultivation and are gaining the attention of the farmers as it produces the similar yield as compared to TPR [4] under good water management and efficient weed control conditions [5,6]. DSR saves water by 40-46 per cent, reduces the total duration by 8-10 days as well as engages fewer agricultural labours, and reduces negative environmental footprints. Despite all these recompenses, the potential yield losses through enormous weed menaces under DSR and remains a challenge and may reduce yield by up to 50% [7]. DSR avoids three basic operations; namely, puddling (a process where the soil is compacted to reduce water seepage), transplanting and maintaining standing water [8].

Despite these compensations, the major snag with practicing DSR is the potential biotic threat posed by diverse weeds flora

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and their rigorous growth and wide infestation,causing severe yield losses up to 50-90% [9], and therefore, the weed menace is aggravated. In DSR, weeds emerge simultaneously with the germination of crop seedlings and grow more quickly in moist soil resulting in severe competition for resources to the crop, namely, nutrients, light, water, space, and CO_2. Therefore, an effective and economical weed control strategy is to be required to meet the demand for staple food for the increasing population.

The major weed problem is sought to be addressed from two basic points: weed control and weed management. The control approach only emphasises on reduction of weed pressure by mechanical, cultural and chemical methods and the management approach, by contrast, focuses on keeping weed infestation at a level compatible with environmentally and economically sustainable production. The mechanical method of weed control consisted of repeated weeding and hoeing using "*Khurpi/Hoe/Weeder*", which is highly effective but labour-intensive and it ultimately reduces the overall profitability. Hence, for DSR, the herbicide-dominant integrated weed management best-suited option as it can take care of weeds right from the beginning of crop growth and is cost-effective [10].

Aerobic soil conditions and alternate wetting and drying in DSR are conducive to the germination and growth of weeds, causing grain yield losses of up to 80%. The critical period of weed competition in DSR remains up to 45 days after sowing (DAS), yet a weed-free situation until 70 DAS remains desirable for higher productivity [11]. The weed species diversity in DSR fields remains greater than TPR in general and grassy weeds (*Echinochloacrusgalli*) and sedges (*Fimbristylis miliacea, Cyperus rotundus, Cyperus iria and Cyperus difformis*) in particular [41].

It is [12] mentioned that farmers generally apply herbicides by mixing them in the sand for easy operation, and they prefer to use a single application of pre and/or post-herbicides which fails to control diverse weed flora associated with DSR. However, the excessive use of herbicides for the control of annual grasses shifted the dominant species from grasses to broad-leaf weeds and sedges and from annuals to perennials. The advent of direct seeding and insufficient water supply is perceived as factors responsible for the shift in weed species dominance and diversity in rice ecosystems. Therefore, A single weed control approach may not be able to keep weeds below the threshold level of economic damage and may result in a shift in the weed flora, resistance development and environmental hazards. Multiple setbacks to weeds seem to be the best strategy to control weeds in DSR. Nonetheless, it is important to use a diverse technology and broad-spectrum herbicide program, including the sequential application of pre and post-herbicides for achieving season-long effective and sustainable weed control and to avoid shifts toward problematic weed species and the evolution of herbicide-resistant weed biotypes.

We all know that pesticides (herbicides) are generally toxic, so they have to be handled carefully to reduce or avoid excessive and costly wastes, environmental concerns, crop damage, damage to adjacent crops by spray drift, injury to the applicator, excessive contamination and residues, and injury to beneficial organisms. It is advisable to rotate the herbicide combination each year to delay the development of herbicide resistance in weeds. Keeping the above facts in view, the present study entitled *Effect of sequential application of pre & post-emergent herbicides coupled with cultural/mechanical practices on weed dynamics, growth and yield of direct seeded rice* was undertaken with broader aims to find out the best sequential herbicide options for effective weed control in DSR.

MATERIALS AND METHODS

This field study was carried out at the Agronomy Research Farm of Narendra Deva University of Agriculture and Technology, Kumarganj, Ayodhya (Uttar Pradesh, India),during the wet season (*Kharif*) of 2016 and 2017. The soil type of the experimental field was silty loam with a slightly alkaline (pH range 8.1-8.3) reaction. The field was poorly fertile, being moderately low in organic content (0.39-0.53), available nitrogen (142.6-147.5 kg ha^{-1}) & phosphorus (14.3-15.7 kg ha^{-1}), and medium in potassium (256.1-268.4 kg ha^{-1}). The Awadh region is popularly known for course rice cultivation, and Rice-wheat is the predominant cropping system. The experiment was conducted in Randomized Complete Block Design (RCBD) with twelve treatments and three replication. The treatments consisted of nine Pre and Post-emergence herbicide sequential combinations, namely, ***1)*** *Bispyribac-Na (Post) @ 25g ha^{-1}*, ***2)*** *Pendimethaline (Pre) followed by (Fb) Bispyribac-Na (Post) @ 1000 g Fb 25g ha^{-1}*, ***3)*** *Oxidiragyl (Pre) Fb Bispyribac-Na (Post) @ 100 Fb 25 g ha^{-1}*,***4)*** *Pyrazosulfuron (Pre) Fb Bispyribac-Na (Post) @ 20 Fb 25g ha^{-1}*, ***5)*** *Bispyribac-Na + almix (Post) @ 25 g + 4 g ha^{-1}*, ***6)*** *Pendimethaline (Pre) Fb Bispyribac-Na (Post) @ 1000 g Fb 25g ha^{-1} + HW 40 DAS*, ***7)*** *Oxadiragyl (Pre) Fb Pretilachlor(Post) @ 100 Fb 1000g ha^{-1}*, ***8)*** *Pendimethaline (Pre) Fb Pretilachlor (Post) @ 1000 Fb 1000 g ha^{-1}*, ***9)*** *Pendimethaline (Pre) @ 1000g ha^{-1} Fb HW (20 DAS), along with three distinct controls i.e.* ***10)*** *Hand weeding (done at20 & 40 DAS)*, ***11)*** *Weed-Free (weeding at every 15 days interval from crop establishment to panicle initiation stage) and* ***12)*** *Weedy-Check*.

The stale seedbed (SSB) technique was commonly practised, which is highly effective against weedy rice, volunteer rice seedlings and viable seed banks of diverse weed flora, particularly *C. rotundus*, *E. colona*, *Dactyloctenium aegyptiumto*, *Digitaria ciliaris*, *L. chinensis* and *Eclipta prostrata*. In this technique, pre-sowing irrigation was supplied to the study field and the left it as such for 10 days, weeds were allowed to germinate there and thereafter the emerged weed seedlings were killed by a tank mixed application of the non-selective post-emergence herbicides namely, paraquat and glyphosate.

The pre-soaked seeds of the test variety "NDR-97 were drill-seeded at a rate of 60 kg ha^{-1} with a Zero-till cum-fertilizer drill, at 2-3 cm soil depth. Subsequently, light irrigation was provided after seeding. The herbicides were applied as per treatment using a battery operated back-pack knapsack sprayer fitted with a flat-fan nozzle and calibrated to deliver 750 litre ha^{-1} for pre-emergent and 500 litres ha^{-1} for post-emergent herbicidal spray, respectively. The pre-emergent herbicides namely Oxadiargyl (with 10 kg sand mixed application) broadcasted in standing water (2-3 cm) after irrigation on the day of seeding, and pendimethalin was sprayed on the second day of light irrigation. Similarly, all the post-emergent herbicides, except oxadiargyl, were applied at three-to four-leaf stage of rice (22-25DAS) and the sequential application of oxadiargyl (post) was applied at the two to three leaf stage of rice (15-18 DAS).

The crop was raised following the standard recommended practices for the state. The fertilizers, 120 kg N + 60 kg P + 60 kg K + 25 kg $ZnSO_4$ per hectare was applied through urea, DAP, MOP and $ZnSO_4$, respectively. The full dose of phosphorus, potassium and Zn was applied as a basal and the N was top dressed into four equal splits at the active tillering (25 and 40DAS), booting

(60DAS) and panicle initiation (75DAS) stages, respectively. The crop was supplemented by 4 and 3 irrigations only in 2016 and 2017, respectively as these years coincided with good rainfall (820 and 1010 mm). The second year of field experimentation received a uniform distribution of rainfall as compared to the first year in the cropping period. The test crop took 123-125 days from seed to seed.

Data on the dry weed weight (biomass) and weed density were determined at 50 and 75DAS from a randomly taken 1 m^2 quadrat in each plot. The weeds were cut from the ground level, washed with tap water, and sun-dried followed by oven drying at 65°C ± 2 for 40-48 hours (till the constant weight was attained) for recording the observation on weeds biomass however, weed density was subjected to square root transformation (x+0.5) before statistical analysis to normalize their distribution. Visual injury (25 and 45DAS) was evaluated for the test crop based on chlorosis, and stunting, whereas visual weed control included chlorosis, necrosis and plant stand reduction as well. To determine the effect of crop growth, data on plant height (cm), tillers (m/row), plant dry matter (g/m row) and leaf area index were recorded at 50 and 75 days after sowing. Weed control efficiency and weed index were calculated using following formula given by [13] and [14].

$$WCE = \frac{WPC - WPT}{WPT} x\ 100$$

Where WPC = Weed population in ctheontrol plot

WPT = Weed population in the treated plot

$$WI = \frac{X - Y}{Y} x\ 100$$

Where X= Yield from minimum weed competition plot

Y= Weed from treatment for which WI is to be worked out

Data were subjected to analysis of variance using SAS 9.3 version software with randomized complete block design (RCBD) with three replications where treatments and fields were fixed during both years of field study. Means were separated using Fisher's protected LSD at 5% probability (P=0.05).

Result And Discussion

Weed density: The weed density, irrespective of weed species in the weedy check plot, correspondingly increased with the growth of crops up to 75DAS and it subsequently decreased. Similarly, the *Echinochloa crusgalli* and *C. auxillaris* were the most dominant weeds among the narrow-leave (NLWs) and broad-leave weeds (BLWs) in the weedy check plot during the crop growing period. However, some other BLWs,e.g.*Phyllanthus niruri* and Sedges like *Cyperus rotundus* and *Cyperus iria* were also present in significant numbers. By and large, the dominancy of BLWs was more over NLWs and sedges. The experimental results of this study reveal that weed density per unit area was significantly decreased in treated plots over the weedy check at both the growth stages (50 and 75 DAS). The sequential application of Pendimethalin (1000 g ha^{-1}) and Fb Bispyribac-Na (25g ha^{-1}) was found at par with the same treatment coupled with one-hand weeding at 40DAS and application of Oxidiragyl (100 g ha^{-1} as PE) *Fb* Bispyribac-Na (25 g ha^{-1} as PoE). All three combinations of treatments were found to be more effective in reducing the weeds density as compared to other herbicide treatments (table-1) during the first and second years of field study, respectively. This might be because of Bispyribac-Na controls the young grassy weeds and pendimethalin controls the grassy and BLWs more effectively on weed emergence. However, sequential application of Pre after-PoE herbicides was effectively controlling all the weed species fairly compare to alone application and some other herbicides. Likewise, Pretilachlor (750 gha^{-1}as PE)and Fb ethoxysulfuron (18.75 g ha^{-1}as PoE) showed better control of sedges along with grassy and BLWs during both the years. Similar results were found by other workers [15] and [16].

Weed dry matter accumulation (g/m^2):

The dry matter of total weed species correspondingly increased with the advancement of crop age and it was found to be the maximum at the 75th-day stage, thereafter, it was observed decreasing trend. The rate of increase in dry weight accumulation in weeds showed an up-and-down trend and this trend might be due to the emergence of new weed species and the senescence of the common weed species *viz. E. crusgalli, E. colona, P. niruri, C. auxillaris* and *C. rotundas* in different growth phases. Our field study recorded that the weed dry matter accumulation reduced appreciably due to the application of different treatments as compared to weedy checks; This reduction inweed dry weight was due to treatments executed in rice fieldsthat effectively controlled the weeds. Treatment effects varied depending on the time of application. The plots treated with Pendimethalin (1000g ha^{-1}as PE) Fb Bispyribac-Na (25g ha^{-1}PoE) recorded the lowest dry matter accumulation and it was at par with the plot treated with the same herbicides coupled with one additional hand weeding at 40 DAS and the plot treated with Oxidiragyl (100g ha^{-1} as PE) Fb Bispyribac-Na (25 g ha^{-1}PoE). These treatments were significantly superior in respect of reducing the dry matter production of weeds during 2016 and 2017, respectively. However, other treatments T_9: Pendimethalin Fb HW (at 20 DAS) being at par with T_{10}: Hand Weeding (at 20 and 40 DAS) also declined the weed dry weight fairly and T_5: Bispyribac + Almix effectively controlling grassy and broad leaf weeds. However, the plot treated with a sole application of Bispyribac-Na 25 g ha^{-1} (PoE) failed to control the full spectrum of diverse weeds up to the critical growth stages but it controlled more effectively the grassy weeds particularly, *E. colona* and *E. crusgalli*. These herbicides when supplemented with BLWs killer herbicide proved to be very effective in superimposing manual weeding. These results were also in conformity with the work of fellow researchers [17, 18 and 19].

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

The results of our study suggest that herbicide treatments were highly effective inreducing weed density and weed index by more than 72%, and reduced the weed competition for resources and space to the cropduring field study. The maximum weed control efficiency (100 per cent) was recorded with a weed-free plot and it closely followed by T_6: Pendimethalin Fb Bispyribac-Na + HW (40 DAS), T_2: Pendimethalin *fb* Bispyribac-Na (1000 Fb 25g ha^{-1}) and T_3: Oxidiragyl *fb* Bispyribac-Na (100 Fb 25 g ha^{-1}) and they remained statistically superior when compared to other herbicidal treatments and the weedy check which had the least WCE during the first and second years of study. Among the herbicidal applications, Pendimethalin Fb Bispyribac-Na + HW (40 DAS) was found much more effective to control all types of weeds as it enhanced its bio-efficacy to control the grassy and BLWs and recorded the lowest value of weed index (1.82 and 3.88 %).

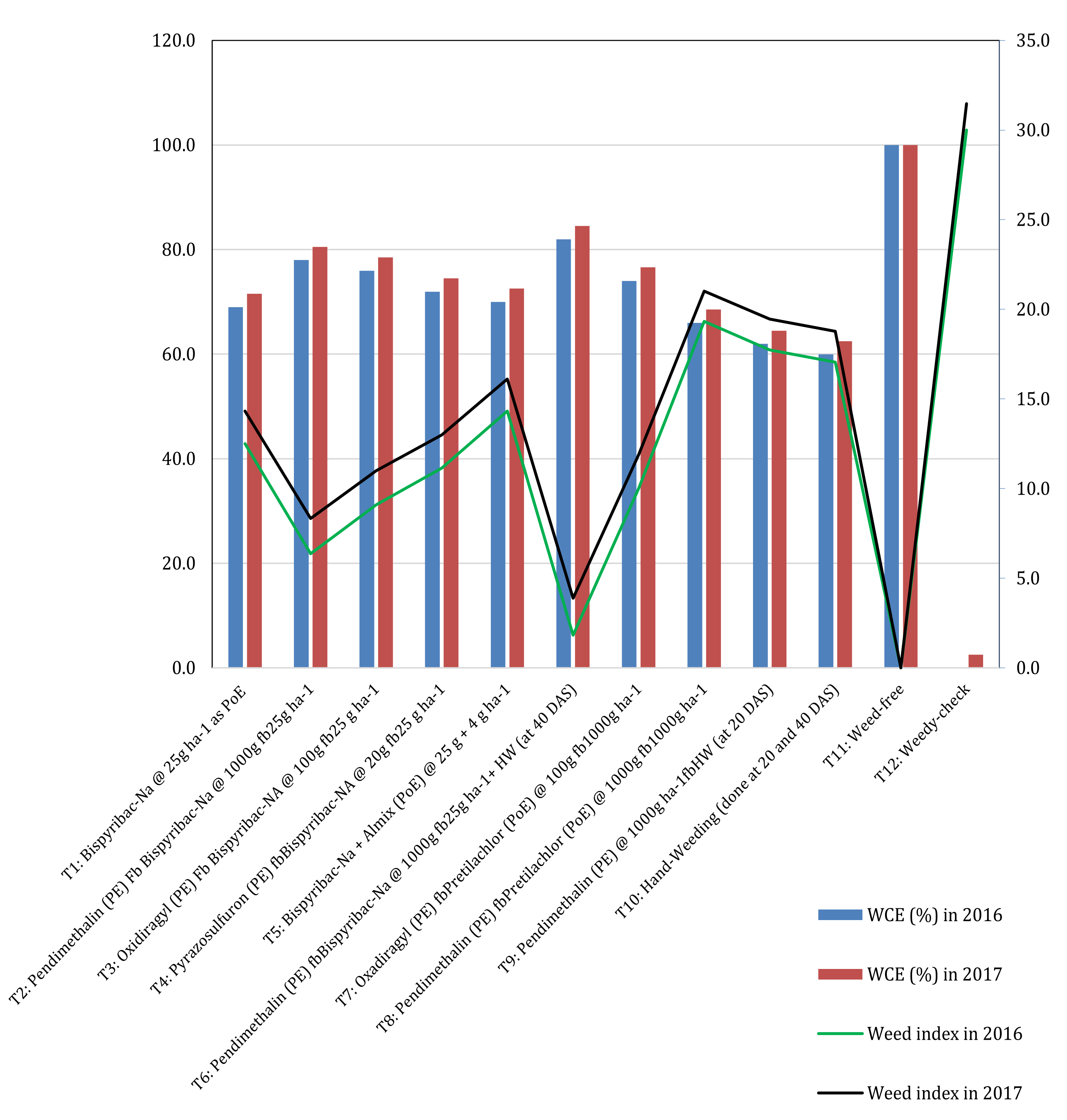

Fig.-1: Effect of sequential application of herbicides (PE & PoE) on weed dynamics in direct-seeded rice

Growth parameters

The growth parameters such as plant height, number of tillers, leaf area index and the plant dry matter accumulation were studied at 50 and 75 DAS. Results of our experiments reveal that the weed-free plot registered the tallest plant, the highest numbers of tillers, the maximum leaf area coverage, and the heaviest dry matter accumulated during 2015 and 2016. The weed-free plot remained statistically comparable with the plots treated with sequential application of Pendimethalin Fb Bispyribac-Na(1000 Fb 25g ha^{-1})+ HW (40 DAS), Pendimethalin Fb Bispyribac-Na (1000 Fb 25g ha^{-1}) and Oxadiragyl Fb Pretilachlor (100 Fb 1000gha^{-1}) in terms of major growth parameters studied. On the contrary, the weed-free plot and the plot treated with Pendimethalin Fb Bispyribac-Na (1000 Fb 25g ha^{-1}) + HW (40 DAS), both, had exhibited their marked superiority over the plots either treated by herbicides in combination or alone including two controls namely, hand weeded plots and weedy plots that noticed the poorest growth during the course of field study. It is a well-established fact that the dense populations (more tillers m^{-2}) had a positive correction with the tallest plants. In our study, diverse weeds, both, BLWs, NLWs and sedges were effectively controlled in herbicide-treated plots resulting in the availability of

Table 2. Effect of weed management practices on growth parameters in direct-seeded rice

Treatments	Plant height (cm)				No. of tillers (m^{-2})				Dry matter accumulation (gm^{-2})				Leaf are index (LAI)			
	50 DAS		75 DAS		50 DAS		75 DAS		50 DAS		75 DAS		50 DAS		75 DAS	
	2016	2017	2016	2017	2016	2017	2016	2017	2016	2017	2016	2017	2016	2017	2016	2017
T_1	74.61	77.60	87.78	91.29	369.50	380.28	396.45	408.31	313.19	325.34	695.97	722.97	3.81	3.96	3.89	4.04
T_2	79.85	83.04	93.94	97.69	388.40	399.94	417.24	429.93	332.82	345.74	739.61	768.30	4.08	4.24	4.16	4.33
T_3	77.52	80.62	91.20	94.85	380.00	391.20	408.00	420.32	322.68	335.20	717.07	744.89	3.96	4.12	4.04	4.20
T_4	75.78	78.81	89.15	92.71	373.70	384.65	401.07	413.11	317.33	329.64	705.17	732.53	3.87	4.03	3.95	4.11
T_5	73.06	75.99	85.96	89.39	363.90	374.46	390.29	401.90	308.12	320.07	684.70	711.26	3.73	3.88	3.81	3.96
T_6	83.72	87.07	98.50	102.44	402.40	414.50	432.64	445.95	347.77	361.27	772.83	802.81	4.28	4.45	4.36	4.54
T_7	76.74	79.81	90.29	93.90	377.20	388.29	404.92	417.12	322.14	334.63	715.86	743.62	3.92	4.08	4.00	4.16
T_8	68.80	71.55	80.94	84.18	348.50	358.44	373.35	384.28	259.94	270.06	577.65	600.12	3.51	3.66	3.59	3.73
T_9	70.16	72.96	82.54	85.84	353.40	363.54	378.74	389.89	295.51	306.97	656.69	682.16	3.58	3.73	3.66	3.80
T_{10}	70.74	73.57	83.22	86.55	355.50	365.72	381.05	392.29	297.61	309.15	661.36	687.01	3.61	3.76	3.69	3.83
T_{11}	85.27	88.68	100.32	104.33	408.00	420.32	438.80	452.35	352.99	366.69	784.42	814.86	4.36	4.53	4.44	4.62
T_{12}	59.69	62.08	70.22	73.03	315.60	324.22	337.16	346.65	255.31	265.21	567.36	589.35	3.05	3.17	3.11	3.23
SE. m	3.30	2.90	2.97	3.93	13.84	15.83	13.75	14.37	8.78	10.94	22.61	33.73	0.15	0.18	0.15	0.17
CD (5%)	9.64	8.46	8.66	11.46	40.41	46.22	40.13	41.94	25.63	31.92	65.98	98.45	0.43	0.54	0.44	0.49

T_1: Bispyribac-Na (Post) @ 25gha^{-1}, T_2: Pendimethalin (Pre) *fb* Bispyribac-Na (Post) @ 1000g *fb* 25g ha^{-1}, T_3: Oxidiragyl (Pre) *fb* Bispyribac-NA (Post) @ 100g *fb* 25 gha^{-1}, T_4: Pyrazosulfuron (Pre) *fb* Bispyribac-NA (Post) @ 20g *fb* 25 g ha^{-1}, T_5: Bispyribac-Na + Almix (Post) @ 25 g + 4 g ha^{-1}, T_6: Pendimethalin (Pre) *fb* Bispyribac-Na (Post) @ 1000g *fb* 25g ha^{-1}+ HW (40 DAS), T_7: Oxadiragyl (Pre) *fb* Pretilachlor (Post) @ 100g *fb* 1000g ha^{-1}, T_8: Pendimethalin (Pre) *fb* Pretilachlor (Post) @ 1000g *fb* 1000gha^{-1}, T_9: Pendimethalin (Pre) @ 1000g ha^{-1} *fb* HW (20 DAS), T_{10}: Hand-Weeding (20 and 40 DAS), T_{11}: Weed-free, T_{12}: Weedy-check.more space and nutrients for crop plants that favoured more growth [22].

Plant dry matter is a net result of photosynthesis and leaf coverage which remains in the balance after the respiration process. The dry matter accumulation brought a significant difference at 50 and 75 DAS in the plots treated with herbicides and weed-free that controls weeds, particularly BLWs and NWLs effectively during both years. The plots treated with herbicides had noticed longer and wider leaves, taller plants, and more tillers/m^2, and all led to more leaf area index because of the fact that its effective controls of the BLWs as well as NLWs without damaging the crop [22]. Similarly, in our study, it was also noticed that more numbers of filled grains and lesser chaffy grains/panicles in rice were measured, which led to higher rice grain yield [23, 24 and 25].

Grain yield (q ha^{-1})

The sequential applications of pre & post-emergent herbicides resulted in significantly higher grain yield compared to non-treated control and it remained comparable with weed-free plots and 2-hand weeded plots. However, the highest grain yield of 44.90 and 46.69q ha^{-1} was recorded with weed-free and the highest grain yield was at par with the grain yield of herbicide-treated plots namely, Pendimethalin Fb Bispyribac-Na + HW (40 DAS), Pendimethalin Fb Bispyribac-Na (1000 Fb 25g ha^{-1}) and Oxadiragyl Fb Pretilachlor (100 Fb 1000gha^{-1}). And they exhibited their significant superiority over the rest of the treatments tested during both years. Although, the lowest grain yield (31.43 and 32.69q ha^{-1}) was registered with the weedy check. The unchecked weeds reduce the grain yield of rice by 30 and 31.5 per cent as compared to weed free. It might be because of the fact that both herbicides have the potential to control all types of weeds more effectively, resulting in enhanced grain yield [26]. These results conform with the findings of [27], who reported that effective and timely weed management under these treatments reduced the density and dry weight of weeds which facilitated the crop with sufficient space, light, nutrients and moisture, and hence improved yield attributes and yield of rice.

Straw yield (q ha^{-1})

The crop biomass straw yield (q ha^{-1}) is directly proportional to WCE and with different weed-management practices in direct-seeded rice. The highest straw yield (58.32 & 60.53q ha^{-1}) was recorded with weed-free plots during both years of field experimentation. The weed-free plot remained statistically at par with the plots treated with Pendimethalin Fb Bispyribac-Na + HW (40 DAS) or Pendimethalin Fb Bispyribac-Na (1000 Fb 25g ha^{-1}) and Oxadiragyl Fb Pretilachlor (100 Fb 1000gha^{-1})., which was found significantly superior rest of the treatments respectively, during both years. Although, the lowest straw yield (43.22 and 44.86q ha^{-1}) was noticed with a weedy check during 2015 and 2016, respectively [26]. Reduced competition for moisture, space, light and nutrients among crop and weeds with effective suppression of weeds by a combination of herbicides has helped in obtaining higher straw yield in both years [26, 27 and 28].

Table 3. Effect of weed management practices on Yield in direct-seeded rice

Treatment	Grain yield (q ha^{-1})		Straw yield (q ha^{-1})		Harvest index(%)	
	2016	2017	2016	2017	2016	2017
T1	39.29	40.86	52.29	54.27	42.90	42.95
T2	42.04	43.72	55.28	57.37	43.20	43.25
T3	40.82	42.45	53.53	55.56	43.26	43.31
T4	39.90	41.49	52.89	54.89	43.00	43.05
T5	38.47	40.01	51.62	53.58	42.70	42.75
T6	44.08	45.84	57.61	59.79	43.35	43.40
T7	40.41	42.02	53.78	55.82	42.90	42.95
T8	36.22	37.67	39.78	41.29	47.66	47.71
T9	36.94	38.42	49.47	51.34	42.75	42.80
T10	37.24	38.73	49.78	51.66	42.80	42.85
T11	44.90	46.69	58.32	60.53	43.50	43.55
T12	31.43	32.69	43.22	44.86	42.10	42.15
SEm	1.55	1.74	2.19	1.89	1.77	1.64
CD (at 5%)	4.53	5.07	6.39	5.53	NS	NS

$T_{1:}$ Bispyribac-Na (Post) @ 25gha^{-1}, $T_{2:}$ Pendimethalin (Pre) *fb* Bispyribac-Na (Post) @ 1000g *fb* 25g ha^{-1}, $T_{3:}$ Oxidiragyl (Pre) *fb* Bispyribac-NA (Post) @ 100g *fb* 25 gha^{-1}, $T_{4:}$ Pyrazosulfuron (Pre) *fb* Bispyribac-NA (Post) @ 20g *fb* 25 g ha^{-1}, $T_{5:}$ Bispyribac-Na + Almix (Post) @ 25 g + 4 g ha^{-1}, $T_{6:}$ Pendimethalin (Pre) *fb* Bispyribac-Na (Post) @ 1000g *fb* 25g ha^{-1}+ HW (40 DAS), $T_{7:}$ Oxadiragyl (Pre) *fb* Pretilachlor (Post) @ 100g *fb* 1000g ha^{-1}, $T_{8:}$ Pendimethalin (Pre) *fb* Pretilachlor (Post) @ 1000g *fb*1000gha^{-1}, $T_{9:}$ Pendimethalin (Pre) @ 1000g ha^{-1}*fb* HW (20 DAS), $T_{10:}$ Hand-Weeding (20 and 40 DAS), $T_{11:}$ Weed-free, $T_{12:}$ Weedy-check.

Harvest index (%)

The maximum and minimum harvest index (%) was recorded with weed-free and weedy plots, however, the difference between the maximum and minimum recorded as non-significant.

CONCLUSION

Diverse weeds flora are the captain limitations to rice production in DSR. To achieve effective, long-term and sustainable weed control in a DSR, the superlative weed management strategy "sequential herbicide application at adequate timing coupled with one manual or mechanical weeding" is the appropriate. Based on the results achieved in our experiment, we recommend the most effective and sensible technique in which sequential application of the pre & post emergent herbicide namely Pendimethaline" @ 1000 g a.i. at 1-2, DAS and "Bispyribac-Na" @ 25 g a.i. at 20 DAS coupled with one-hand weeding at 40 DAS and it effectively controlled the diverse weeds flora and enhanced the weed control efficiency resulting in the maximum rice-grain yield.

Future Scope of the Study: Returns over variable cost will be a driving force for farmers in adopting DSR and achieving better weed control in future. The proper focus should be given to weed swiftness in the direct seeded rice ecosystem and weeds' biology and competitive behaviour. The sustained yield of rice could be achieved under the DSR system when diverse weeds will greatly be controlled by the integration of appropriate weed management techniques including newer herbicides and their right doses and time of application with mechanical weeding.

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