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WEED SUPPRESSION, GROWTH AND YIELD ATTRIBUTES AND YIELD OF DIRECT SEEDED RICE (*ORYZA SATIVA* L.) AS INFLUENCED BY NITROGEN RATES AND HERBICIDE SEQUENCE

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Abstract

Weeds are major constraints for increasing productivity of direct seeded rice (DSR) in dry field. Nitrogen fertilization and herbicide selectivity play significant role in deciding the weed dynamics and level of weed infestation. With the said view in mind, for management of weeds and enhanced performance of DSR, a field study was conducted in split plot design with three replications. Main plot comprised of three nitrogen rates (120, 150, and 180 kg/ha), whereas, sub-plot included single application of pendimethalin (PRE), sequential application of PRE *fb* bispyribac sodium/penoxsulam/metsulfuron + chlorimuron (almix) [POST] and two controls (weedy check and weed free). N-rates affected the growth of weed species, but total density and biomass were not affected. Sub-optimal (120 kg/ha) and supra-optimal (180 kg/ha) nitrogen rates enhanced biomass of *Cynodon dactylon* (L.) Pers. and *Echinochloa colonum* (L.) Link. but in *Caesulia axilliaris* Roxb. density and biomass decreased at supra-optimal N-rate. However, density of *Cyperus rotundus* L. increased at optimal N-rate (150 kg kg/ha). Supra optimal rate of N-application enhanced plant height, biomass, tiller count, total grain, filled grain, panicle count, biological yield, straw yield and weed index of DSR. Amongst herbicides, sequential application of pendimethalin *fb* penoxulam produced lowest density and biomass of *C. rotundus*, *E. colonum*, *C. axillaris*. Moreover, this treatment reduced density and biomass of total weed by 70.14 and 53.66 per cent over weedy check, and consistently produced higher growth, yield attributes and yield of DSR. However, antagonistic interaction between PRE and all tested post-emergence herbicide were observed for the management of *C. dactylon*.

Introduction

Rice is one of the major staple crops of India and plays an important role in Indian economy. In fact, India is having the largest cultivating area (44 M ha) (Singh and Prasad 2014b) and second largest producer of rice in the world (Singh *et al.* 2014a). For millennia, puddle transplanted rice (PTR) cultivation has become widespread practiced in Asia, with the prime motive to reduce weed competition and maximize yield (Ziska *et al.* 2015). Recently, however, there has been a shift in system of paddy cultivation from PTR to direct-seeded rice (DSR) in many parts of Asia, particularly India (Singh *et al.* 2014c). The major reasons behind this shift are labour and water scarcity. These resources are becoming increasingly limiting, making rice production less remunerative (Singh *et al.* 2013).

Though, DSR is a resource-conserving technology relative to PTR, but it is subjected to heavy weed infestation (Awan *et al.* 2015, Mahajan and Chauhan 2015). It is noteworthy that, weed infestation is a major bottleneck in sustaining yield and widespread expansion of DSR. In fact, it has been demonstrated that, if the weeds are not properly managed resulted in reduced grain yield by 67.4 - 70.4 per cent in DSR (Kumar *et al.* 2010). Given the importance of weeds in impacting

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rice yields, numerous weed management practices have been suggested for sustained higher productivity of DSR (Singh *et al.* 2014c, Ahmed and Chauhan 2014). Amongst them, increasing competitive ability of crops against weeds through fertilization (Jordan *et al.* 1987) and herbicidal management of weeds (Singh *et al.* 2014c, Mahajan and Chauhan 2015) are found to be the reliable strategies.

In the current scenario of labor scarcity, herbicides are widely preferred by farmers, because of ease in application and cost effectiveness (Mahajan and Chauhan 2015, Ahmed and Chauhan 2014). Furthermore, researches revealed that single application of particular herbicide seldom provides adequate control of weed in DSR (Khaliq *et al.* 2011, Ahmed and Chauhan 2014). Indeed, application of a single herbicide may provide good control of certain specific weeds, but have a narrow spectrum of weed control at the recommended rates (Damalas 2004). Therefore, for increasing weed control spectrum, the combinations of herbicides are applied either simultaneously (tank-mixed) or sequentially. Practically, herbicidal combinations are selected based on assumption that herbicides would act independently. However, in reality, herbicides interact differently before or after entering the plants and the outcome of the interaction may be synergistic, antagonistic, or additive (Zhang *et al.* 1995).

Similar to herbicides, fertilization also plays a significant role in increasing competitive ability of crops against weeds. Indeed, fertilization is more important during early stages because poorly fertilized crops are less competitive with weeds than optimally fertilized crops (Jordan *et al.* 1987, Awan *et al.* 2015). For optimal fertilization, application of nitrogen (N) is considered most important because it is one of the most yield-limiting nutrients in all rice growing soils of the world (Fageria 2014). Invariably, yield of DSR enhanced with increase in N rates (Sharma *et al.* 2007). Besides effect on crop growth and yield, N-fertility influences the dynamics of weed flora (Schreiber and Orwick 1978). However, effect of rates of N application on level of crop-weed infestation is often contradictory (Sheibani and Ghadiri 2012). For example, it has been observed that lower infestation of grasses and sedges under lower rates of N application (Mahajan and Timisina 2011). In contrast, in another experiment, density of grasses, sedges and broadleaf weeds increased with increase in N rate from 120 to 150 kg/ha, however, further increase in N rate (180 kg N/ha) leads to decrease in density of grasses, sedges and broadleaf weeds (Singh *et al.* 2014a).

Keeping the above facts in view, to obtain more definitive and conclusive understanding of phenomenon, this research was conducted with twin objectives, i.e. firstly, to investigate the influence of variable rate of nitrogen application on weed dynamics, growth and yield of direct seeded rice; secondly, to evaluate the compatible herbicide combinations used as sequential application for effective management of pre-dominant weeds, assess the dynamics of weeds flora and its impact on growth and yield of direct seeded rice.

Materials and Methods

A field study was conducted during wet season of 2013 at the Agricultural Research Farm of Banaras Hindu University, Varanasi (25º18' N latitude and 80º30' E longitude; at an altitude of 128.93 m from mean sea level), India. The soil of experimental field was sandy clay loam, classified as Inceptisol (Typic Ustochrept), normal in reaction (pH 7.52), low in organic carbon content (0.59%) and available NPK 175.56, 22.1, 227.5 kg/ha, respectively. The weather in this area is characterized by hot, dry summers and cold winters. During experimentation, the total rainfall received was 825 mm, with an average evaporation varied from 1.5 - 5.9 mm per day. During crop season, maximum and minimum temperature ranged from 26.2 - 38.0^{0}C and 11.5 - 28.3^{0}C, respectively.

The experiment laid out in split plot design, having 18 treatments, and replicated thrice. Main plot comprised of three nitrogen (N) rates (120, 150 and 180 kg/ha), whereas, sub-plot comprised of six herbicidal treatments (including 2-checks), *viz.,* pendimethalin 1000 g a.i./ha (PRE) [pendi], pendimethalin 1000 g a.i./ha (PRE) *fb* bispyribac sodium 25 ml a.i./ha (POST) [pendi *fb* bispyri], pendimethalin 1000 g a.i./ha (PRE) *fb* penoxsulam 22.5 g a.i./ha (Early POST) [pendi *fb* penox] and pendimethalin 1000 g a.i./ha (PRE) *fb* metsulfuron + chlorimuron (Pre-mixed formulation-Almix^{TM}) 20 g/ha (POST) [pendi *fb* almix] (Table 1).

Table 1. List of weeds flora infested in experimental field.

Botanical name	Common English name	Family
Sedges		
Cyperus rotundus L.	Purple nutsedge, nut grass	Cyperaceae
Grasses		
Echinochloa colonum (L.) Link	Jungle rice	Poaceae
Cynodon dactylon (L.) Pers.	Bermudagrass	Poaceae
Broad leaf weed		
Caesulia axillaris Roxb.	Pink node flower	Asteraceae
Phyllanthus niruri L.	Stonebreaker or seed-under-leaf	Phyllanthaceae
Parthenium hysterophorus L.	Parthenium	Asteraceae

Rice (CV. HUR-105) seed was line sown with a single-row drill at the row spacing of 18 cm with 40 kg seeds/ha on last week of June and harvested in second week of November. The size of the plots was 5.0 m by 2.0 m. After sowing, the field was given light irrigation, by flooding, so that ample moisture was available at the time of pendi (pre-emergence herbicide) application. Nitrogen was applied as per treatment through urea, whereas, recommended rate of fertilizers i.e. 60 kg P_2O_5 and 60 kg K_2O/ha were applied through single super phosphate and muriate of potash, respectively. Whole of phosphorus and potassium and half rate of N were applied at the time of sowing. The remaining half-rate of N was applied in two equal splits at 30 days interval. Pre-emergence (PRE) herbicides were applied at 3 DAS, whereas, early post-emergence (Early POST) and post-emergence (POST) herbicides were applied at 15 DAS and 22 DAS, respectively. Before spraying, herbicides were dissolved in water at the rate of 500 liter/ha and sprayed with a knapsack sprayer fitted with a flat-fan nozzle.

Species-wise density and biomass of weeds were measured at 60 DAS i.e. at the critical period of crop weed competition (Mahajan *et al.* 2014), as per the procedure given by Singh and Saini (2008) and presented as number/m^2 and g/m^2, respectively. Weed index (WI%) was calculated using the following formula:

$$\text{Weed index (WI)} = \frac{\text{Yield from weed free plot} - \text{Yield from treated plot}}{\text{Yield from weed free plot}} \times 100$$

Plant height, from five randomly tagged plants in net plot area, was measured in cm from ground level to base of fully opened leaf. After earing the height was measured from ground level to the top of ear. However, to perform tiller count, three hills per plot were selected at random and the values from each measurement were then averaged per treatment. For recording the dry biomass, after leaving the border row, selected plants from one meter row length were taken out from each plot. These samples were sun dried and later on transferred to hot air oven and dried at 70ºC for 40 hrs to get constant dry weight of plant and is expressed in g/m^2.

Moreover, yield attributes were estimated at harvest. Panicle count was performed by placing 0.25 m^2 quadrate at two places randomly in each net plot and were averaged, and values were presented in number/m^2. Whereas, grains of 10 randomly selected panicle were counted and their mean value expressed as average grain per panicle. Furthermore, from these selected panicles the filled grains per panicle were also counted. Biological yield was calculated from all the above ground plants part of each net plot will sun dried, weighed and values were expressed into kg/ha. After threshing the biological yield from each plot, straw yield was obtained by deducting grain yield (having 14% moisture) from total biological yield and values were presented in kg/ha.

Data generated from the experiments were analysed using CPCS-1 and mean comparisons were performed based on the least significant difference (LSD) test at 0.05 probability. Heterogeneous weed (density and biomass) data were square-root transformed i.e. $\sqrt{(X + 0.5)}$, prior to analysis to produce a near normal distribution, however, non-transformed data are also presented for clarity.

Results and Discussion

In the present experimental rice field six weed species occurred (Table 1). Contrary to present experiment, some workers reported diverse weed flora infestation in DSR (Naresh *et al.* 2011, Singh *et al.* 2007). Indeed, the infesting weed species belonged to 4 families and 6 genera. Predominant weed species among grasses were *Echinochloa colonum* (L.) Link and *Cynodon dactylon* (L.) Pers., whereas, *Caesulia axillaris* Roxb. and *Cyperus rotundus* L. among broadleaf weeds (BLWs) and sedges, respectively. Similar weed flora infestation in DSR was also reported by Walia *et al.* (2012). From this study it was revealed (Table 2) that it is not possible to generalize growth responses of different weed species with variable rates of N application. Similarly, Blank and Young (2004), Kim *et al.* (2006) and Andreasen *et al.* (2006) were also in view that weed species respond differently with variable rates of nitrogen application. Surprisingly, in totality density and biomass accumulation by weeds are not much affected by variable rates of N application. The results depicted the third dimension of nitrogen-weed interaction, where no difference was observed in total weed infestation with the increased N rates, whereas, previous studies showed either increased (Mahajan and Timisina 2011) or decreased (Abouziena *et al.* 2007) density and biomass of weeds with increased nitrogen rates. Whereas, Venkitaswamy *et al.* (1991) observed that total weeds biomass decreased with increasing rates of nitrogen application during north-east monsoon and summer season and vice-versa trend observed during south-west monsoon season. Furthermore, among the predominant grasses, *C. dactylon* and *E. colonum*, which altogether constitute 38 - 45% relative density among total weed density, germinates and maintains almost similar population irrespective of N-rates and crop-weed competition. Interestingly, these grasses showed bi-modular response to biomass accumulation with respect to N fertilization; it means to say that higher competitiveness and increased biomass accumulation at both sub-optimal (120 kg N/ha) and supra-optimal (150 kg N/ha) N application. Optimum rate (150 kg N/ha) of N-fertilization, not only helps increased density of pre-dominant sedge (*C. rotundus*) and BLWs (*C. axillaris*) but also favour rice and *C. axillaris* to enhance their biomass accumulation. Simultaneously, supra-optimal rate (180 kg N/ha) of N application reduced density of *C. rotundus* and *C. axiliaris*. Biomass accumulation by *C. rotundus* and total weeds did not differed significantly with rates of N application. On the contrary to present findings, Mahajan and Timsina (2011) reported that successive increase in density of grasses and sedges with increase in N fertilizer rate (120 to 180 kg/ha), whereas the density of broad leaf weeds was not influenced significantly with increasing N rates.

Table 2. Effect of nitrogen rates and sequential herbicide application on density and biomass of weeds in direct seeded rice.

Treatments	Density of weeds (Number/m^2)[a]					Biomass of weeds (g/m^2)[a]				
	Cyperus rotundus	*Cynodon dactylon*	*Echinochloa colonum*	*Caesulia axillaris*	Total weed	*Cyperus rotundus*	*Cynodon dactylon*	*Echinochloa colonum*	*Caesulia axillaris*	Total weed
Nitrogen rates										
120 kg/ha	7.01*b* (58.33)	5.22 (32.78)	7.20 (75.56)	7.18*a* (70.56)	14.60 (268.89)	7.68 (72.90)	10.45*a* (137.02)	15.76*a* (327.48)	6.02*a* (43.37)	22.35 (612.12)
150 kg/ha	8.24*a* (88.33)	4.86 (30.56)	7.17 (77.78)	6.74*a* (61.67)	15.31 (283.89)	8.88 (110.26)	8.04*b* (83.62)	12.35*b* (222.65)	6.69*a* (58.00)	20.53 (513.89)
180 kg/ha	7.27*b* (63.33)	5.08 (30.56)	7.44 (75.56)	5.36*b* (40.56)	13.78 (234.44)	7.90 (79.23)	9.70*a* (116.98)	18.44*a* (419.04)	4.93*b* (30.76)	23.72 (683.58)
SEm±	0.19	0.20	0.26	0.20	0.36	0.37	0.26	0.81	0.19	0.86
LSD (p = 0.05)	0.75*	NS	NS	0.80*	NS	NS	1.02*	3.18*	0.75*	NS
Herbicides										
Pendi *fb* Bispyri	9.86*a* (100.00)	6.44*b* (41.11)	6.23*d* (38.89)	7.22*c* (56.67)	16.13*c* (265.56)	9.51*b* (95.06)	12.13*b* (148.12)	15.67*c* (270.77)	7.49*b* (59.43)	24.60*c* (609.81)
Pendi *fb* Penox	6.47*c* (43.33)	7.82*a* (62.22)	4.35*e* (20.00)	4.44*d* (20.00)	12.71*d* (162.22)	6.39*c* (41.37)	14.96*a* (223.89)	12.62*d* (172.80)	5.12*c* (26.56)	21.67*d* (476.80)
Pendi *fb* Almix	9.80*a* (98.89)	5.31*c* (30.00)	9.14*b* (84.44)	4.96*d* (27.78)	16.24*c* (264.44)	10.09*b* (108.47)	9.93*c* (111.98)	19.14*b* (370.86)	5.66*c* (37.39)	25.83*c* (669.14)
Pendi	10.11*a* (105.56)	4.29*d* (18.89)	8.08*c* (82.22)	9.14*b* (92.22)	18.36*b* (338.89)	14.43*a* (212.41)	7.94*d* (65.98)	18.65*b* (426.93)	7.73*b* (61.47)	28.46*b* (837.47)
Weedy check	8.07*b* (72.22)	5.76*c* (35.56)	15.10*a* (232.22)	12.10*a* (148.89)	23.26*a* (543.33)	7.79*c* (67.48)	10.73*c* (125.29)	26.32*a* (697.00)	8.57*a* (79.42)	31.94*a* (1025.98)
Weed free	0.71*c* (0.00)	0.71*e* (0.00)	0.71*f* (0.00)	0.71*e* (0.00)	0.71*e* (0.00)	0.71*d* (0.00)	0.71*e* (0.00)	0.71*e* (0.00)	0.71*d* (0.00)	0.71*e* (0.00)
SEm ±	0.50	0.20	0.29	0.32	0.31	0.58	0.36	0.92	0.27	0.79
LSD (p = 0.05)	1.43*	0.58*	0.84*	0.93*	0.89*	1.68*	1.04*	2.65*	0.78*	2.28*

Data are subjected to square root transformation. Original value given in parenthesis. [a] Data recorded at 60 DAS. Mean values within the same category (row) followed by different letters are significantly different from each other using LSD test at p = 0.05. *p = 0.05, NS- Not significant. Pendi *fb* bispyri = Pendimethalin 1000 g a.i./ha (PE) *fb* bispyribac sodium 25 ml a.i./ha (POST); Pendi *fb* Penox = Pendimethalin 1000 g a.i./ha (PE) *fb* Penoxsulam 22.5 g a.i./ha (Early POST); Pendi *fb* Almix = Pendimethalin 1000 g a.i./ha (PE) *fb* metsulfuron + chlorimuron (Almix^{TN}) 4 g a.i./ha (POST); Pendi = Pendimethalin 1000 g a.i./ha (PE).

Table 3. Influence of nitrogen rates and sequential herbicide application on growth, yield attributes and yield of direct seeded rice.

	Growth characters				Yield attributes and yield					
	Plant height (cm)		Biomass (g/m^2)	Tillers count (No.. /hill)	Total grain (No./ear)	Filled grain (No./ear)	Panicle count (No./ m^2)	Biological yield (kg/ha)	Straw yield (kg/ha)	Weed Index
	60 DAS	At harvest								
Nitrogen rates										
120 kg/ha	44.52c	64.90	141.37c	3.24b	116.40	91.28b	73.89	2138.71b	1316.27	51.89
150 "	49.01b	71.48	155.93b	3.84a	120.64	93.26b	70.89	2294.84ab	1386.71	53.64
180 "	54.64a	72.68	164.07a	4.03a	131.66	103.22a	74.11	2592.59a	1543.94	55.01
SEm±	0.708	2.555	0.916	0.113	4.070	1.536	2.542	111.917	76.115	3.003
LSD (p = 0.05)	2.781*	NS	3.596*	0.442*	NS	6.033*	NS	439.442*	NS	NS
Herbicides										
Pendi *fb* Bispyri	54.22ab	83.73a	157.86b	4.69b	137.38b	110.17b	103.11b	3006.54b	1750.18b	36.41c
Pendi *fb* Penox	55.27ab	83.76a	178.25b	4.80b	152.12ab	118.39ab	100.11b	3086.42b	1684.82b	28.70d
Pendi *fb* Almix	58.69a	75.60ab	157.31b	3.02c	144.09ab	113.92b	50.11c	2069.72c	1343.50c	64.44b
Pendi	52.82b	67.91b	96.00c	2.38c	103.89c	70.56c	30.22d	806.10d	705.16d	94.99a
Weedy check	29.18d	28.93c	48.97d	1.38d	45.63d	29.36d	4.22e	755.27d	686.27d	96.52a
Weed free	46.18c	78.18a	284.34a	5.98a	154.28a	133.14a	150.00a	4328.25a	2323.89a	0.00e
SEm±	1.60	3.32	1.41	0.26	5.48	5.50	3.30	62.74	43.83	1.94
LSD (p = 0.05)	4.630*	9.581*	4.075*	0.759*	15.827*	15.895*	9.520*	181.201*	126.577*	5.613*

Mean values within the same category (row) followed by different letters are significantly different from each other using LSD test at p = 0.05. *p = 0.05, NS- Not significant. Pendi *fb* bispyri= Pendimethalin 1000 g a.i./ha (PE) *fb* bispyribac sodium 25 ml a.i./ha (POST). Pendi *fb* Penox = pendimethalin 1000 g a.i./ha (PE) *fb* penoxsulam 22.5 g a.i./ha (Early POST). Pendi *fb* Almix = pendimethalin 1000 g a.i./ha (PE) *fb* metsulfuron + chlorimuron (Almix^{TN}) 4 g a.i./ha^{-}(POST). Pendi = Pendimethalin 1000 g a.i./ha (PE)

Further, Table 3 shows that plant height (at 60 DAS), biomass, tiller count, number of filled grain/ear and biological yield increased with successive increase in nitrogen rates and significantly the highest values recorded with 180 kg N/ha. This result was in conformity with the findings of Mahajan and Timsina (2011). The relationship between the damage caused by weeds and fertilization was better explained by Alkamper (1976), who was of opinion that damaged caused by weeds decreased with increase fertilization, only when level of weed infestation is lower, however, under heavy weed infestation increased fertilization may give negative results. Result further revealed, plant height at harvest, total grain/ear, panicle count, straw yield and weed index differed non-significantly with variable rates of N application.

Among sequential application of herbicide, pendi *fb* penox proved to be most effective in suppression of density as well as biomass of predominant weeds like, *C. rotundus*, *E. colonum*, *C. axiliaris* and total weeds, except *C. dactylon* (Table 2). Efficacy of this treatment was comparatively higher because both the herbicide in sequence are broad-spectrum herbicide; pendi being pre-emergence herbicide manages the weeds during the initial stage of crop growth thus facilitates a head start and thus gives competitive advantage to rice, whereas, later flushes of weeds are managed by penoxsulam. This result was in conformity with the findings of Khaliq *et al.* (2011). Nonetheless, both density and biomass of *C. dactylon* significantly reduced with single application of pendi as compared to its sequential combination with bispyri, penox and almix. The reduced efficacy was in decreasing order of pendi *fb* penox > pendi *fb* bispyri > pendi *fb* almix. Reduced efficacy for suppression of *C. dactylon* might be associated with antagonist relationship between these herbicides with pendi. Damalas (2004) has compiled 4-basic mechanisms of herbicide interactions *viz.* biochemical, competitive, physiological, and chemical. These interactions are highly complex and may be result of two or more mechanisms. Zhang *et al.* (1995) and Ottis *et al.* (2005) also reported antagonistic relationship between different herbicides.

Average plant height at 60 DAS was found higher in all the herbicidal treatment over weed free; but, at harvest, weed free produced statistically similar higher plant height in pendi *fb* bispyri and pendi *fb* penox (Table 3). Among herbicidal treatments, a consistently higher value recorded under sequential application of pendi *fb* penox for all the tested parameters and was statistically at par with pendi *fb* bispyri, except for weed index in which pendi *fb* penox showed significantly highest values. Khaliq *et al.* (2011) also observed higher yield attributes and yield with sequential application of pendi *fb* penox followed pendi *fb* bispyri.

From this study it has now been concluded that weeds are major constraints for increasing productivity of DSR in dry field. Weed flora influence differently with variable rates of nitrogen application. Invariably, grassy weeds (particularly *C. dactylon* and *E. colonum*), and *C. axillaris* showed reduced biomass accumulation at optimal (150 kg N/ha) and supra-optimal (180 kg/ha) rates of nitrogen application, respectively. Total weed growth not affected with differential rates of N application. Supra-optimal (180 kg N/ha) rate of N application enhanced the growth and yield of dry DSR. Further studies are required under various agro-ecological situations and weed infestation levels to understand species-wise interaction with variable rates of N application. These experiments help to device sound recommendation of nitrogen application to DSR in dry field.

In general, sequential application of pendi followed by penoxsulam/bispyribac-Na/almix found better in weed suppression and enhanced growth and yield of DSR as compared to single application of pendimethalin. Sequential application of pendimethalin with all the tested post-emergence herbicide for the management of *C. dactylon* showed antagonistic interaction. It is a serious issue and needs to be further investigated as *C. dactylon* is one of the major weed floras under rainfed upland rice ecology (Galinato *et al.*1999, Mahajan *et al.* 2014) and their infestation caused substantial loss to DSR.

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