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WEED MANAGEMENT EFFICIENCY OF POST EMERGENCE HERBICIDES IN DIRECT SEEDED RICE AND THEIR RESIDUALITY ON SOIL MICROORGANISMS

Rajib Kundu, Ramyajit Mondal, Sourav Garai*, Mousumi Mondal,
Ratneswar Poddar, Sibajee Banerjee

Department of Agronomy, Bidhan Chandra Krishi Viswavidyalaya, Mohanpur-741252

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ABSTRACT

An increasing water crisis as well as shortage of farm labour farmers in many Asian regions are forcing a shift from puddled transplanted rice to direct-seeded rice. The weeds, however, are a major constraint to the production of direct-seeded rice. In this context, field experiment was conducted at the Research farm of Bidhan Chandra Krishi Viswavidyalaya, West Bengal, India (23°5.3' N, 83°5.3' E, and 9.75 m above MSL) under natural weed infestations during *boro* seasons of 2017 and 2018 to evaluate the herbicidal effects on diversified weed flora, rice yield, non-target soil organisms and nutrient uptake pattern for achieving the optimization of herbicide dose for sustainable rice production. Seven weed control treatments including three doses of bispyribac sodium 10% SC (150, 200 and 250 ml ha⁻¹), two doses of fenoxaprop-p-ethyl 9.3% EC (500 and 625 ml ha⁻¹), one weed free and weedy check were laid out in a randomized complete block design with three replications. Among the tested herbicides, application of bispyribac Sodium 10% SC (250 ml ha⁻¹) effectively reduced total weed density (77.38%) and dry weight (81.50%) over control at 30 days after herbicide application and as a consequence yielded maximum (4.07 t ha⁻¹). Based on overall performance, the bispyribac-sodium 10 % SC (250 ml ha⁻¹) may be considered as the best herbicide treatment for weed management in direct seeded rice.

* Corresponding author

E-mail: garai.sourav93@gmail.com (Sourav Garai)

Contact no. – +918900509245

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1 Introduction

Rice (*Oryza sativa* L.) is the principle source of food for almost 60% population of India (Biswas et al., 2019). About 56% of gross cropped area of Bengal has been occupied by rice and ranks first in terms of cultivated area (Directorate of Agriculture, GoWB, 2018). It was predicted that a 50 - 60% increases in rice production will be required to meet the food demand of population growth by 2025 (Banerjee et al., 2018). Rice is mainly grown by manual transplanting (puddle transplanted rice, i.e. PTR) of 3-6-week-old seedlings into puddled soil (wet tillage), with continuous flooding (Ghosh et al., 2016). Puddling creates a hard pan in soil layer, leads to high water losses through surface evaporation, and influences soil physical properties because of the dispersion of soil particles and compacting soil (Chauhan et al., 2012a). According to Mahajan et al. (2012), huge amount of water, energy and labour are required for the puddled transplanted rice. Transplanting of the seedlings is mostly delayed because of mainly manual transplanting and also for different timing which end in above-optimal age of rice seedlings that record lower productivity (Khaliq et al., 2011) as well as increasing transplanting shock. In spite of that, for growing rice nursery in time scale, energy, capital and monetary investment are the risky enterprises, as because failure of the entire transplanted crop under particular situations accordingly depends upon failure of the nursery management mostly (Matloob et al., 2015). The higher productivity of irrigated lowland rice, however, is threatened by increasing the water scarcity, as agriculture's share of freshwater supplies is likely to decline by 8 -10% (Seckler et al., 1998). Several water-saving technologies have been developed to cope with water scarcity in lowland rice areas, such as alternate wetting and drying (Belder et al., 2004), direct seeded rice (Vijayakumar et al., 2019), continuous soil saturation (Borell et al., 1997), aerobic rice (Jana et al., 2020) and ground cover rice production system (Tao et al., 2006). Exposal of mechanization, rapid and easy sowing, reduced labour requirement and drudgery, earlier crop maturity, increased water use efficiency, higher tolerance to water deficit, lower methane emission and often higher profit in the areas with assured water supply are the advantages of direct-seeded rice (DSR) over transplanted rice (Chauhan et al., 2012b). Early DSR matures 1-2 weeks before transplanted rice, thus reducing the risk of terminal drought and allowing earlier planting of a following non-rice crop (Rana et al., 2014). Though DSR has several advantages and it could be an effective alternative to traditional transplanting, poor germination, uneven crop stand and high weed infestation are the major constraints in DSR (Farooq et al., 2010). Severe and diversified weed infestation, high weed emergence during rice seed germination due to lack of standing water layer, and for the zero-seedling size benefit of rice over weed seedlings as both germinate simultaneously, managing weed in DSR system is very much challenging. Therefore, a systematic, efficient and effective weed management depends on timing and method of land preparation,

effectiveness of herbicides; relative to the dominant weed species are urgently needed. These are in conformity with many scientists and researchers related with weed management in DSR, that application of herbicide may be reckoned as a viable substitute than hand weeding (Ghosh et al. 2016; Jana et al. 2020). Identification of new herbicides is vital and urgently needed to reduce the possibility of evolution of resistant biotype of weeds and getting higher rice yield. Though many pre-emergence herbicides are available for controlling weeds, the need for post-emergence herbicide is often realized to combat the weeds emerged during later stages of crop growth (Kundu et al., 2020). Among the post-emergence herbicides, bispyribac-sodium {sodium 2,6-bis [(4, 6-dimethoxy-2-pyrimidinyl) oxy] benzoate} is a systemic herbicide absorbed by roots and leaves, and also inhibits the enzyme acetolactate synthase in susceptible weed plants (Pathak et al., 2011). Fenoxaprop-p-ethyl also is a selective, post-emergent herbicide having action on broad-spectrum of grasses (Rana et al., 2004).

Therefore, this study was undertaken to evaluate herbicidal effects on weed flora, rice yield, non-target soil organisms for achieving the optimization of herbicide use for sustainable rice production system.

2 Materials and Methods

2.1 Experimental site

A field experiment was conducted during 2017 and 2018 at the research farm of Bidhan Chandra Krishi Viswavidyalaya (23°5.3' N, 88°5.3' E, and 9.75 m above MSL), West Bengal India under natural weed infestations in direct seeded rice. Soil was loamy containing 53.48% sand, 24.70% silt and 21.82% with a pH of 6.88 and electrical conductivity of 0.296 ds m⁻¹. It contained 0.57% organic C, 215.2 kg available N ha⁻¹, 27.6 kg available P₂O₅ ha⁻¹ and 156.4 kg available K₂O ha⁻¹. The climate of the study site was sub-tropical. Weekly maximum and minimum temperatures ranged between 30.3 to 36.3°C and 15.2 and 27.0 °C during 2017 and 2018 respectively. Maximum relative humidity ranged from 89 to 91.8% in 2017 and 89.2 to 93% in 2018 respectively. The annual rainfall during the experimental period was 1250.0 and 1400.5 mm in 2017 and 2018, respectively.

2.2. Herbicidal treatments

The experiment was laid out in randomized block design and replicated thrice and the area of each plot was 20 m² (5.0 m x 4.0 m) with inter- row spacing of 20 cm. The treatments were consisted of bispyribac Sodium (10% SC) at three different dosages (150, 200 and 250 ml ha⁻¹) and fenoxaprop-p-ethyl (9.3% EC) with two altered doses (500 and 625 ml ha⁻¹) along with weedy check and weed free check. The amount of the herbicides was calculated as per treatments on the basis of gross plot area. All the herbicides were applied as solution in water at the rate of 500 litres ha⁻¹. The herbicide solutions were sprayed uniformly in the experimental plots as per treatments

with the help of knapsack sprayer. Both of the herbicides bispyribac sodium and fenoxaprop-p-ethyl with their different doses were applied at 20-25 DAS. For the weed-free treatment, two hand weeding (20 DAS and 40 DAS) were done to maintain a weed-free situation. In the weedy control, no weeding was done.

2.3. Crop management practices

Healthy paddy seeds (cv.IET 4786) soaked for 24 hours in clean water for better germination. The seeds were treated with *Trichoderma viride* @ 4 g kg⁻¹ and shade drying for 6 hours prior to sowing. Sowing was done with the help of seed drill at a spacing of 20cm×15cm with a depth of 2-3 cm on 3rd and 5th February in 2017 and 2018, respectively. Urea, SSP and MOP were applied uniformly as a source of N, P, and K. At the time of final land preparation FYM @ 10 t ha⁻¹, and entire dose of P and K each at 50 kg ha⁻¹ were applied as basal dose. Recommended dose of N @ 100 kg ha⁻¹ was applied in three splits, 1/3 each as basal, 28DAS (tillering) and 60 DAS (panicle initiation). Irrigation was given in accordance with crop need. Pressure due to insect pests and disease was generally low. However, eco-safe protection measures were taken against yellow stem borer and rice bug. The crops were harvested manually with sickle at a height of 25-30 cm from ground level on 4th and 9th June in 2017 and 2018, respectively, then grain yield after threshing and cleaning was recorded from unit plot area and converted into t ha⁻¹ at 15% moisture content.

2.4. Observations on weeds

In each plot four permanent quadrates (0.5 m x 0.5 m) were earmarked for recording weed density and biomass. Weed density was measured as the number of weeds per unit area at 30 and 45 days after herbicide application. After counting the destructed samples were first washed in fresh tap water, then sun-dried and kept in a hot air oven for 48 h at 70°C, and weighed. Different weed indices were worked out by using following equations (Banerjee et al. 2019; Kundu et al., 2020) respectively:

$$WCE = \frac{WDM_c - WDM_t}{WDM_c} \times 100$$

Where, WCE is weed control efficiency; WDM_c is the weed dry matter weight (g m⁻²) in control plot; WDM_t is the weed dry matter weight (g m⁻²) in treated plot.

Weed infestation =

$$\frac{\text{Total number of weeds in unit area}}{(\text{Total number of weeds and crop plants in the same area})} \times 100$$

$$TEI = \frac{Y_t - Y_c}{Y_t} \times \frac{WDM_c}{WDM_t}$$

Where TEI is treatment efficiency index; Y_t is crop yield from the treated plot; Y_c is crop yield from the control plot

$$WI = \frac{Y_f - Y_t}{Y_f} \times 100$$

Where WI is weed index; Y_f is yield from weed free plot; Y_t is yield from treated plot

$$CRI = \frac{CDM_t}{CRM_c} \times \frac{WDM_c}{WDM_t}$$

Where CRI is crop resistance index; CDM_t is crop dry matter (g m⁻²) in treated plot; CRM_c is crop dry matter (g m⁻²) in control plot.

$$HI = \frac{\text{Economic yield}}{\text{Biological yield}}$$

Where HI is harvest index

2.5. Microbiological observations

The enumeration of the microbial population was carried out on agar plates containing appropriate media following serial dilution technique and pour plate method as described by Kundu et al. (2020).

2.6 Analytical procedures

Initial soil samples were collected from different parts of the field and were air-dried, thoroughly mixed and ground to pass through a 2 mm sieve. The soil textural class was determined by textural triangular method (Bouyoucos, 1962). Soil mechanical composition (sand, silt and clay %) was determined by hydrometer method (Bouyoucos, 1962). Soil pH and EC (in 1:2.5 soil:water) was measured by μ-processor based pH-EC-Ion meter (Jackson, 1967). The available nitrogen was estimated through the hot alkaline permanganate method (Subbiah & Asija, 1956). The available phosphorus (P) was extracted with 0.5 M NaHCO₃ (pH 8.5) and estimated through a UV-VIS spectrophotometer (Olsen et al., 1954). Available fraction of potassium (K) was extracted with neutral normal ammonium acetate (pH 7.0; 1:10 w/v) solution and estimated through a Flame photometer (Brown & Warncke, 1988).

The above ground parts of samples (both weed and crop) were dried in a hot air oven at 60 ± 5° C to constant weight, then ground and sieved through 0.5 mm sieve. The required quantity of samples were weighed out accurately and was subjected to acid extraction and determination of N, P, and K content. Total Nitrogen, phosphorus and potassium content of the samples was determined (Jackson, 1973) and subsequently the nutrient uptake by weeds, grain and straw was computed on hectare basis as computed by Sunil et al. (2011).

2.7. Statistical analysis

All the collected data was subjected to analysis of variance (ANOVA) according to the techniques define for simple randomized complete block design (RCBD) as described by Gomez & Gomez (1984).

3 Results and discussion

3.1 Weed density

The experimental plots were infested with mixed weed flora where broad leaves weeds (BLW) were the most dominating one, followed by grassy weeds and sedges, irrespective of the dates of observations. Experimental results revealed that least weed population in terms of grasses, sedges and broadleaf weeds were registered under weed free check whereas maximum weed density was recorded under weedy check. Among the tested herbicides the treatment plot received bispyribac sodium 10% SC (250 ml ha⁻¹) resulted lowest weed density of *Echinochloa colona* throughout the growing period (1.82 and 3.11 g m⁻² respectively for 30 DAA and 45 DAA) and it was significantly at par with the fenoxaprop-p-ethyl 9.3% EC (625 ml ha⁻¹) treated plot. The similar trend was observed in other grassy weed species. The same treatment significantly ($p \leq 0.05$) reduced the densities of *Cyperus iria* during both 30 DAA and 45 DAA (Table 1). The total densities of weed in 30 DAA depicted lower value (15.52 g m⁻²) and maximum reduction (77.38%) where bispyribac sodium was applied with its utmost dose and this treatment was statistically similar with another post emergence herbicide fenoxaprop-p-ethyl @ 625 ml ha⁻¹ (Table 3). At later phases i.e. 45 DAA the higher dose of bispyribac-sodium resulted best but statistically dissimilar with each others. This necessitates the use of post emergence herbicides for weed control in direct seeded rice, which provides broad spectrum weed control and tackle the problem of herbicide resistance. These results were also in conformity with the findings of Kumaran et al. (2012) who registered lower weed density under bispyribac-sodium than other weed management treatments. This was due to the fact that bispyribac-sodium inhibited the plant enzyme acetolactate synthase (ALS), which was involved in biosynthesis of the branched-chain amino acids. Without these amino acids, protein synthesis and growth are inhibited,

ultimately causing plant death (WSSA, 2007).

3.2 Weed biomass

The weed dry weight in terms of weed biomass at 30 and 45 DAA varied significantly among the treatments (Table 2). Amongst tested herbicides least weed biomass in grassy population was registered with the plot received bispyribac-sodium @ 250 ml ha⁻¹ irrespective of weed species and dates of observation. The biomass accumulation by *Cyperus sp.* was highly reduced by the same herbicide with its maximum dose at 30 and 45 DAA (2.07 and 7.07 gm⁻² respectively) and closely followed by the higher dose of fenoxaprop-p-ethyl (625 ml ha⁻¹) and second lowest dose of bispyribac-sodium. In case of BLWs the similar observations were recorded. Singh et al. (2009) and Kumar et al. (2013) also concluded that application of bispyribac-sodium resulted in the accumulation of minimum biomass of BLWs. The results depicted from table 3, it can be concluded that total biomass accumulation by several weed flora was reduced over control with the post emergent application of bispyribac-sodium (250 ml ha⁻¹), accounting a value of 81.50% and 83.43% at 30 DAA and 45 DAA respectively (Table 3). These results also in tune with Nalini et al. (2012) who opined that the post emergent application of bispyribac-sodium with higher dose had maximum efficacy in respect to dry biomass accumulation against broad-spectrum weed flora in rice.

3.3 Weed control efficiency

Data in table 4 revealed that hand weeding (twice at 20 and 40 DAT) was the most efficient technique irrespective of different weed species and growth stages of rice. *Echinochloa colonum*, a dominant grassy weed in rice field was most efficiently (> 80%)

Table 1: Effect of treatments on weed density (no. m⁻²) at 30 DAA and 45 DAA in direct seeded paddy (mean value of two years)

Treatments	<i>Echinochloa colona</i>		<i>Dactyloctenium aegyptium</i>		Other Grass		<i>Cyperus Sp</i>		<i>Physalis minima</i>		<i>Digera arvensis</i>		Other BLW	
	30	45	30	45	30	45	30	45	30	45	30	45	30	45
Bispyribac Sodium (150 ml ha ⁻¹)	5.33	9.03	4.44	8.22	3.44	6.11	8.11	15.11	7.11	10.33	5.22	8.22	3.44	7.89
Bispyribac Sodium (200 ml ha ⁻¹)	2.67	5.11	2.44	4.44	1.67	2.56	3.78	9.02	3.33	4.89	2.44	4.78	1.44	3.00
Bispyribac Sodium (250 ml ha ⁻¹)	2.33	4.56	2.11	4.33	1.33	1.78	3.44	8.00	3.07	4.56	2.11	4.56	1.11	2.67
Fenoxaprop-p-ethyl (500 ml ha ⁻¹)	2.88	5.33	2.56	4.78	1.78	2.78	4.00	9.33	3.78	5.07	2.56	5.03	1.67	3.11
Fenoxaprop-p-ethyl (625 ml ha ⁻¹)	2.56	4.89	2.22	4.44	1.56	2.06	3.56	8.22	3.22	4.78	2.22	4.67	1.33	2.89
Weedy check	10.56	16.11	8.11	13.22	6.67	12.22	14.33	28.22	11.44	15.56	10.33	14.33	7.07	13.44
Weed free check	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
LSD ($P \leq 0.05$)	0.46	0.69	0.50	0.55	0.49	0.36	0.65	1.05	0.43	0.56	0.31	0.46	0.41	0.53

† DAA, Days after application; LSD- Least significant difference

Table 2: Effect of treatments on weed dry weight (g m⁻²) at 30 DAA and 45 DAA in direct seeded paddy (mean value of two years)

Treatments	<i>Echinochloa colona</i>		<i>Dactyloctenium aegyptium</i>		Other Grass		<i>Cyperus Sp</i>		<i>Physalis minima</i>		<i>Digera arvensis</i>		Other BLW	
	30	45	30	45	30	45	30	45	30	45	30	45	30	45
Bispyribac Sodium (150 ml ha ⁻¹)	2.74	5.87	3.20	5.19	3.19	4.17	3.11	9.89	3.98	5.33	2.81	5.42	2.97	4.95
Bispyribac Sodium (200 ml ha ⁻¹)	1.93	3.29	1.88	3.07	1.64	2.27	2.32	7.56	2.45	3.42	1.90	3.15	1.52	3.35
Bispyribac Sodium (250 ml ha ⁻¹)	1.82	3.11	1.76	2.82	1.49	2.13	2.07	7.07	2.11	3.31	1.72	3.01	1.40	3.25
Fenoxaprop-p-ethyl (500 ml ha ⁻¹)	1.98	3.34	1.92	3.26	1.68	2.41	2.48	7.61	2.68	3.59	1.99	3.35	1.57	3.62
Fenoxaprop-p-ethyl (625 ml ha ⁻¹)	1.90	3.23	1.80	2.87	1.59	2.22	2.25	7.37	2.34	3.36	1.83	3.08	1.44	3.31
Weedy check	9.70	15.88	8.52	18.29	7.53	12.38	11.73	43.51	12.58	20.62	8.82	19.86	7.99	18.55
Weed free check	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
LSD ($P \leq 0.05$)	0.12	0.15	0.10	0.38	0.20	0.38	0.15	0.13	0.22	0.39	0.14	0.34	0.16	0.26

† DAA, Days after application; LSD- Least significant difference

Table 3: Effects of different weed control treatments on the total density (no. m⁻²) and dry weight (g m⁻²) of weeds in direct seeded paddy (mean value of two years)

Treatments	Density				Dry weight			
	30 DAA	% of control	45 DAA	% of control	30 DAA	% of control	45 DAA	% of control
Bispyribac Sodium (150 ml ha ⁻¹)	37.09	45.86	64.91	42.61	22.00	67.10	40.82	72.62
Bispyribac Sodium (200 ml ha ⁻¹)	17.77	74.06	33.80	70.11	13.45	79.89	26.11	82.49
Bispyribac Sodium (250 ml ha ⁻¹)	15.52	77.38	30.46	73.07	12.37	81.50	24.7	83.43
Fenoxaprop-p-ethyl (500 ml ha ⁻¹)	19.23	71.93	35.43	68.67	13.80	79.36	27.18	81.77
Fenoxaprop-p-ethyl (625 ml ha ⁻¹)	16.67	75.67	31.95	71.75	12.97	80.60	25.44	82.94
Weedy check	68.51	0.00	113.10	0.00	66.87	0.00	149.09	0.00
Weed free check	0	100.00	0	100.00	0	100.00	0	100.00
LSD ($P \leq 0.05$)	0.78	-	1.24	-	0.62	-	1.76	-

† DAA, Days after application; LSD- Least significant difference

Table 4: Effect of treatments on weed control efficiency at 30 DAA and 45 DAA in direct seeded paddy (mean value of two years)

Treatments	<i>Echinochloa colona</i>		<i>Dactyloctenium aegyptium</i>		Other Grass		<i>Cyperus Sp</i>		<i>Physalis minima</i>		<i>Digera arvensis</i>		Other BLW	
	30	45	30	45	30	45	30	45	30	45	30	45	30	45
Bispyribac Sodium (150 ml ha ⁻¹)	71.75	62.83	62.44	71.62	57.64	66.32	73.49	77.27	68.36	76.15	68.14	74.15	62.83	73.32
Bispyribac Sodium (200 ml ha ⁻¹)	79.50	80.98	77.93	83.21	78.22	81.66	80.82	82.62	81.48	82.41	78.46	83.41	80.98	81.94
Bispyribac Sodium (250 ml ha ⁻¹)	81.24	82.48	79.34	84.58	80.21	82.79	82.35	83.75	83.23	84.95	80.50	85.72	82.48	82.48
Fenoxaprop-p-ethyl (500 ml ha ⁻¹)	78.59	80.35	77.46	82.18	77.69	80.53	80.56	82.51	81.08	82.01	77.44	82.59	80.35	80.49
Fenoxaprop-p-ethyl (625 ml ha ⁻¹)	80.41	81.98	78.87	84.31	78.88	82.07	81.50	83.06	82.19	83.71	79.25	83.71	81.98	82.16
Weedy check	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Weed free check	100.00	100.00	100.00	100.00	100.0	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00
LSD ($P \leq 0.05$)	1.75	0.83	1.44	1.62	1.64	0.32	0.49	0.27	0.36	0.53	0.14	0.15	1.02	0.28

† DAA, Days after application; LSD- Least significant difference

managed by bispyribac-sodium 10% SC applied @ 250 ml ha⁻¹ at both date of observations, being statistically similar with fenoxaprop-p-ethyl applied @ 625 ml ha⁻¹, and bispyribac-sodium 10% SC applied @ 200 ml ha⁻¹, whereas lower efficiency was obtained from weedy check as no weed control measures were taken. These findings also supported by Singh (2004) and Rana et al. (2014) who demonstrated that fenoxaprop-p-ethyl @ 600 ml ha⁻¹ was most efficient to control *E. crusgalli* (89.74 %) than rest other doses (400 ml ha⁻¹ and 500 ml ha⁻¹). The leaves and stems of the grassy weeds quickly take up the active ingredient of fenoxaprop-p-ethyl. Biochemically, it predominantly inhibits the synthesis of fatty acids in the meristematic tissues of the grassy weeds. The maximum efficiency (85.72%) was observed against *Digera arvensis* at later stage of observation where bispyribac-sodium @ 625 ml ha⁻¹ was applied (Table 4). The standard of efficiency was declining with the subordinate chemical doses. Former researchers also established that application of post emergence herbicide bispyribac-sodium (25 g a.i. ha⁻¹) recorded significantly ($p \leq 0.05$) lowest weed density (16.8 & 16.5 m⁻²), lowest weed dry weight g m⁻² (2.4 and 2.1 g m⁻²), and highest weed control efficiency (83 and 86%) during both the year 2015-16 & 2016-17 respectively (Kumar et al., 2018).

3.4 Weed indices

Weed infestation index refers to the percentage of weeds in the composite population of weed and crop plants. Data in Table 5 indicated that among the herbicidal treatments bispyribac-sodium (250 ml ha⁻¹) treated plot resulted lowest infestation index (0.24) which established in another way that this particular treatment had supreme efficiency against weed flora. Weedy check plot depicted higher value of infestation as no control measure was taken. The

treatment efficiency index (TEI) indicates the weed killing potential of a treatment and its phytotoxicity on the crop. From the table 5, it was concluded that highest dose of bispyribac-sodium resulted maximum treatment efficiency (2.22) and excluding weedy check plot lowest efficiency was found from the same herbicide treated plot in lower dose. The similar trend of observations was found in crop resistance index. Furthermore, lowest weed index (4.24) was recorded with bispyribac-sodium 10% SC @ 250 ml ha⁻¹ that means it resulted highest increase of grain yield over control. Previously Mishra & Singh (2011) also reported that sole application of bispyribac-sodium proved superiority than other herbicides for rice ecosystem in respect to these weed indices.

3.5 Yield and yield attributes

In Lieu of weed free check, significant ($p \leq 0.05$) higher yield were exhibited from all the herbicide application treatments as compared to non-treated control. Differential herbicide management had resulted significant grain yield variation of rice cv. Satabdi ranging from 2.57 to 4.25 t ha⁻¹ and the yield increase was to tune of 17.89 to 65.36 % over control (Table 6). Among the herbicidal treatment the higher dose of herbicide i.e. bispyribac-sodium applied @ 250 ml ha⁻¹ recorded the significant higher grain yield closely fenoxaprop-p-ethyl applied @ 625 ml ha⁻¹ and bispyribac-sodium 10% SC applied @ 200 ml ha⁻¹ respectively, but the treatments are statistically dissimilar with each other's. However, yield obtained from weed free plot was statistically similar with the treatment received utmost dose of bispyribac-sodium. While the minimum grain yield was found from the weedy check (2.57 t ha⁻¹). Similar trend of findings were obtained in straw yield and harvest index of direct seeded rice. This encouraging findings of current study

Table 5: Effect of treatments on weed infestation index (WII), treatment efficiency index (TEI), weed index (WI), crop resistance index (CRI) in direct seeded paddy (mean value of two years)

Treatments	WII (%)		TEI	WI	CRI
	30 DAA	45 DAA			
Bispyribac Sodium (150 ml ha ⁻¹)	0.43	0.56	0.55	28.71	4.28
Bispyribac Sodium (200 ml ha ⁻¹)	0.26	0.40	1.86	10.35	8.54
Bispyribac Sodium (250 ml ha ⁻¹)	0.24	0.38	2.22	4.24	9.45
Fenoxaprop-p-ethyl (500 ml ha ⁻¹)	0.28	0.41	1.60	14.59	7.76
Fenoxaprop-p-ethyl (625 ml ha ⁻¹)	0.25	0.39	1.98	8.71	8.68
Weedy check	0.58	0.69	0.00	39.53	1.00
Weed free check	0.00	0.00	-	0.00	-
LSD ($P \leq 0.05$)	-	-	-	-	-

† DAA, Days after application; LSD- Least significant difference

Table 6: Effect of treatments on yield in direct seeded paddy (mean value of two years)

Treatments	Yield (t ha ⁻¹)		Harvest Index (%)
	Grain	Straw	
Bispyribac Sodium (150 ml ha ⁻¹)	3.03	4.21	41.85
Bispyribac Sodium (200 ml ha ⁻¹)	3.61	5.13	41.30
Bispyribac Sodium (250 ml ha ⁻¹)	4.07	5.61	42.05
Fenoxaprop-p-ethyl (500 ml ha ⁻¹)	3.53	5.11	40.86
Fenoxaprop-p-ethyl (625 ml ha ⁻¹)	3.68	5.27	41.12
Weedy check	2.57	3.61	41.59
Weed free check	4.25	5.83	41.85
LSD ($P \leq 0.05$)	0.27	0.43	-

†LSD- Least significant difference

revealed that the application of herbicide is highly efficient and non-laborious and strategically better than manual weeding. It may be also better in respect to economics involved in direct seed rice cultivation as higher cost has been incurred during manual weeding. Such increase in yield might have been attributed to effective suppression of weeds thus growth performance of the plant was desirable, because occurrence of low weed density in this treatment and also improved soil physical condition. There was a strong negative correlation ($R^2=0.738$) have been reported between weed dry matter at 45 DAA and rice grain yield (Figure 1). The above findings distinctly emphasize that poor competitive efficiency of rice with weeds and there is essential need to control them during initial period of crop growth effectively. Similar result was recorded by Chauhan & Opena (2013) regarding grain yield of rice and weed biomass at harvest. Advantages of herbicide application and judicious weed management strategies in improving yield attributes and yield of several crops are supported also by various other research reports (Razzaq et al., 2010; Farooq et al. 2011).

3.6 Soil microbial population

The impact of application of different herbicide on total bacteria (*Pseudomonas fluorescence*), total fungi (*Trichoderma viridae*, *Trichoderma harzianum*) and Actinomycetes were recorded during harvesting of rice (Figure 2). Different weed management treatments significantly ($p \leq 0.05$) influence the soil microbial populations. Bacterial population sharply hampered by the application of fenoxaprop-p-ethyl 9.3% EC (625 ml ha⁻¹) followed by the highest dose bispyribac-sodium 10% SC in compared to herbicide free plot i.e. weedy check and weed free check. However, lowest fungal and actinomycetes population were depicted from the treatment treated with bispyribac-sodium (250 ml ha⁻¹). The population of soil micro flora was increased with

lowering doses of herbicides and ultimately weed free check and weedy check resulted in significantly greater microbial population respectively. It is also obtained in the findings of Anderson (2003) and Das et al. (2010), who have reported that there is no longer harmful effects of herbicides generally on soil microbial population except in case of higher concentrations beyond recommended doses. This is might be due to the fact that microorganisms are able to degrade herbicides and utilize them as a source of biogenic elements for their own physiological processes (Bera & Ghosh 2013).

3.7 Nutrient removal by weeds

Uptake of N, P and K by weeds followed the trend of weed biomass. Hence, there was no uptake was found in weed free plot and in contrast, maximum removal of major nutrients was found from the weedy check (Figure 3). Owing to an efficient controller of weeds, bispyribac-sodium @ 250 ml ha⁻¹ treated plot removed least amount of N, P, and K (5.56, 0.86, and 5.41 kg ha⁻¹ respectively) and least was found from the treatment comprised of similar herbicide with lower dose. Being an efficient weed killer bispyribac-sodium depicted meagre removal of nutrients in this experiment. These results are in line with Singh et al. (2003).

3.8 Nutrient uptake by rice

The nutrient uptake by crops was inversely proportional to nutrient uptake by weeds. All weed control treatments were significantly superior to weedy check in increasing NPK uptake by rice at 45 DAA (Figure 3). Irrespective of three major nutrients, total maximum uptake was found from the weed free plot (78.18, 18.85, and 109.89 kg ha⁻¹ NPK respectively) closely followed by bispyribac and fenoxaprop-p-ethyl treated plots in consequence with their grain and straw yield of rice. The crop cultivated under

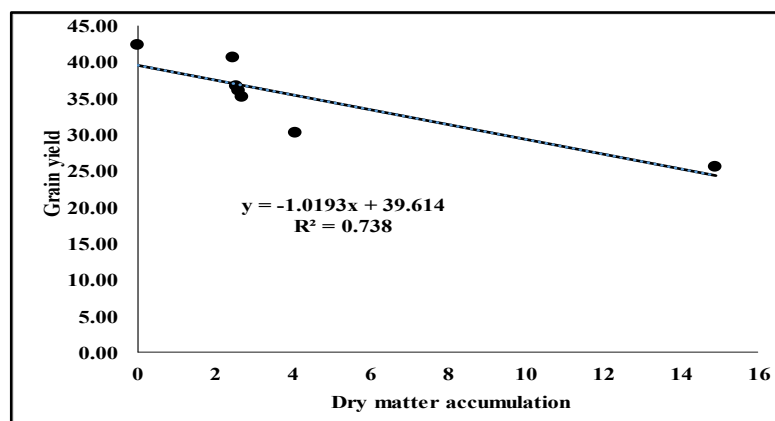


Figure 1 Relationship between dry matter accumulation (q ha^{-1}) and grain yield (q ha^{-1}) of rice

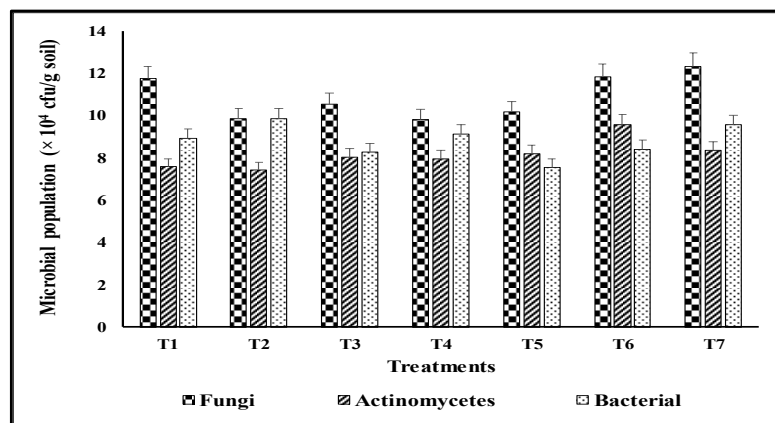


Figure 2 Microbial populations in soil as affected by weed control treatments at the time of rice harvesting. T₁- Bispyribac Sodium (150 ml ha^{-1}), T₂- Bispyribac Sodium (200 ml ha^{-1}), T₃- Bispyribac Sodium (250 ml ha^{-1}), T₄- Fenoxaprop-p-ethyl (500 ml ha^{-1}), T₅- Fenoxaprop-p-ethyl (625 ml ha^{-1}), T₆- Weedy free check; Error bars represent LSD ($P \leq 0.05$).

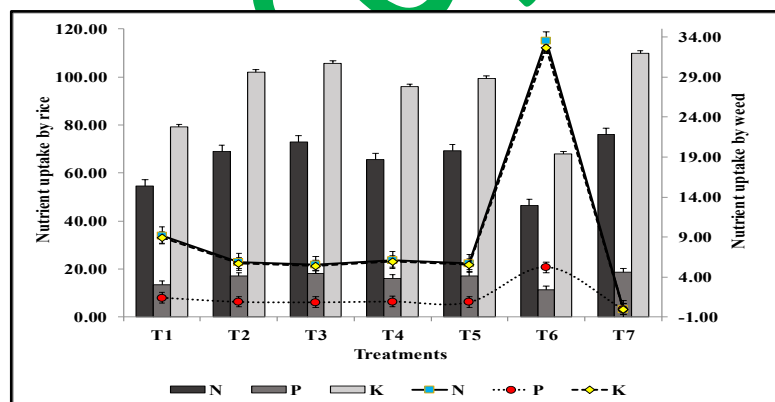


Figure 3 Nutrient uptake (kg ha^{-1}) by rice (column) and weed (line) as affected by weed control treatments at the time of rice harvesting. T₁- Bispyribac Sodium (150 ml ha^{-1}), T₂- Bispyribac Sodium (200 ml ha^{-1}), T₃- Bispyribac Sodium (250 ml ha^{-1}), T₄- Fenoxaprop-p-ethyl (500 ml ha^{-1}), T₅- Fenoxaprop-p-ethyl (625 ml ha^{-1}); Error bars represent LSD ($P \leq 0.05$).

the treatment associated with uppermost dose of bispyribac-sodium ensued 73.06, 18.07, and $105.70 \text{ kg ha}^{-1}$ NPK uptake which was highest than other tested herbicides. It might be due to better control of weeds resulted by the application of herbicides and manual weeding in the weed management treatments, minimized the crop weed competition and enhanced the nutrient availability and uptake. Nutrient uptake by crop also is a function of nutrient content in dry matter and the dry matter production. The lowest NPK uptake in weedy check might be due to severe competition for growth factors. This result is in agreement with the findings of Nath et al. (2014) and Chakraborti et al. (2017).

3.9 Phytotoxicity of herbicides

The rice plants were critically examined for phytotoxic symptoms at 1, 3, 5, 7 and 10 days after herbicide application. As per our observation, we found no phytotoxicity like epinasty, hyponasty, necrosis, vein clearing, wilting and leaf injury on tip/surface in the plants.

Conclusions

The present experiment had an intention to discern the effectiveness of herbicides on various weed floras in direct seeded rice. From this experiment, it can be concluded that the herbicide bispyribac-sodium 10% SC applied @ 250 ml ha^{-1} was most effective treatment in respect of suppression of all types of weeds, their density and biomass throughout the observation period and resulted in about 58.36 % yield increment of rice over control without showing any phytotoxicity on plants. Based on overall performance, we could be suggested that the application of bispyribac-sodium 10% SC @ 250 ml ha^{-1} exploit not only better weed management but also improves the yield of direct seeded rice. The field history regarding dominance of specific weed species and their level of virulence is the prime factor in deciding the selection of weed management practices. Further research is needed to evaluate the carry over effect of herbicides towards next cropping window, and develop timing strategies with minimum effective

dosages which could be most economic and ecologically desirable weed management approach for rice based cropping system in eastern India.

Conflict of interest

Authors would hereby like to declare that there is no conflict of interests that could possibly arise.

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