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Research Paper

Herbicidal weed-management options for dry direct-seeded rice (*Oryza sativa*) in North-Eastern Plains of India

MOHAMMAD HASHIM[1], V.K. SINGH[2], K.K. SINGH[3] AND SHIVA DHAR[4]

Regional Station, ICAR-Indian Agricultural Research Institute, Pusa, Bihar 848 125

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ABSTRACT

A field experiment was conducted during the rainy (*kharif*) seasons of 2017 and 2018 at Regional Station of the ICAR-Indian Agricultural Research Institute, Pusa, Samastipur, Bihar, to study the effect of herbicides in controlling mixed weed flora in direct-seeded rice (*Oryza sativa* L.). The experimental results revealed that, the alone and sequential application of herbicides significantly reduced the weed density and biomass of complex weed flora. The growth and yield attributes, viz. plant height at maturity, effective tillers/m^2, 1,000grain weight, grains/panicle and panicle length, were significantly influenced by application of herbicides. Weed-free condition resulted in significantly highest grain yield (4.49 t/ha). Among different herbicidal treatments, application of pendimethalin @ 1,000 ml/ha followed by (*fb*) tank-mix application of bispyribac sodium (25 g/ha) + pyrazosulfuron (15 g/ha) resulted in higher plant height (110.7 cm), higher number of effective tillers (320.0/m^2), grains/panicle (132.2), ear length (29.8 cm), grain yield (4.49 t/ha), net returns (₹ 70,600/ha) and benefit : cost ratio (1.67), which was superior to rest of the treatments. Application of pendimethalin (1,000 ml/ha) *fb* tank-mix application of bispyribac sodium (25 g/ha) + pyrazosulfuron (15 g/ha) significantly reduced the weed density (56.8/m^2) and weed biomass (26.6 g/m^2).

Key words: Direct-seeded rice, Herbicides, Net returns, Weed biomass, Weed control efficiency, Yield

Rice (*Oryza sativa* L.) is a principal source of food for more than half of the world population, and more than 90% of rice worldwide is grown and consumed in Asia (Mahajan and Chauhan, 2015). Traditionally, rice in India is established through transplanting (25-30 days old seedlings) into a puddled rice field, making it cumbersome, costly and labour intensive. Continuous flooding for rice cultivation is not only a huge drain on already scarce freshwater resources, but often results in lower water productivity. Looming water crises, rising wage rates, and the stagnant productivity of the rice-wheat cropping system have compelled researchers and farmers to seek alternative methods of rice establishment (Singh *et al*., 2016). Dry-seeded rice (DSR) is a potential alternative that can help improve water productivity, and eliminate time and edaphic conflicts in the rice-wheat cropping system (Mahajan *et al*., 2011). Growing of rice under aerobic conditions can reduce water losses to a great extent during hot summer months (May-June). The water resources both under surface and water are becoming a limiting factor. Hence, direct-seeding of rice instead of conventional transplanting is being practiced to reduce water losses (Mahajan and Chauhan, 2015). Direct-seeding of rice refers to the process of establishing the crop from seeds sown in the field rather than by transplanting seedlings from the nursery (Farooq *et al.,* 2011). The DSR saves about 11-18% irrigation water (Tabbal *et al*., 2002) and reduces 11-16% total labour requirement compared to puddle transplanted rice (PTR) depending on season, location and type of DSR (Rashid *et al*., 2009). There are a few limiting factors associated with direct-seeded rice that impair yields including crop-weed competition. Compared to transplanted rice, the yield losses in direct-seeded rice are greater due to absence of flooding water at the early stage of the crop to suppress weed growth (Rao *et al*., 2007; Singh *et al*., 2007). Weeds emerge with the crop simultaneously and grow more quickly in moist soil of direct-seeded rice than in PTR (Khaliq and Matloob, 2011). It has been estimated that, yield loss in rice could be high (50-94%) due to weed infestations (Chauhan and Johnson, 2011; Chauhan and Opena, 2012). As regards the various weed-management measures, manual eradication has proved its superiority to all the measures in managing weeds; however, the adoption

[1]**Corresponding author's Email:** hashimagronomy@gmail.com
[1]Scientist, Senior Scale, [3]Head, ICAR-Indian Agricultural Research Institute, Regional Station, Pusa, Samastipur, Bihar 848 125; [2]Director, ICAR-Central Research Institute for Dryland Agriculture, Hyderabad, Telangana 500 059; [4]Principal Scientist, Division of Agronomy, ICAR-Indian Agricultural Research Institute, New Delhi 110 012

of this technique is not gaining popularity amongst the rice growers as it is time-consuming, labour-intensive and many times become impractical due to scarcity of labour (Chauhan and Johnson, 2011; Anwar *et al*., 2012). Timely weeding is most important to minimize yield losses and therefore under such circumstances the only effective tool is left to control weeds through the use of chemicals.

Management of weeds through the use of chemicals has also been found as effective as realized under manual eradication in various crops including rice with over and above benefits in saving extra costs involved in use of labour on manual eradication of weed. Therefore, keeping the weeds below threshold level, herbicides provide the low-cost and effective tool through which excessive weed population can be controlled before crop-weed competition. Hence, present investigation was undertaken to assess the effect of multiple herbicidal interventions on productivity of dry direct-seeded rice.

MATERIALS AND METHODS

The field experiment was conducted during the rainy (*kharif*) season of 2017 and 2018 at the experimental field of Regional Station of the ICAR-Indian Agricultural Research Institute, Pusa Samastipur (25°58'49'' N, 85°40'48'' E, 52.12 m above mean sea-level), Bihar. The soil of the experimental field was sandy loam with low organic carbon (0.34-0.36%) and low available nitrogen (118-120 kg/ha), available phosphorus (6770 kg/ha) and medium level of potassium (250-255 kg/ha) and slightly alkaline (*p*H 8.3). The climate of the site is sub-humid tropical with hot summer and cold winter, with an average annual rainfall of 1,000-1,200 mm, of which 75-80% received from July to September. The experiment was laid out in a randomized complete-block design with 3 replications. The experiment comprised of 12 weed management practices, viz. oxadiargyl (90 g/ha), pretilachlor (750 ml/ha), bispyribac sodium (25 g/ha), pyrazosulfuron (15 g/ha), pendimethalin (1,000 ml/ha) followed by (*fb*) bispyribac sodium (25 g/ha), oxadiargyl (90 g/ha) *fb* bispyribac sodium (25 g/ha), pretilachlor (750 ml/ha) *fb* bispyribac sodium (25 g/ha), oxadiargyl (90 g/ha) *fb* pyrazosulfuron (15 g/ha), pretilachlor (750 ml/ha) *fb* pyrazosulfuron (15 g/ha), pendimethalin (1,000 ml/ha) *fb* bispyribac sodium (25 g/ha) + pyrazosulfuron (15 g/ha). Different pre- and post-emergence herbicides tested in the study were: oxadiargyl, pretilachlor and pendimethalin as pre-emergence and bispyribac and pyrazosulfuron as post-emergence. Rice variety 'Pusa Sugandha 5' was sown in the last week of June and harvested in October during both the years of experimentation. The crop was sown at a row spacing of 20 cm. The crop was fertilized with 120, 60 and 40 kg of N, P_2O_5 and K_2O/ha. The sources for nitrogen, phosphorus and potassium were urea, diammonium phosphate and muriate of potash, respectively. Half nitrogen, full dose of phosphorus and potash were applied basal and the remaining nitrogen was applied in 2 equal split doses at active tillering and panicle-initiation stage in all treatments. Pre-emergence and post-emergence herbicides were applied at 3 days after sowing (DAS) and 22 DAS (3 to 4 leaf stages), respectively, with the help of manualy operated knapsack sprayer, fitted with a flatfan nozzle using water as a carrier by keeping a thin film of water in the field. Weedy check plots were kept undisturbed and weed-free plots were kept weed-free/ devoid of weed for the entire growing period of crop. Data on weed density were recorded from an area enclosed in the quadrate of 1 m^2 randomly selected at 3 places in each plot. Weeds collected from 1 m^2 area at 3 places were first sun-dried for 2-3 days and then oven-dried at 65°C till the constant weight obtained. The weed dry matter obtained at 60 DAS was expressed in g/m^2. The data on weed density and weed dry weight thus obtained were subjected to square-root transformation ($\sqrt{x+0.5}$) as wide variations existed among the treatments before statistical analysis. Weed-control efficiency (WCE), Weed-control index (WCI) were calculated as:

$$\text{WCE} = \frac{(\text{Weed density in control plot} - \text{weed density in treated plot})}{\text{Weed density in control plot}} \times 100$$

$$\text{WCI} = \frac{(\text{Weed dry weight in control plot} - \text{weed dry weight in treated plot})}{\text{Weed dry weight in control plot}}$$

The degree of association between the yield components and grain yield was determined using correlation and regression analysis. Net returns were computed by deducting the total cost of cultivation from the gross returns as per treatments. Benefit : cost ratio was calculated by dividing net returns with the cost of cultivation for each treatment. Data of weed count, weed density, yield attributes and yield and economics were tabulated and subjected to analysis of variance techniques as described by Gomez and Gomez (1984). The relationship between grain yield and weed biomass were assessed using linear regression analysis.

RESULTS AND DISCUSSION

Weed density, weed dry weight, weed-control efficiency and weed-control index

The experimental field was severely infested with grassy, broad-leaf weeds and sedges, viz. black nightshade (*Solanum nigrum* L.), awnless barnyard grass [*Echinochloa colona* (L.) Link], nut grass (*Cyperus rotundus* L.), rice flat sedge (*Cyperus iria* L.), false daisy [*Eclipta prostrate* (L.) L.; syn, *E. alba* (L.) Kuntze], white top weed (*Parthenium hysterophorus* L.), store breaker (*Phyllanthus niruri* L.), carabao grass *(Paspalum conjugatum* P.J. Bergius), kachri *(Cucumis pubesescens* willd.) etc. However, out of total weed populations the field was dominated by sedges followed by grasses and broadleaf weeds. Total weed density (grasses, broad leaf weeds and sedges) in the non-treated weedy check was 251.3 weeds/m^2 and it was highly significant than rest of the treatments (Table 1). All herbicidal treatments significantly reduced the total weed density as compared to the weedy check. Among the herbicidal treatments, significantly lowest weed density (56.8/m^2) was recorded with the application of pendimethalin (1,000 ml/ha) *fb* tank-mix application of bispyribac sodium (25 g/ha) + pyrazosulfuron (15 g/ha). Total weed density following the alone application of pretilachlor (750 ml/ha) was 138.3/m^2 and it was similar to the application of oxadiargyl @ 90 g/ha (135.0/m^2) and significantly higher than rest of the treatments; however, lower than weedy check (non-treated control). Pretilachlor (750 ml/ha) *fb* pyrazosulfuron (15 g/ha) showed the highest total weed density (112.3/m^2) among the sequential herbicide treatments, which was comparable higher than oxadiargyl (90 g/ha) *fb* pyrazosulfuron (15 g/ha) and lower than the non-treated control. The treatment with alone application of oxadiargyl (90 g/ha) and pretilachlor (750 ml/ha) showed 46.3 and 44.9% reduction or bispyribac sodium and pyrazosulfuron showed 55.1 and 52.2% reduction in weed density compared to 77.4% reduction in weed density achieved with the sequential and tank-mix application of pendimethalin (1,000 ml/ha) *fb* bispyribac sodium (25 g/ha) + pyrazosulfuron (15 g/ha). Singh *et al*. (2006) reported that sequential application of pre- and post-emergence herbicides reduced the grassy and broad-leaf weeds significantly. Mahajan *et al*. (2009) also found that, sequential application of pendimethalin (1,000 g/ha) *fb* bispyribac-sodium (30 g/ha) applied at 15 DAS provided better control of weeds in direct-seeded rice. Significantly highest weed-control efficiency (77.4%) was observed with sequential and tank-mix application of pendimethalin (1,000 g/ha) *fb* bispyribac (25 g/ha) + pyrazosulfuron (15 g/ha). The lowest WCE (44.9%) was recorded with alone application of pretilachlor as pre-emergence. These results confirm findings of Mahajan and Chauhan (2013), Ganie *et al.* (2013) and Sanodiya and Singh (2019).

Similar to weed density, total weed biomass was 120.5 g/m^2 in the nontreated control (weedy check). Total weed dry weight reduced significantly with all the herbicidal treatments as compared to non-treated control (Table 1). The lowest weed dry weight (26.6 g/m^2) and the highest weed-control index (77.9%) was recorded with application of pendimethalin (1,000 ml/ha) *fb* tank-mix application of

Table 1. Effect of weed-management practices on weed density and weed dry weight of different weeds at 60 days after sowing in rice (pooled data of 2 years)

Treatment	Weed density (no./m^2) at 60 DAS			Total weed density (no./m^2) at 60 DAS	Weed-control efficiency (%)	Weed-dry weight (gm/m^2)	Weed-control index
	Grasses	Broad-leaf	Sedges				
Oxadiargyl @ 90 g/ha (pre)	3.1 (8.8)	2.7 (6.8)	10.9 (119.3)	11.6 (135.0)	46.3	7.3 (52.6)	56.3
Pretilachlor @ 750 ml/ha (pre)	3.1 (9.0)	2.7 (7.0)	11.1 (122.3)	11.8 (138.3)	44.9	7.7 (59.6)	50.6
Bispyribac-sodium @ 25 g/ha (post)	2.3 (5.0)	2.5 (5.8)	10.1 (102.0)	10.6 (112.8)	55.1	6.4 (41.3)	65.6
Pyrazosulfuron @ 15 g/ha (post)	3.0 (8.7)	2.7 (6.7)	10.2 (104.5)	11.0 (119.8)	52.2	6.6 (42.8)	64.6
Pendimethalin @ 1000 ml/ha (pre) *fb* bispyribac sodium @ 25 g/ha (post)	1.6 (2.0)	2.0 (3.3)	8.2 (66.7)	8.5 (72.0)	71.3	5.6 (30.8)	74.3
Oxadiargyl @ 90 g/ha (pre) *fb* bispyribac sodium @ 25 g/ha (post)	2.0 (3.5)	2.0 (3.7)	8.9 (79.7)	9.3 (86.3)	65.6	5.9 (34.3)	71.5
Pretilachlor @ 750 ml/ha (pre) *fb* bispyribac sodium @ 25 g/ha (post)	2.2 (4.5)	2.0 (3.7)	9.4 (88.0)	9.8 (96.2)	61.7	6.1 (36.7)	69.5
Oxadiargyl @ 90 g/ha (pre) *fb* pyrazosulfuron 15 g/ha (post)	2.3 (4.7)	2.1 (4.0)	10.0 (99.7)	10.4 (108.3)	56.9	6.2 (38.1)	68.4
Pretilachlor @ 750 ml/ha (pre) *fb* pyrazosulfuron @ 15 g/ha (post)	2.3 (5.0)	2.2 (4.5)	10.2 (102.8)	10.6 (112.3)	55.3	6.3 (39.1)	67.3
Pendimethalin @ 1,000 ml/ha (pre) *fb* bispyribac sodium @ 25 g/ha (post) + pyrazosulfuron @ 15 g/ha (post)	1.6 (2.0)	1.4 (1.3)	7.4 (53.5)	7.6 (56.8)	77.4	5.2 (26.6)	77.9
Weedy check	3.5 (12.0)	3.1 (9.0)	15.2 (230.3)	15.9 (251.3)	0.0	11.0 (120.5)	0.0
Weed-free check	0.7 (0.0)	0.7 (0.0)	0.7 (0.0)	0.7 (0.0)	100.0	0.7 (0.0)	100.0
SEm±	0.18 (0.88)	0.16 (0.74)	0.21 (4.23)	0.21 (4.57)	1.76	0.23 (3.16)	2.40
CD (P=0.05)	0.57 (2.73)	0.50 (2.29)	0.65 (13.16)	0.66 (14.24)	5.49	0.72 (9.83)	7.46

DAS, days after sowing; pre, pre-emergence; post, post-emergence; *fb*, followed by

*****Data subjected to $\sqrt{x} + 0.5$ transformation; figures in the parentheses are original value bispyribac sodium (25 g/ha) + pyrazosulfuron (15 g/ha). Weed biomass in this plot was comparable lower to that produced in plots treated with pendimethalin *fb* bispyribac (30.8 g/m^2) and oxadiargyl *fb* bispyribac sodium (34.3 g/m^2) applied sequentially. The sequential and tank-mix application of all the herbicides exhibited superiority in controlling weeds to alone application of herbicides. Significantly highest weed-control index (77.9) was recorded with sequential and tank-mix application of pendimethalin (1,000 ml/ha) *fb* bispyribac sodium (25 g/ha) + pyrazosulfuron (15 g/ha). The lowest WCI (50.6) was recorded with the pretilachlor (750 ml/ha) as pre-emergence.

Growth, yield attributes and yield

All the herbicidal treatments resulted in significantly higher plant height, yield parameters and yield than the weedy check control (Table 2). The weed-free treatment resulted in significantly highest plant height, highest number of effective tillers, 1,000-grain weight, grains/panicle and panicle length and weedy check treatment recorded significantly lowest plant height, number of effective tillers, 1,000 grain-weight, grains/panicle and the panicle length. Among the herbicidal treatments, significantly highest plant height, effective tillers, 1,000-grain weight, grains/panicle and panicle length were observed with application of pendimethalin (1,000 ml/ha) *fb* tank-mix application of bispyribac sodium (25 g/ha) + pyrazosulfuron (15 g/ha) over the weedy check. Significantly lowest plant height and number of effective tillers were recorded with alone application of pretilachlor (750 ml/ha) as pre-emergence owing to a high weed pressure experienced by the crop. In the plots treated with pendimethalin (1,000 ml/ha) *fb* tank-mix application of bispyribac sodium (25 g/ha) + pyrazosulfuron (15 g/ha), grains/panicle were higher by 23.5% than the weedy control. All the growth and yield-attributing characters were higher with the weed-control treatments and weed-free check owing to low weed pressure experienced by the crop and the lowest value was recorded in weedy check owing to a high weed competition on them.

Application of herbicidal treatments significantly influenced the grain and straw yields (Table 2). Among herbicidal treatments, significantly highest grain yield (4.49 t/ha) and straw yield (7.64 t/ha) were recorded with pendimethalin (1,000 ml/ha) *fb* tank-mix application of bispyribac sodium (25 g/ha) + pyrazosulfuron (15 g/ha). The highest grain production was mainly ascribed to the lowest weed biomass. These herbicidal treatments [pendimethalin (1,000 ml/ha) *fb* tank-mix application of bispyribac sodium (25 g/ha) + pyrazosulfuron (15 g/ha)] resulted in excellent weed control and higher yields. It was observed that, crop faced the weed competition before

Table 2. Effect of weed management practices on growth, yield attributes and yield of rice (pooled data of 2 years)

Treatment	Plant height at maturity (cm)	1,000 grain weight (g)	Effective tillers/m^2	Grains/panicle	Panicle length (cm)	Grain yield (t/ha)	Straw yield (t/ha)	Economics	
								Net returns (₹/ha)	Benefit: cost ratio
Oxadiargyl @ 90 g/ha (pre)	105.0	22.60	273.7	113.7	28.3	3.71	7.09	57,500	1.47
Pretilachlor @ 750 ml/ha (pre)	104.7	21.91	264.7	112.5	28.1	3.55	6.91	54,600	1.42
Bispyribac sodium @ 25 g/ha (post)	106.2	22.99	289.1	118.4	28.6	3.93	7.36	61,400	1.53
Pyrazosulfuron @ 15 g/ha (post)	105.4	22.82	276.4	117.7	28.3	3.85	7.31	61,500	1.59
Pendimethalin @ 1,000 ml/ha (pre) *fb* bispyribac sodium @ 25 g/ha (post)	109.6	24.57	312.2	130.5	29.4	4.30	7.52	66,900	1.61
Oxadiargyl @ 90 g/ha (pre) *fb* bispyribac sodium @ 25 g/ha (post)	108.9	24.35	309.7	125.1	29.1	4.26	7.49	66,400	1.60
Pretilachlor @ 750 ml/ha (pre) *fb* bispyribac sodium @ 25 g/ha (post)	108.7	23.89	304.3	121.0	29.0	4.14	7.57	65,600	1.61
Oxadiargyl @ 90 g/ha (pre) *fb* pyrazosulfuron 15 g/ha (post)	107.6	23.69	300.7	121.5	28.9	4.10	7.53	65,400	1.64
Pretilachlor @ 750 ml/ha (pre) *fb* pyrazosulfuron @ 15 g/ha (post)	107.2	23.41	292.9	119.7	28.8	4.05	7.45	64,900	1.66
Pendimethalin @1,000 ml/ha (pre) *fb* bispyribac sodium @ 25 g/ha (post) + pyrazosulfuron @ 15 g/ha (post)	110.7	24.89	320.0	132.2	29.8	4.49	7.64	70,600	1.67
Weedy check	101.6	21.25	238.4	102.1	26.2	2.93	6.34	42,000	1.10
Weed-free check	112.0	25.66	332.6	136.3	30.1	4.67	7.83	71,700	1.61
SEm±	1.00	0.53	4.7	2.70	0.41	0.106	0.25	—	—
CD (P=0.05)	3.11	1.66	14.7	8.40	1.29	0.331	0.78	—	—

DAS, days after sowing; pre, pre-emergence; post, post-emergence; fb, followed by tank-mix application of bispyribac sodium (25 g/ha) + pyrazosulfuron (15 g/ha). Alone application of pretilachlor resulted in significantly lowest grain yield among all the herbicidal treatments, owing to the crop's severe weed pressure. These findings revealed that weeds competed heavily with the crop for water, nutrients, light, and space, resulting in poor crop development and decreased grain yield in pretilachlor-treated plots compared to the other treatments. These results are in conformity with the findings of Mahajan and Chauhan (2015), Singh *et al.* (2016) and Sanodiya and Singh (2019).

A significant and positive correlation was observed between the yield attributes and the grain yield and all the correlation coefficients were highly significant (Fig. 1). The grain yield was more correlated to effective tillers/m^2 followed by panicle length. Negative correlation was observed between weed biomass and grain yield (Fig. 2). Weed biomass accounted for 92% variation in the grain yield. These results support the findings of Chauhan and Johnson (2011).

Economics

Sequential application of pendimethalin (1,000 ml/ha) *fb* tank-mix application of bispyribac sodium (25 g/ha) + pyrazosulfuron (15 g/ha) was found superior to the other herbicidal treatments in terms of net returns and benefit: cost ratio. The highest net returns (₹ 70,600/ha) and benefit: cost ratio (1.67) were observed with pendimethalin (1,000 ml/ha) *fb* tank-mix application of bispyribac sodium (25 g/ha) + pyrazosulfuron (15 g/ha). Lower net returns and benefit: cost ratio were recorded with single application of herbicides either as pre-emergence or post-emergence herbicides. Khaliq *et al.* (2012) reported higher economic returns with application of bispyribac sodium. Prameela *et al.* (2014), Dhanapal *et al.* (2018) and Sanodiya and Singh (2019) also reported similar results.

Based on the above results, it may be concluded that sequential application of pendimethalin (1,000 ml/ha) followed by tank-mix application of bispyribac sodium (25 g/ha) + pyrazosulfuron (15 g/ha) was found effective in controlling weeds, achieving higher yield and economical to rice-growers of north-eastern plains of India.

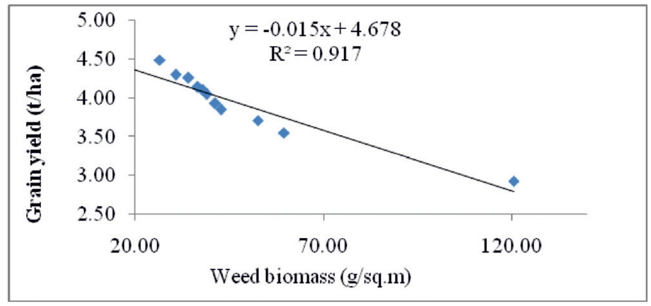

Fig. 2. Relationship between weed biomass (g/m^2) and grain yield (t/ha) of rice

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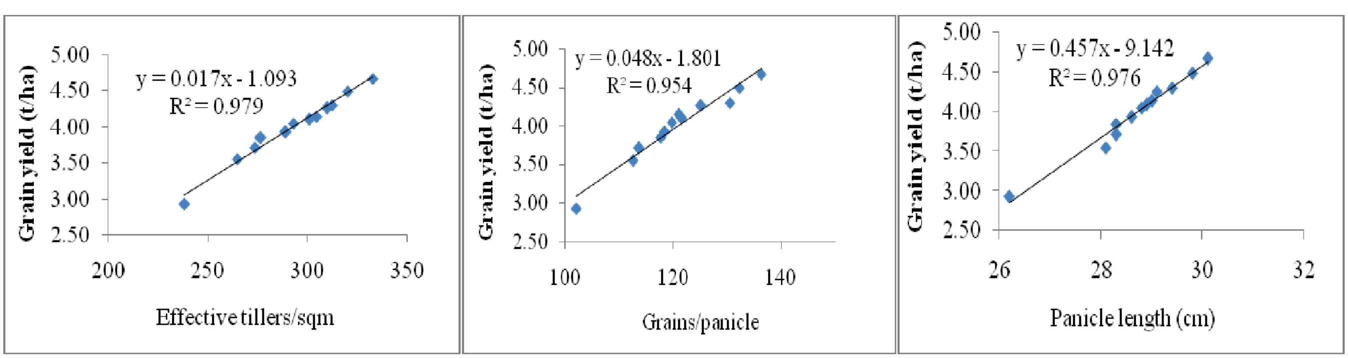

Fig. 1. Regression equation and trend lines of rice grain yield and major yield attributes as influenced by different herbicidal treatments

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