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RESEARCH ARTICLE

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Weed management through herbicide application in direct-seeded rice and yield modeling by artificial neural network

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Abstract

In direct seeded rice (DSR) cultivation, weed is the major constraint mainly due to absence of puddling in field. The yield loss due to weed interference is huge, may be up to 100%. In this perspective, the present experiment was conducted to study the efficacy of selected herbicides, and to predict the rice yield using artificial neural network (ANN) models. The dry weight and density of weeds were recorded at different growth stages and consequently herbicide efficacy was evaluated. Experimental results revealed that pre-emergence (PRE) herbicide effectively controlled the germination of grassy weeds. Application bispyribac-sodium as post-emergence (POST) following PRE herbicides (clomazone or pendimethalin) or as tank-mixture with clomazone effectively reduced the density and biomass accumulation of diverse weed flora in DSR. Herbicidal treatments improved the plant height, yield attributes and grain yield (2.7 to 5.5 times) over weedy check. The sensitivity of the best ANN model clearly depicts that the weed control index (WCI) of herbicides was most important than their weed control efficiency (WCE). Besides, the early control of weeds is a better prescription to improve rice yield. Differences in sensitivity values of WCI and WCE across the crop growth stages also suggest that at 15, 30 and 60 days after sowing, herbicides most effectively controlled sedges, broad leaves and grasses, respectively. Based on the grain yield and herbicidal WCE, it can be concluded that the combined application of pendimethalin or clomazone as PRE followed by bispyribac-sodium as POST or tank-mixture of clomazone + bispyribac sodium can effectively control different weed flushes throughout the crop growth period in DSR.

Additional key words: *Oryza sativa*; direct-seeded rice; weed; herbicide; artificial neural network.

Abbreviations used: ANN (artificial neural network); DAS (days after sowing); DSR (direct seeded rice); EPOST (early post-emergence); MLP (multilayer perceptron); POST (post-emergence); PRE (pre-emergence); TPR (transplanted rice); WCE (weed control efficiency); WCI (weed control index).

Authors' contributions: Conceived and designed the experiments: DG and UPS. Performed the experiments: DG, UPS and AD. Analyzed the data: DG, KR and AD. Wrote the paper: DG and KR.

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Introduction

An estimated 106.19·10^6 t rice (*Oryza sativa* L.) production from an area of 43.95·10^6 ha has made India rank second (after China) among global rice producers (GOI, 2014). Rice is the most important staple crop for more than half of the population in India. The most common growing method of rice is manual transplanting of seedlings in puddled soils, creating a hard pan below the plough layer. This practice involves both water (3000-5000 L of water to produce 1 kg rice) (Bouman *et al.*, 2002) and human labour resource both of which are becoming increasingly meager. It influences soil health owing to dispersion of soil particles and consequent compaction of the soil (Chauhan *et al.*, 2012). In addition, this conventional puddled transplanted rice (TPR) is not much relevant in the changing climatic scenario. It has a substantial contribution to the greenhouse gases emission, particularly methane (CH_4) (Pathak, 2013). These above situations have compelled scientists and researchers towards direct-seeded rice (DSR) cultivation, as it does not need puddling and transplanting and is a feasible alternative to save water and labour. In Indian sub-continent, farmers generally do the direct seeding in dry condition. This is owing to the absence of suitable rice varieties for direct seeding in over-flooded situation. On the other hand, several varieties *viz.* 'Narendra 97', 'Narendra 118','Sarju 52', 'NDR 359', 'Sambha mahsuri', 'Swarna mahsuri', 'Krishna Hans', 'PRH 10', and 'Rajshree' have been reported to be largely used by farmers for direct seeding in dry conditions (Pathak *et al.*, 2011; Singh *et al.*, 2012).

But this is just one side of the shield. When farmers shift to DSR from TPR, the weed flora changes drastically (Rao *et al.*, 2007). DSR fields are more species-rich with greater diversity in weed flora than TPR fields (Tomita *et al.*, 2003; Singh *et al.*, 2008; Kamoshita *et al.*, 2010) due to simultaneous germination of weeds with rice in absence of standing water to suppress weed growth (Chauhan & Johnson, 2010). The main weed species associated with rice crop in DSR are *Echinochloa colona* (L.) Link, *Echinochloa crus-galli* (L.) Beauv and *Cyperus iria* Linn, *Cynodon dactylon* (L.) Pers, *Caesulia axillaris*, *Commelina benghalensis* Linn, *Phyllanthus niruri* Linn, *Eclipta alba* (L.) Hassk, and *Physalis minima* (Gupta *et al.*, 2006; Pathak *et al.*, 2011). Yield loss in DSR due to weed interference may be up to 100% (Singh *et al.*, 2014). The species composition change of the accompanying weed flora and also the rapid shift in weed flora is a crucial problem with DSR. The ingression of annual grasses and perennial sedges presents particular menace in weed management with continuous direct seeding. Different weed control measures have been practiced previously to minimize weed pressure in DSR (Chauhan *et al.*, 2010). Among them, chemical control is the most commonly used, and has been proved reliable by several workers for controlling weeds in DSR (De-Datta & Baltazar, 1996; Labrada, 1996; Zhang, 1996). Application of herbicides effectively suppresses weeds and provides DSR with a weed-free environment (Gitsopoulos & Froud-Williams, 2004). So, to effectively control the weed problem and also to harness the fullest benefit of DSR system, the use of herbicides at a right application rate and time is very important at this time. Several pre-emergence or PRE and post-emergence or POST herbicides are now available and being used by farmers in various Asian countries (Ahmed & Chauhan, 2014). Among them, pendimethalin is a soil applied pre-emergence herbicide. It is absorbed by roots and coleoptiles and inhibits cell division and cell elongation (Pathak *et al.*, 2011). Oxadiazon is an inhibitor of protoporphyrinogen oxidase enzyme (Jung & Kuk, 2007). Clomazone, a soil-applied pre-emergence herbicide, has been reported to interfere with chloroplast development in susceptible species (Ferhatoglu & Barrett, 2006). Ethoxysulfuron is used as early post emergence for controlling broadleaved weeds and sedges, and mainly taken by roots and leaves and translocated within the plants (Pathak *et al.*, 2011). As a post-emergence herbicide, azimsulfuron is absorbed by roots and leaves, and also inhibits the enzyme acetolactate sysnthase in susceptible weed plants (Pathak *et al.*, 2011). Similar mode of action has also been reported for another two post emergence herbicides *viz.* pyrazosulfuron (Wang *et al.*, 2013) and bispyribac-sodium (Jabran *et al.*, 2012).

Several experiments have been conducted in last decades to enlighten the effect of combined application of PRE and POST herbicides on controlling weeds in DSR systems. Pre-emergence application of pendimethalin followed by post-emergence application of bispyribac-sodium at 15 days after sowing (DAS) was most effective for controlling weeds in DSR (Mahajan *et al.*, 2009). In another study, application of oxadiazon at 2 DAS followed by fenoxaprop + ethoxysulfuron applied at 28 DAS fetched the best result in DSR (Chauhan & Opena, 2013). Tank mix applications of azimsulfuron +fenoxaprop, or azimsulfuron +bispyribac sodium +fenoxaprop have been reported to effectively control weed and help crop to yield better than single herbicide application in DSR (Mahajan & Chauhan, 2015).

Modeling crop-weed competition for estimating yield loss is an integral part of weed management (Swanton & Weise, 1991; Swanton *et al.*, 1999). To derive accurate physical meaning involved in yield, use of data mining techniques such as artificial neural network (ANN) is a new trend (Nourani & Fard, 2012). The ANN, without considering any initial supposition and previous knowledge of relations among studied parameters, is able to find existed relation between input and output data to predict each output with its corresponding input. Keeping this above matters in mind, we laid out our field experiment with two basic objectives: (a) to estimate the effect of few selected herbicide protocols in reducing population and biomass of different weed flora and ultimately ensuring crop growth and yield, and (b) to predict the rice yield on the basis of weed control efficiency (WCE) and weed control index (WCI) of the selected herbicides at crop growing periods.

Material and methods

Study site and soil

The field experiment was conducted for 3 years (2009, 2010 and 2011) at the Agricultural Research Farm, Banaras Hindu University, Varanasi, UP, India (25°18' N, 83°30' E, and 129 m asl), situated at Indo Gangetic Plain of India. The climate of the area is sub-tropical, with an average annual rainfall of 1100 mm (86% of which is received during South-West monsoon from third week of June to September) and potential evapotranspiration of 1500 mm. The hottest months are May and June, when the maximum temperature reaches 42-43°C, whereas, during December and January, the coldest months of the year, the minimum temperature often goes below 8°C. The soil at the study site had a sandy-clay loam texture with pH of 7.4, low in organic carbon (0.42%), available N (221 kg/ha) and available P (41 kg P_2O_5/ha), and medium in available K (223 kg K_2O/ha).

Experimental design and treatment

The field trial was arranged as a randomized complete block design with eight weed control treatments (Table 1) replicated three times, the area of each plot was 24 m^2 (6.0 m × 4.0 m). Treatments included different rate of clomazone as pre-emergence (PRE), tank mixture application of clomazone in combination with propanil or bispyribac-sodium as early post-emergence (EPOST) and sequential application of clomazone and pendimethalin as PRE followed by bispyribac-sodium application as post-emergence (POST). The field was irrigated to promote weed germination and then weeds were eliminated 7 days before seeding using glyphosate. The herbicides were applied with a knapsack sprayer that delivered ~ 500 L/ha spray solution through flat fan nozzles. For the weed-free treatment, six hand-weedings were done to maintain a weed-free situation. In the weedy control, no weeding was done.

Crop management

The field was prepared by giving two plowings, one with cultivator and another with rotavator. Rice (cv. Sarju-52) was dry-seeded at 30 kg/ha with tractor-mounted seed-cum-fertilizer drill. Each year, rice was sown in rows 18.5 cm apart at a depth of 2-3 cm on June and harvested manually with sickle at a height of 25-30 cm from ground level in early November. The field was surface-irrigated after the rice seeding for uniform germination, and visited regularly to check the irrigation demand of the crop according to the crop and soil conditions. Nitrogen was applied at 120 kg/ha in three splits, 1/3 each as basal, at 28 DAS (tillering) and at 60 DAS (panicle initiation). Phosphorus at 60 kg/ha as P_2O_5 was applied with the zero-till cum fertilizer drill machine during seeding. Potassium at 60 kg/ha as K_2O was broadcast uniformly before rice seeding.

Measurements and data analysis

For weed count and weed biomass, four permanent quadrats (0.5 m × 0.5 m) were earmarked in each plot after rice sowing. Weed density were measured at 12 and 30 DAS from four permanent quadrats and weed dry weight data were measured at 30 DAS from two quadrats and sorted into three categories: grasses, sedges and broadleaved. Individual species wise weed counts and dry weight at 60 DAS was taken from two remaining quadrats. For dry weight weeds were cut at ground level and washed with tap water, sun dried, hot-air oven-dried at 70°C for 48 h, and then weighed. At crop harvest stage, only weed biomass was determined from 1.0 m^2 of remaining areas (excluding the area of previous four quadrats). Rice plant stands were counted at 12 DAS from quadrats placed randomly at four spots in each plot. Rice grain yield was determined from the harvested area (15 m^2) and converted to t/ha at 14% moisture content. The weed control efficiency (WCE) and weed control index (WCI) were calculated using the following formula (ISA, 2009):

$$WCE = \frac{WD_c - WD_T}{WD_c} \times 100 \qquad [1]$$

where WD_C and WD_T are weed density in control and herbicide-treated plots, respectively.

$$WCI = \frac{WDM_c - WDM_T}{WDM_c} \times 100 \qquad [2]$$

where WDM_C and WDM_T are weed dry matter in control and herbicide-treated plots, respectively.

Table 1. Treatment details.

Treatment	Dose (g/ha)	Time of application[1]
Clomazone	500	3 DAS (PRE)
Clomazone	670	3 DAS (PRE)
Clomazone+Propanil	500 + 2000	10 DAS (EPOST)
Clomazone+Bispyribac	500 + 25	10 DAS (EPOST)
Clomazone followed by Bispyribac	670, 25	3 DAS followed by 20 DAS (POST)
Pendimethalin followed by Bispyribac	1 000, 25	3 DAS followed by 20 DAS (POST)
Weed-free	–	–
Weedy check	–	–

[1] DAS, days after sowing; PRE, pre-emergence; EPOST, early post-emergence; POST, post-emergence.

Statistical methodologies

The data of actual weed population and dry weight were transformed by square root transformation due to high variance for statistical analysis. The statistical analysis of data was done using SAS Windows 9.3. The effect of the years was non-significant and there were no significant interactions between treatments and years. Therefore, the data were combined over the years and subjected to ANOVA. Treatment means were separated with the use of Tukey's Honest Significant Difference test at the 5% level of significance. The best model for predicting yield from inputs (WCE and WCI at different DAS) has been explored through artificial neural network (Chester, 1993) in SPSS 21.0.

For ANN, WCE and WCI of treatments for grass, sedge, broad leaf and three most prominent individual grassy weeds (*E. colona*, *E. crus-galli* and *C. iria*) at different periods within the crop-weed competition period were taken as inputs of the model and rice yield as the output of the model. Multilayer perceptron (MLP) networks with various numbers of layers and neurons in each layer were employed to predict the yield. As driving function for hidden and output layer, hyperbolic tangent and sigmoid functions were used in different combinations. Data were randomly classified in three groups. Of total data, the training group had 60%, cross validation 20%, and testing group had the rest. Gradient-descent training algorithm was used and thus the network weights were moved along negative of the gradient of the driving function.

To measure the strength of the relationship between variables, the coefficient of determination (R^2) was estimated for models (Khoshnevisan *et al.*, 2013). To indicate the prediction error and objectively evaluate the best network created, the statistical indices of Phonglosa *et al.* (2015) were used. The importance of independent variables was determined to estimate the sensitivity of each predictor in determining the neural network.

Results

Weed density and biomass

Experimental results revealed that the weed control treatments had significant effect on weed diversity. The PRE herbicides had a significant negative effect on grassy weed germination, but they did not have any consequence on the germination of *C. iria* and the results in case of broad leaves were erratic (Table 2). The density and biomass of grasses with all the weed control treatments at 30 DAS were significantly lower than those of the weedy check. Bispyribac-sodium applied as EPOST and POST

Table 2. Effect of different treatments on weed density and dry biomass accumulation (pooled data of 3 years).

Treatments	Weed density (No./m^2)						Weed dry biomass accumulation (g/m^2)		
	15 DAS			30 DAS			30 DAS		
	Grasses	Sedges	Broad leaves	Grasses	Sedges	Broad leaves	Grasses	Sedges	Broad leaves
Clomazone (PRE), 500 g/ha	6.62b (43.3)	5.46a (29.3)	5.71ab (32.1)	14.28b (203)	10.14a (102.2)	6.89a (46.9)	8.47b (71.2)	7.14a (50.5)	5.11ab (25.6)
Clomazone (PRE), 670 g/ha	6.74b (45.0)	5.30a (27.6)	6.07a (36.3)	13.22b (174)	11.21a (125.1)	5.85a (33.7)	7.96b (62.9)	7.90a (61.9)	4.78ab (22.4)
Clomazone+Propanil, 500+2000 g/ha at 10 DAS	7.48ab (55.5)	4.04a (15.9)	3.62b (12.6)	14.51b (210)	9.78a (95.1)	6.43a (40.8)	8.32b (68.7)	6.36ab (40.0)	5.08ab (25.3)
Clomazone+Bispyribac, 500+25 g/ha at 10 DAS	7.55ab (56.5)	4.32a (18.1)	4.32ab (18.1)	15.52b (240)	5.66b (31.5)	5.23ab (26.9)	7.52b (56.0)	4.42b (19.0)	3.10bc (9.1)
Clomazone (PRE), 670 g/ha followed by Bispyribac, 25 g/ha at 20 DAS	6.82b (46.0)	6.11a (36.8)	5.99a (35.3)	13.79b (190)	6.57b (42.7)	2.70bc (6.8)	7.87b (61.4)	4.74b (22.0)	3.21bc (9.8)
Pendimethalin, 1000 g/ha (PRE) followed by Bispyribac, 25 g/ha at 20 DAS	6.96b (47.9)	5.13a (25.8)	5.76ab (32.7)	12.75b (162)	6.02b (35.8)	2.39c (5.2)	6.96b (47.9)	4.69b (21.5)	2.40cd (5.3)
Weed-free	0.71c (0.0)	0.71b (0.0)	0.71c (0.0)	0.71c (0)	0.71c (0.0)	0.71c (0.0)	0.71c (0.0)	0.71c (0.0)	0.71d (0.0)
Weedy check	9.08a (81.9)	6.60a (43.1)	5.32ab (27.8)	19.74a (389)	11.07a (122.0)	7.13a (50.3)	14.46a (208.6)	8.20a (66.7)	5.68a (31.8)

DAS, days after sowing; PRE, pre-emergence. Data in parenthesis represent original values. Values followed by a similar letter within a column for a particular treatment are not significantly different at $p<0.05$ level of significance according to Tukey's HSD mean separation test.

significantly reduced the density and dry-biomass accumulation of *C. iria* at 30 DAS (Table 2). Among the weed management practices the lower density and dry biomass of broad leaved weeds were observed when the bispyribac-sodium was applied as sequential application after PRE herbicides (Table 2). This remarks the existence of a combination effect of PRE and POST herbicides that broadened the weed control spectrum. PRE herbicides followed by bispyribac-sodium as POST and clomazone+propanil as EPOST effectively reduced the density of *E. colona* at 60 DAS. But the lowest dry biomass accumulated by *E. colona* was recorded from the sequential application of clomazone as PRE and bispyribac-sodium as POST. Among the herbicide treatments lower density and dry biomass of *E. crus-galli* and *C. iria* was observed from bispyribac-sodium treated plots. Herbicide-treated plots recorded statistically lower total weed density and dry biomass at 60 DAS as compared to the weedy check. Among the herbicide-treated plots the lowest weed biomass at harvest was found from the sequential application of clomazone as PRE and bispyribac-sodium as POST (Table 3).

Rice emergence and yield-related traits

Rice plant stands differed significantly among the weed control treatments (Table 4). The PRE herbicides had negative effect on rice emergence. Among the PRE herbicides clomazone had more detrimental effect on germination of rice as compared to pendimethalin, but the EPOST application of clomazone did not show any negative impact on crop stand. The dry matter accumulated by the rice plant during the maximum tillering stage (45 DAS) was significantly higher in all the herbicide treatments as compared to the zero-herbicide plot (weedy) (Table 4). The height of the rice plant did not differ statistically among the weed control measures at 45 and 60 DAS (Table 4), but during the final crop growth stage a wide variation was found among the herbicide treatments. At harvest the maximum plant height was recorded when clomazone was applied as EPOST in combination with bispyribac-sodium as a tank mixture. On the other hand, the smallest rice plant was observed in the weedy check.

Rice panicles per unit area, grains per panicle and test weight (1000 grain weight) were influenced by the herbicide application, and the weedy plots had the lowest number of panicles among the treatments (Table 4). The sequential and tank-mixture application of herbicides produced higher panicles per unit area, grains per panicle and test weight among different weed control measures.

A wide variation in rice grain yield was observed among different the weed management practices

Table 3. Effect of different treatments on weed density at 60 DAS and dry biomass accumulation at 60 DAS and harvest (pooled data of 3years).

Treatment	Weed density (No./m^2)				Weed dry biomass accumulation (g/m^2)				
	E. colona	*E. crus-galli*	*C. iria*	Total	*E. colona*	*E. crus-galli*	*C. iria*	Total	At harvest
Clomazone (PRE), 500 g/ha	13.96b (194.4)	7.53b (56.1)	15.64ab (244.2)	24.77b (613)	9.90bc (97.5)	9.48bc (89.4)	10.55a (110.7)	18.8b (352)	12.93ab (166.6)
Clomazone (PRE), 670 g/ha	12.66bc (159.7)	7.30b (52.8)	14.36bc (205.7)	23.59bc (556)	8.07bc (64.7)	10.20b (103.6)	11.23a (125.6)	18.8b (352)	13.28ab (175.8)
Clomazone+Propanil, 500 + 2000 g/ha at 10 DAS	9.38cd (87.5)	6.14bc (37.2)	12.52bcd (156.2)	20.48c (419)	11.42b (129.9)	7.59bcd (57.1)	8.62ab (73.7)	19.5b (378)	10.90abc (118.4)
Clomazone+Bispyribac, 500 + 25 g/ha at 10 DAS	11.65bc (135.2)	4.11c (16.4)	11.82bcd (139.1)	20.88bc (436)	11.53b (132.4)	7.04bcd (49.1)	6.95b (47.8)	17.8b (315)	9.74bc (94.3)
Clomazone (PRE), 670 g/ha followed by Bispyribac, 25 g/ha at 20 DAS	8.28d (68.0)	4.79c (22.5)	10.60cd (111.8)	19.72c (388)	5.01cd (24.6)	6.33cd (39.6)	6.54b (42.3)	17.2b (295)	6.97cd (48.1)
Pendimethalin, 1000 g/ha (PRE) followed by Bispyribac 25 g/ha 20 DAS	9.37cd (87.3)	4.50c (19.8)	9.91d (97.7)	19.60c (384)	7.77bc (59.8)	5.80d (33.1)	6.42b (40.7)	16.2b (263)	8.94bc (79.4)
Weed-free	0.71e (0.0)	0.71d (0.0)	0.71e (0.0)	0.71d (0)	0.71d (0.0)	0.71e (0.0)	0.71c (0.0)	0.7c (0)	3.83d (14.1)
Weedy check	20.34a (413.3)	9.98a (99.1)	18.43a (339.1)	30.92a (956)	19.92a (396.2)	16.78a (281.2)	11.70a (136.5)	29.9a (891)	14.55a (211.2)

DAS, days after sowing; PRE, pre-emergence. Data in parenthesis represent original values. Values followed by a similar letter within a column for a particular treatment are not significantly different at $p<0.05$ level of significance according to Tukey's HSD mean separation test.

Table 4. Effect of different treatments on plant growth, yield attributes and yield (pooled data of 3 years).

Treatment	Plant population at 15 DAS	Crop biomass (g) at 45 DAS	Plant height (cm) at 45 DAS	Plant height (cm) at 60 DAS	Plant height (cm) at harvest	Panicle/ m^2	Grain/ Panicle	Test weight (g)	Grain yield (t/ha)
Clomazone (PRE), 500 g/ha	114b	1.35a	62.9a	85.0a	106ab	209b	99c	23.3bc	1.55d
Clomazone (PRE), 670 g/ha	100b	1.37a	65.3a	83.1a	106a	214b	113bc	24.5ab	2.02cd
Clomazone+Propanil, 500+2000 g/ha at 10 DAS	177a	1.36a	63.6a	76.9a	103ab	261ab	108bc	24.8a	2.23c
Clomazone+Bispyribac, 500+25 g/ha at 10 DAS	184a	1.60a	69.6a	84.3a	110a	252ab	123ab	23.8abc	2.86b
Clomazone (PRE), 670 g/ha followed by Bispyribac, 25 g/ha at 20 DAS	118b	1.49a	68.0a	69.7a	100ab	248ab	113bc	24.5ab	3.26b
Pendimethalin, 1000 g/ha (PRE) followed by Bispyribac, 25 g/ha at 20 DAS	135b	1.56a	67.6a	72.8a	104ab	268ab	112bc	24.6ab	3.13b
Weed free	164a	1.46a	63.8a	78.9a	103ab	342a	138a	25.2a	4.06a
Weedy check	153a	0.73b	64.1a	72.4a	88b	21c	68d	22.8c	0.57e

DAS, days after sowing; PRE, pre-emergence. Values followed by a similar letter within a column for a particular treatment are not significantly different at p<0.05 level of significance according to Tukey's HSD mean separation test.

(Table 4). There was ~86% grain yield loss in the weedy check due to severe weed infestation as compared to the weed-free plots. Moreover, the application of different herbicides rectified the damaging effects of the weed infestation on the productivity of direct-seeded rice. The herbicide-treated plots produced significantly higher rice grain yield as compared to weedy situation. The weed free plots recorded maximum grain yield and none of the herbicide-treated plots was at par with it. Among the herbicides when bispyribac-sodium was applied as POST following the PRE herbicides or in combination with clomazone as tank mixture recorded significantly higher rice grain yield.

Rice yield modeling through artificial neural network

WCE and WCI of the herbicides at different dates of observation were considered as inputs and yield as the output of the model. MLP network with various numbers of layers and neurons in each layer was constructed to predict the yield; and the topology of the ANN models is shown in Table 5. As we attempted a lot of combinations in hidden layer neurons and hidden and output layer functions, it was not possible to list all of them in the table. So, only twelve models with closer values of MAE, MSE, RMSE, MRE and R^2 have been catalogued in Table 5.

The best model for predicting yield was one input layer having seventeen neurons, two hidden layers with nine neurons in the first one and four neurons in the second one, and an output layer (structure 17-9-4-1; model 10; Table 5). The best model for yield prediction was selected on the basis of its lowest error values and highest R^2 value. Scatter plot of predicted yield against actual values is shown in Fig. 1 for the testing data set which clearly denotes that 88% of the predicted yield in our case can be explained from actual yield calculated from field experiment.

To evaluate the predictive ability of the ANN, sensitivity analysis was done for the best network (Table 6). The robustness of the model was determined by examining and comparing the output produced during validation with the calculated values. Models were trained by withdrawing each input item one at a time while not changing any of the other items for every pattern. A perusal of the data presented in Table 6 clearly gives an estimation of the contribution of WCE and WCI of different treatments on predicted output (rice yield). Based on the importance value, the WCE for sedges at 15 DAS had higher sensitivity for rice yield than the grasses and broad leaves. WCI had greater importance than WCE for different category of weeds at different crop growth stages. At 30 DAS, both the WCI and WCE for broad leaves were highly sensitive for grain yield of rice. The WCE and WCI at 30 DAS for different categories of weeds had higher importance values as compared to those at 60 DAS for different weeds. At 60 DAS, among all weed species, WCE for *E. colona* and WCI for *E. crus-galli* showed higher sensitivity towards rice grain yield.

Table 5. Network performance of rice yield for different arrangement in the first (NH1) and second (NH2) hidden layers with different number of neurons in hidden layers (based on mean data of three years) using gradient descent optimization algorithm.

Model No.	NH1	NH2	Activation function[1]		Yield[2]				
			Hidden layer	Output layer	MAE	MSE	RMSE	MRE (%)	R^2
1	4	0	HT	HT	0.225	0.112	0.335	11.458	0.983
2	5	0	HT	S	0.398	0.285	0.534	17.927	0.958
3	6	0	S	HT	0.316	0.144	0.379	13.345	0.979
4	7	0	S	S	0.449	0.323	0.568	18.791	0.952
5	5	3	HT	HT	0.214	0.079	0.281	8.972	0.988
6	6	3	HT	S	0.259	0.238	0.488	9.399	0.965
7	7	3	S	HT	0.214	0.105	0.324	9.608	0.984
8	8	3	S	S	0.460	0.333	0.577	22.105	0.951
9	8	4	HT	HT	0.236	0.151	0.389	9.588	0.978
10	9	4	HT	S	**0.173**	**0.056**	**0.237**	**7.738**	**0.992**
11	10	4	S	HT	0.513	0.382	0.618	23.632	0.943
12	11	4	S	S	0.274	0.214	0.463	10.476	0.968

[1] HT: hyperbolic tangent, S: sigmoid. [2] MAE: mean absolute error; MSE: mean square error; RMSE: root mean square error; MRE: mean relative error.

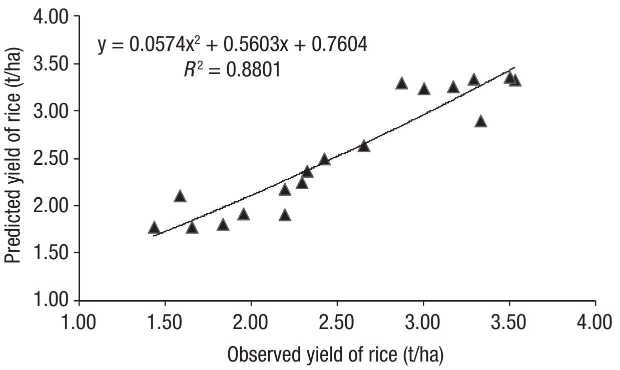

Figure 1. Scatter plot of actual and predicted rice yield for the testing data set.

Table 6. Sensitivity of different inputs (weed control efficiency= WCE; weed control index = WCI) for rice yield (based on mean data of three years).

Inputs	Importance value
WCE for grasses at 15 DAS	0.046
WCE for grasses at 30 DAS	**0.055**[1]
WCE for sedges at 15 DAS	**0.052**
WCE for sedges at 30 DAS	0.022
WCE for broad leaves at 15 DAS	0.036
WCE for broad leaves at 30 DAS	**0.109**
WCE for *Echinochloa colona* at 60 DAS	**0.099**
WCE for *Echinochloa crus-galli* at 60 DAS	0.039
WCE for *Cyperus iria* at 60 DAS	0.037
WCE for total weeds at 60 DAS	0.026
WCI for grasses at 30 DAS	**0.051**
WCI for sedges at 30 DAS	**0.096**
WCI for broad leaves at 30 DAS at 30 DAS	**0.128**
WCI for *Echinochloa colona* at 60 DAS	**0.054**
WCI for *Echinochloa crus-galli* at 60 DAS	**0.061**
WCI for *Cyperus iria* at 60 DAS	0.042
WCI for total weeds at 60 DAS	0.047

[1] Bold figures represent importance values ≥0.05.

Discussion

Weeds are important biotic constrict if not controlled timely by adopting proper management practices in zero-till direct seeded rice, and it can impose a serious threat to the productivity and sustainability of DSR (Rao *et al.,* 2007; Farooq *et al.,* 2011b). In our study under the un-weeded situation *E. colona*, *E. crus-galli* and *C. iria* were the main dominant weeds, comprising 89% of total weed density (Table 3). The dominance of *E. colona* can be attributed to simultaneous germination of this species along with rice seeds under favorable soil moisture and temperature. Saini & Angiras (2002) and Singh *et al.* (2003) also reported dominance of grassy weeds over other species in DSR. The application of PRE herbicide was found to be most effective against germination of grassy weeds in DSR. According to an earlier study, the application of PRE herbicide effectively reduced the grassy weeds emergence in rice (Chauhan & Opena, 2013). From this study it is comprehensible that only PRE herbicide application was not adequate to manage the weed flora in direct seeded rice. In DSR, due to favorable situation, weeds show several cohorts. Thus when bispyribac-sodium was applied as POST following PRE herbicides or as tank-mix with clomazone as EPOST effectively controlled the subsequent weed cohorts and provided a better environment for crop growth. Application of herbicides in sequence (PRE followed by POST) or as tank-mixture performed better against diverse weed flora as compared to single herbicide by providing more than one technical molecule against a diverse group of weeds (Chauhan, 2013; Antralina *et al.*, 2015). In direct-seeded rice the control of different weed cohorts is largely dependent on the performance and persistence of herbicides in active form (Mahajan & Chauhan, 2013).

The PRE herbicides, mainly clomazone, had some inhibitory effect on rice seedling emergence. Andres *et al.* (2013) also evaluated the selectivity of clomazone on rice, and found that the application of clomazone as PRE caused high rice injury at the initial crop growth stage. The adoption of proper weed management practices in DSR can provide a better environment for crop growth and productivity. The application of PRE herbicides followed by bispyribac-sodium and tank-mixture of clomazone+bispyribac-sodium contributed to a sizeable improvement in plant growth (plant height and biomass accumulation) and all other yield traits, like the number of productive tillers, grains per panicle and the test weight. Many reports support the role of herbicide application in improving the yield and yield-related traits of several crops through efficient weed management (Jabran *et al.*, 2008; Razzaq *et al.*, 2010; Farooq *et al.*, 2011a). The improvement in the crop growth and yield attributes was positively associated with reduced weed density and biomass because of efficient weed control. Reduction in weed density vis-à-vis weed biomass provides more utilization of space, water, light and nutrients by the crop, and thus ultimately results in escalated crop yield through better photosynthesis and overall growth and metabolic activities of the crop. Walia (2006) opined, in similar manner, that the greatest loss caused by the weeds resulted from their competition with crop for growth factors viz., nutrients, soil moisture, light, or space.

The ANN models were used to precisely predict the grain yield using herbicidal efficacy as inputs of the model. As mentioned earlier, the best model was selected considering the highest R^2 and the lowest error values. Further the importance values of the parameters in case of the best ANN model were used to validate the role of WCE and WCI of selected herbicides in increasing rice yield. Considering the sensitivity values of the best ANN model, it can be inferred that the effective control of weeds by way of curbing their dry matter production and density through efficient use of herbicides at peak crop-weed competition period (30 DAS) may increase the rice yield and reduce the yield loss caused by those weeds. To evaluate any weed management practices, weed dry weight is the main realistic information as compared to weed density as the former is more indicative of the competitive nature of weed. The early weed competition reduces crop yield far greater than late season weed growth. So, controlling weeds at early crop growth stages provide a better environment for crop growth and yield. The sensitivity values of WCI and WCE differed across the crop growth stages. At 15, 30 and 60 DAS, herbicides most effectively controlled sedges, broad leaves and grasses, respectively. Such findings also suggest the combined application of PRE followed by POST herbicide or tank-mixed herbicide for effectively controlling different weed flushes throughout the crop growth period in case of DSR system.

In summary, in direct-seeded rice cultivation, the problem of weed infestation causes drastic yield reduction; and the situation needs a suitable solution with efficient weed management strategy. The present experiment had an intention to discern the effectiveness of herbicides of various modes of action either alone or in combination. It was noticed that the combined effect of PRE and POST herbicides and application of herbicides as tank mix broadened the weed control spectrum in this study. Such type of combination helped decreasing the weed density and biomass and as a consequence augmented rice yield. Modeling rice yield through artificial neural network also reflected the manifest role of the combined (PRE followed by POST) or tank-mixed applications of herbicides in decreasing weed density and biomass and subsequent yield improvement.

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