DETERMINING ECONOMIC THRESHOLD OF DOWNY BROME (Bromustectorum L.) IN WHEAT (Triticum aestivum L.)

Muhammad Ahsan[1], Muhammad Ehsan Safdar[1]*, Muhammad Mansoor Javaid[1], Ahsan Aziz[1], Asif Tanveer[2] and Raja Awais Sarwar[1]

https://doi.org/10.28941/24-1(2018)-3

ABSTRACT

Weed economic threshold in a specific crop serves as a tool for employing cost-effective management program. The response of wheat (Triticumaestivum L.) yield to varying densities of downy brome (Bromus tectorum L.) was tested during winter season of 2014-15. Increasing densities of B. tectorum (0, 5, 10, 20 and 40 plants m^{-2}) increased B. tectorum dry weight up to 322%. Wheat plant height, tillers m^{-2}, spike length, grains $spike^{-1}$, 1000-grain weight, biological, grain and straw yields were reduced at downy brome density at and above10 plants per m^2. Grain yield losses of wheat varied from3 to 19% with B. tectorum density between5 and 40 plants per m^2. Maximum plant height, tillers m^{-2}, grains $spike^{-1}$ of downy brome were observed in its lowest (5 plants m^{-2}) density. The economic threshold of B. tectorum as determined by prediction model was 2.6 plants per m^2 indicating that downy brome weed in wheat should be managed at this density level.

Keywords: Density, economic threshold level, downy brome weed, yield losses.

Citation: Ahsan, M., M.E. Safdar, M.M.Javaid, A. Aziz, A.Tanveer and R. A.Sarwar. 2018. Determining economic threshold of downy brome (Bromus tectorumL.) in wheat (Triticum aestivum L.). Pak. J. Weed Sci. Res. 24 (1):21-29.

[1]Department of Agronomy, University College of Agriculture, University of Sargodha, Sargodha, Pakistan
[2]Department of Agronomy, University of Agriculture Faisalabad, Pakistan
*Corresponding author's email: ehsan_safdar2002@yahoo.com

INTRODUCTION

Wheat (Triticum aestivum L.), the highest rankedcereal food in Pakistan bears key position in economy of the country constituting 2.2% to gross domestic product and10.3% to the value added in agriculture. About9052thousand hectares area of Pakistan is occupied by wheat crop which produces 25.7 million tonnes grain (Economic Survey of Pakistan, 2016-17). Weed infestation is amongst majorlimiting factors responsible for low yield of major crops in Pakistan. At world level, monetary losses due to weeds have touched a level of 100 billion dollars (Buruchara, 2007; Le Tourneau et al., 1956). According to an estimate, about 34% crop yield occur due to presence of weeds which are more than those caused by animal pests and diseases(Oerke, 2006).

Previous investigations have indicated that weed competition for environmental resources with cereal crops is mainly determined by plants' physiological and morphological traits (Didon, 2002). Important ones are early vigor,till erring ability, initial root and shoot growth rates, plant height, interception of photosynthetically active radiation, and seed size (Berthold son, 2004). The term weed economic threshold is defined as the weed population per unit area at which its control expense becomes equal to the benefit in terms of crop yieldobtained from its control (Coble and Mortensen, 1992). The economic threshold of a particular weed fluctuates between differentcrops, tillage systems adopted, and other crop management practices.

Overthe previous few years, downy brome (Bromustectorum L.) has become a serious weed inwheat fieldsin various agro-ecological zonesof Pakistan. It is a winter annual grassy weedthat has originated from Mediterranean Europe. ItinvadedtheNorthern America from Europe near1861 from where it was spread to other countries (Morrow and Stahlman, 1984).

Downy brome's plant attains height up to 60 cm, it has fibrous root system and its reproduction occurs through seed. Leaf color at emergence is brownish green and leafblades are hairy have soft hair. Fully grownplants are red-brown with erect and slender stem. Spike has 5-8 spikelets terminating in straight and slender awns at maturity (Upadhyaya et al., 1986). It was widespread as problematical weed in range lands and wheat fields ofNorth America.

Literature showed that B. tectorum infestation resulted in 28-92% reduction of wheat yield at its different population densities, time of emergence and soil moisture contents (Rydrych and Muzik, 1968). Downy brome at its 24, 40 and 65 plants per m^2densities caused 10, 15 and 20% losses to wheat yield, respectively. However, emergence of this weed 21 days after wheat emergence could not cause significant reduction in wheat yield (Stahlman and Miller, 1990). Rydrych (1974)reported that of downy brome declined wheat yields up to 40 and 92%, respectively. A reduction of up to 59% in wheat biomass and up to 68% in wheat grain yield was recorded due to downy brome infestation.

A number of studies have been carried out to estimate the losses of downy brome in wheat. However, despite the widespread occurrence of this weed in wheat fields of Pakistan, no such studies have yet been publishedregarding economic threshold level of B. tectorum in wheat and its competitive ability against wheat in Pakistan. The present study was aimed at determining the effect of B. tectorum density on growth and yield of wheat under field conditions, and estimating the economic threshold density of B. tectorum in wheat.

MATERIALS AND METHODS

Site description

A field experiment was conducted at the Agronomic Research Area (Latitude 31.32^{o}N, Longitude 73.18^{o}E and Altitude 190 m), College of Agriculture, University of Sargodha, Sargodha, Pakistan during winter season 2014-15 to study effect of different downy brome densities in wheat. Before the sowing of crop soil analyses showed pH 8.0, N 0.061 %, phosphorus

7.43 mg kg^{-1} and potash 165.33 mg kg^{-1}, respectively.During the growing season, mean monthly temperatures ranged from 12 to 26°C and total precipitation was 1100 mm.

Experimentation

The experimental layout was randomized complete block design havingfour replications. Wheat variety "Faisalabad 2008" was sown along with different densities of downy brome.Wheat seed rate of 100 kg per hectare was used. Crop was sown on 25th October 2014 by usingmanually operated single row hand drill maintaining line to line space of 25 cm. The plot size was 2 m x 1.5 m. Downy brome was sown by broadcasting its seed in field before wheat sowing to achieve maximum density. To avoid the risk of germination failure, a higher seed rate of downy brome was used. After the establishment of downy brome plants, desired densities were maintained in each plot according to treatment plan by thinning surplus plants after 1 week of emergence. There were six rows of wheat, each 2 meter long in each plot. Keeping in view the fertility status of soil, N, P and K were used at the rate of 125, 85 and 62 kg per hectarewith a source of urea, diammonium phosphate and potassium sulphate, respectively.Half dose of N with full P, K doses was applied while preparing land. The remaining dose of N was applied at first irrigation (25 days after sowing). Recommended agronomic practices were uniformly applied to whole experiment. The all other weeds which emerge naturally in the field were uprooted through hand pulling. The crop harvestingwas done manually at its physiological maturity on 5th April, 2015.

Downy brome plant height, tillers per plant, dry weight and number of grains per spike were recorded with standard procedures. Grain yield and yield components of wheat were recorded at maturity by harvesting all plants in each plot.

Statistical analysis

Data were analyzedusingFischer's analysis of variance (ANOVA) technique and means were separated usingleast significant difference test at $p \leq 0.05$ (Steel et al., 1997). Trend analysis was madeby polynomial contrast comparison function of Statistix 8.1 (Analytical Software, 2005) computer software. A non-linear rectangular hyperbolic functional relationship was drawn between the wheat grain yield (Y) and downy brome weed density (X) through modified regression model suggested by Cousens (1985) (Equation 1):

$Y = Y_o / 1 + \beta X$ (Equation 1)

where 'Y' is predicted wheat yield at 'X' downy brome weed density,Y_o is weed-free wheat yield and β is measure of weed competitiveness (a weed density of 1/β that reduces the wheat yield by 50%).

Economic threshold (ET) of B. tectorumwas estimated by the equation 2 developed by Cousens (1987):

$ET = (C_h + C_a) / (Y_o PLH)$ (Equation 2)

where 'C_h' and 'C_a' are herbicide and herbicide application costs(Rs. ha^{-1}), respectively, Y_o is weed free wheat yield (t ha^{-1}), H is herbicide efficacy, L is proportional loss per unit weed density and P is value per unit of crop (Rs. t^{-1}).

RESULTS AND DISCUSSION

Growth characteristics of B. tectorum

Plant height (cm)

Data showing the effect of various downy brome densities on its plant height are presented in Table-1. The results of study revealed that downy brome plant height was significantly reduced with increase in its density. The maximum height (108.8 cm) of downy brome was recorded at 5 plants per m^2. However, by increasing downy brome density at and beyond 20 plants per m^2 in wheat, its plant height was significantly decreased. The minimum weed plant height (98.6 cm) was recorded with 40 plants per m^2 in wheat. Trend analysis showed linear trend to be significant (Table-1).

Our findings are in line with the results of Nassab and Lalelo (2012) who concluded that higher wild oat densities imparted significant effects and reduced on its own height as well as wheat plant height. Higher number of plants of weed as well as wheat caused significant reduction in

vegetative growth of both species (Armin and Asghripour, 2011).

Number of tillers per plant

Data indicating the effects of various weed densities on its tillers per plant are shown in Table-1. The maximum tillers (14.8 plant^{-1}) of downy brome was recorded with its lowest density (5 plants per m^2) in wheat. However, higher density of 20 plants per m^2 of downy brome significantly reduced its tillers. Minimum tillers per plant (6.0) of downy brome weed was recorded in plot where its density was kept the highest (40 plants per m^2). Trend comparison showed only linear trend to be significant (Table-1).

Decrease in number of tillers per plant of downy brome weed in response to increase in its density might be attributed to reduction in space available for its growth. Tillers are responsible of producing grain heads which may lead to multiplication of weeds in next consecutive years. As the density increases, competition for space, water and nutrients increase which may lead to reduction in plant growth and consequently reduce number of tillers per plant. The results are in line with the findings of Khan et al. (2007). Khan andHassan (2006) found that number of tillers of wild oat was significantly decreased by increase in its densities.

Number of grains per spike

The results of study revealed that increase in density significantly reduced the number of grains per spike of downy brome (Table-1). Maximum number of grains (217 spike^{-1}) was recorded with 5 plants per m^2 of downy brome. As the downy brome density increased up to 20 plants m^2, its grains per spike decreased significantly. The minimum number of grains per spike (147.3) was recorded with 40 downy brome plants per m^2. Number of downy brome grains per spike showed linear response to its increasing density (Table-1).Under severe competition stress, lack of growth factors resulted in lesser growth that might reduce the number of grains per spike. Our findings are in line with the results of Khan and Hassan (2006) that wild oat densities exert significant effect on its number of grains per spike.

Dry weight per m^2

The higher downy brome dry weight (197 g m^{-2}) was recorded with a density of its 40 plants m^{-2}(Table-1). The lowest downy brome density (5 plants m^{-2}) produced the lowest dry weight (61.1 g m^{-2}) of downy brome (Table-1). The increase in dry weight of downy brome by increasing its density might be the result of increase in fresh weight of downy brome in response to its increasing density. Our findings are in conformity with those of Nadeemet al. (2013) who concluded that increase in number of plants of weeds per unit area produce higher dry biomass. Similarly, Cortés et al. (2010) reported an increase in velvetleaf (Abutilon theophrasti M.) biomass by enhancing its density from 0 to 25 plants m^{-2} in cotton.

Relative competitive index (RCI) (%)

Data of RCI of downy brome(Table-1) indicated that values of RCI increased gradually with increase in downy brome densities. The highest density (40 plants m^{-2})of downy brome produced its highest RCI (19.6%). Whereas, the minimum downy brome density of 5 m^{-2} produced lowest RCI (3.1%). Trend analysis showed only linear trend to be significant. The enhancement inRCI of downy brome with increase in its density in wheat was the result of gradualloss in wheat grain yield due to severity in weed competition stress.

Growth and yield parameters of wheat

Plant height (cm)

Effect of downy brome weed density on wheat plant height (cm) was recorded (Table-). Data revealed that increase as the weed plant increase from 5 to 40 per m^2, the wheat plant height consequently keep on declining compared to the control treatment (94.2 cm).However, downy brome plant density at and beyond 10 plants m^{-2} caused significant reduction in wheat plant height compared with control. The lowest plant height of wheat (85.8 cm) was recorded with the highest density of B. tectorum (40 plants m^{-2}). Linear and quadratic trends were found to be

significant (Table-2) in the trend comparison of different B. tectorum densities (5 to 40 plants m^{-2}).These findings are alike with that of Hassan and Khan (2007) that increase in wild oat densities from 0 to 20 plants per m^2 reduced plant height significantly. They observed higher wheat plant height in 0 wild oat density while minimum plant height in 20 plants per m^2. Sarwaret al.(2013) reported that varying densities ofPhalaris minor and Avenafatua exerted significant effect on wheat plant height. The increase in weed density from 0 to 8 plants per m^2 caused reduction in plant height.

Number of productive tillers (m^{-2})

Data showing the effect of downy brome densities on number of productive tillers per m^2 of wheat are presented (Table-2). Analysis of data showed that weed density progress from 0 to 40 plants per m^2, the number of productive tillers per m^2 of wheat decreased significantly. The maximum numbers of productive tillers per m^2 (322.3) of wheat was recorded in weed free plots (control treatment) that did not decrease significantly by increasing its density up to 10 plants per m^2. However, a significant decline in number of productive tillers of wheat was noticed at andbeyondB. tectorumweed density of 20 plants per m^2. The lowest number of productive tillers per m^2 (295.3) of wheat was recorded in the highest weed density (40 plants m^{-2}). Data showed a linear response of downy brome tillers toits increasing densities (Table-2).

Our findings are in line with those of Chaudharyet al. (2008) and Sarwaret al. (2013). They discovered that wild oat density increase significantly decreased productive tillers of wheat and consequently lowered wheat grain yield.

Spike length (cm)

Spike length of wheat varied significantly by different downy brome densities (Table-2). The control treatment gave the highest spike length (12.7 cm) of wheat whereas minimum wheat spike length (7.3 cm) was recorded with 40 plants per m^2. Trend comparison of data showed only linear trend to be significant in response to different densities of downy brome in wheat (Table=2). Decrease in spike length of wheat by increasing downy brome densities is the result of shorter growth period of wheat on account of increase in severity of weed-crop competition. These results corroborate the findings of Khan et al. (2012) who estimated10% decrease in spike length of wheat by increases wild oat density up to 2.6 plants per m^2.

Number of grains per spike

Data (Table- 2) indicated that the number of grains per spike of wheat as influenced by different downy brome densities. The maximum number of grains per spike (53.4) was recorded in control treatment which is kept free from all kind of weeds. At 20 downy brome plants per m^2, the number of grains was significantly reduced as compared to control treatment. The minimum number of grains per spike (44.4) was recorded in treatment of 40 plants per m^2. The trend analysis showed number of grains per spike of wheat reduced in a linear fashion in response to increasing B. tectorum density (Table-2). Previous findings also showed that number of grains per spike of wheat was decreased with increase in weed density. Chaudharyet al. (2008) and Noshadianet al. (2014) found that higher the number of plants per m^2 of weed, lower was the number of grains per spike.

1000-grain weight

Effect of downy brome densities on 1000-grain weight of wheat can be over-viewed in Table-2. Analysis of data showed maximum 1000-grain weight (32.9) in control treatment which remained weed free. As the downy brome density increased up to 20 plants per m2, the 1000-grain weight of wheat was significantly reduced as compared to control treatment. The lowest 1000-grain weight (28.25 g) was recorded with 40 plants per m2. Data of 1000-grain weight of wheat followed quadratic trend in response to increasing B. tectorum density (Table=2). Our findings arein agreement with those of Khan and Hassan (2006) and Noshadianet al. (2014) reported that

increase in wild oat and canary grass density from 0 to 320 plants per m^2 caused significant reduction in 1000-grain wheat.

Grain yield (t ha^{-1})

Statistical analysis of data (Table-2) showed that the increase in B. tectorum densities impart significant effect on wheat yield. Wheat grain yield decreased linearly with increase in downy brome density. The maximum wheat yield (4.7 t ha-1) was recorded in the treatment where downy brome and other weed plants were eradicated. However the wheat yield was decreased significantly at and beyond downy brome density of 20 plants per m2. The minimum grain yield (3.8 t ha-1) was recorded in treatment when downy brome density kept 40 plants per m2. Trend analysis of data revealed that grain yield of wheat shows linear trend to be significant under influence on increasing downy brome densities (Table-2).

The reduction in the grain yield of wheat in response to increase in downy brome density is due to decrease in yield determining traits such as productive tillers, grains per spike and 1000-grain weight. Our findings are supported by those of Hesammi (2011), Khan and Hassan (2006) and Sarwaret al. (2013) concluded that grain yield decreased with increase in wild oat density.

Their model was best fitted showing that it described well the competition between wheat and downy brome(Figure 1). The model estimated 4.7 t ha-1to be the weed-free grain yield of wheat and weed competitively (β) to be the 0.00936. Keeping Rs.2300 to be the herbicide cost, Rs.900 application cost, Rs.30,000 value per unit of crop and 0.95 herbicide efficiency; economic threshold (ET) of downy brome was calculated to be 2.6 plant per m2 during crop season 2015 (Table-3).

CONCLUSION

The field investigation for various densities of B. tectorumconcluded that when the plant density exceeds 2.6 plants m-2, it should be controlled in order to avoid economic loss.

ACKNOWLEDGEMENTS

Authors of this manuscript are grateful to the support staff of University of Sargodha Research Farm.

REFERENCESCITED

Analytical Software. 2005. Statistix 8.1 for Windows. Analytical Software, Tallahassee, Florida.

Armin, M., and M. Asghripour. 2011. Effect of plant density on wild oat competition with competitive and non-competitive wheat cultivars. Agric.Sci. China,10(10):1554-61.

Bertholdsson, N.O. 2004. Variation in allelopathic activity over 100 years of barley selection and breeding. Weed Res.44(2): 78-86.

Buruchara, R. 2007. Background information on Common Beans (Phaseolus vulgaris L.) in Biotech., Breed. & Seed Systems for Afr. Crops. Nairobi, Kenya: The Rockefeller Foundation.

Chaudhary, S.U., M. Hussain, M.A. Ali, and J. Iqbal. 2008. Effect of weed competition period on yield and yield components of wheat. J. Agric. Res. 46(1): 47-54.

Coble, H.D. and D.A. Mortensen. 1992. The threshold concept and its application to weed science. Weed Technol. 6:191-195.

Cortés, J.A., M. A. Mendiola and M. Castejón. 2010. Competition of velvetleaf (Abutilon theophrasti M.) weed with cotton (Gossypiumhirsutum L.). Economic damage threshold. Spanish J. Agric. Res. 8: 391-399.

Cousens, R. 1985. A simple model relating yield loss to weed density. Ann. Appl. Biol. 107: 239-252.

Cousens, R. 1987. Theory and reality of weed control thresholds. Plant Prot. Quart. 2: 13-20.

Didon, U. 2002. Variation between barley cultivars in early response to weed competition. J. Agron.Crop. Sci.188(3): 176-184.

Economic Survey of Pakistan.2016-17. Ministry of Finance. Govt. of Pakistan. pp. 23-24.

Hassan, G. and H. Khan. 2007. Effect of wild oats (Avenafatua L.) density on wheat yield and its components under varying nitrogen regimes. Pak. J. Bot.39(7): 2585-2594.

Hesammi, E. 2011. Different densities of weeds and wild oats (Avenaludoviciana) and canary grass (Phalaris minor) on yield and yield components of wheat cultivar Chamran. Adv. Environ. Biol.5(8): 2497-2500.

Khan, I., and G. Hassan. 2006. Effect of wild oats (Avenafatua) densities and proportions on yield and yield components of wheat.Pak. J. Weed Sci. Res. 12(1/2): 69-77.

Khan, I., G. Hassan., M. I. Khan., and M. Gul. 2007. Effect of wild oat (Avenafatua L.) population and nitrogen levels on some agronomic traits of spring wheat (Triticumaestivum L.). Turk. J. Agric. For.31(2): 91.

Khan, I. A., G. Hassan., S. A. Khan., and S. Shah. 2012. Wheat-wild oats interactions at varying densities and proportions. Pak. J. Bot. 44: 1053-1057.

Le Tourneau, D., G. Failes and H. Heggeness. 1956. The effect of aqueous extracts of plant tissue on germination of seeds and growth of seedlings. Weeds 4(4): 363-368.

Morrow, L. A. and P.W. Stahlman. 1984. The history and distribution of downy brome (Bromus tectorum) in North America. Weed Sci. 32(1): 2-6.

Nadeem, M., A.Tanveer, T. Naqqash, A.Jhala and K. Mubeen. 2013. Determining critical weed competition periods for black seed. J. Anim. Plant Sci. 23(1): 216-221.

Nassab, A.D.M., and F.S. Lalelo, 2012. Effect of density and root-shoot interference on wheat (Triticumaestivum L.) and wild oat (AvenafatuaL.) performance.Int. J. Basic Sci.Appl.Res.3(2):279-285.

Noshadian, H., N.R. Azizi., E. Yasari and A. Kakularimi., 2014. Effects of removal time and Canary grass density on wheat yield and yield components.Int. J. Farm &Alli. Sci. 3(7): 733-741.

Oerke, E.C. 2006. Crop losses to pests. J. Agric. Sci..144(1): 31-43.

Rydrych, D. 1974. Competition between winter wheat and downy brome. Weed Sci. 22(3): 211-214.

Rydrych, D., and T. Muzik. 1968. Downy brome competition and control in dryland wheat. Agron. J.60(3): 279-280.

Sarwar, M., A. Ali., M. M. Maqbool, M. Ahmad., R. Mahmood, and T. U. Haq. 2013. Suppressing Impact of Avena fatua and Phalaris minor on the Growth and Yield in Wheat. Pak.J.Nutr.12(10):912916.

Stahlman, P.W., and S. D. Miller. 1990. Downy brome (Bromustectorum) interference and economic thresholds in winter wheat (Triticum aestivum). Weed Sci. 38(3): 224-228.

Steel, R.G.D., J.H. Torrie and D. Dickey. 1997. Principles and Procedures of Statistics: a biometrical approach. McGraw Hill Book Co. Inc. New York. pp. 172-177.

Upadhyaya, M. K., D. Mcilvride and R. Turkington. 1986. The biology of Canadian weeds: 75. Bromus tectorum L. Can. J. Plant Sci. 66(3):689-709.

Table-1. Effect of B. tectorum density on its growth characteristics.

B. tectorum density (m^{-2})	Plant height (cm)	Number of tillers $plant^{-1}$	Number of grain $spike^{-1}$	Dry weight ($g\ m^{-2}$)	Relative competitive Index (%)
0	-	-	-	-	-
5	108.8 a	14.8 a	217 a	61.1d	3 c
10	107.5 a	13.4 ab	201.5 ab	90.1c	6.8 c
20	103 b	10.6 b	180.4 b	154.1b	12.6 b
40	98.6 c	6 c	147.3 c	197 a	19.5 a
HSD	2.69	4.19	25.70	17.88	5.42
Trend comparison					
Linear	**	**	**	**	**
Quadratic	NS	NS	NS	NS	NS
Cubic	NS	NS	NS	NS	NS

Means sharing the same letter in a column did not significantly differ at 5% probability level.

Table-2. Effect of B. tectorum density on yield and yield components of wheat.

B. tectorum density (m^{-2})	Plant height (cm)	#product, tillers (m^{-2})	Spike length (cm)	# grains per spike	1000 grain wt. (g)	Grain yield ($t\ ha^{-1}$)
0	94.2 a	322.3 a	12.7 a	53.4 a	32.9 a	4.7 a
5	93.3 ab	317.0 a	12.6 a	52.3 a	32.8 a	4.6 a
10	91.9 b	311.8 ab	11.7a	50.9 ab	31.8 ab	4.4ab
20	89.5 c	303.8 bc	9.9 ab	47.7 bc	30.8 b	4.1 b
40	85.8 d	295.3 c	7.3 b	44.4 c	28.3 c	3.8 c
HSD	1.93	10.85	4.39	4.32	1.34	0.29
Trend comparison						
Linear	**	**	**	**	**	**
Quadratic	**	NS	NS	NS	**	NS
Cubic	NS	NS	NS	NS	NS	NS

Means sharing the same letter in a column did not significantly differ at 5% probability level, NS = Non-significant,NS and **indicate non-significant and significant at $p \leq 0.01$ level of probability, respectively.

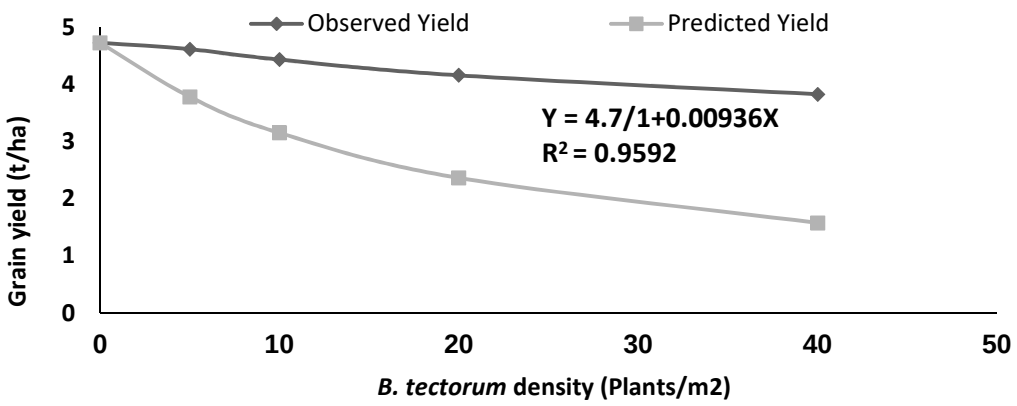

Figure 1: Non-Linear regression between wheat yield and B. tectorum density.

Table-3.Parameter estimates &economic threshold (ET) of parthenium in wheat.

C_h+C_a (Rs)	Y_o (t ha^{-1})	P (Rs. ton^{-})	L	H	ET (plants m^{-2})
2300 + 900	4.7	30000	0.00936	0.95	2.6

C_h = herbicide cost, Ca = application cost, Y_o = weed free wheat yield, P = value per unit of crop, L = proportional loss per unit weed density, H = herbicide efficacy, ET=predicted economic threshold.