PLANTA DANINHA
SOCIEDADE BRASILEIRA DA CIÊNCIA DAS PLANTAS DANINHAS
SBCPD
<http://www.sbcpd.org>
ISSN 0100-8358 (print)
1806-9681 (online)

Article

Effect of Isoproturon With and Without Adjuvants on Photosynthetic Attributes of Wheat and Its Associated Weeds

Efeito do Isoproturon Com e Sem Adjuvantes na Atividade Fotossintética do Trigo e Suas Plantas Daninhas Associadas

JAVAID, M.M.[1*]
ZIA, A.U.H.[1]
WAHEED, H.[1]
NARGIS, J.[2]
SHAHID, A.[3]
AZIZ, A[1]
WASAYA A.[4]

ABSTRACT - Among various weed management strategies, chemical weed control is considered the most effective method. However, optimum dose and suitable combination of herbicide with adjuvants play a vital role in controlling weeds at an acceptable level and produce maximum crop yield. A field study was conducted to investigate the effect of post-emergence herbicide isoproturon alone or with combination of adjuvants on winter wheat and its associated weeds. The treatments were isoproturon at 175 g a.i. ha^{-1}, 140 g a.i. ha^{-1} and 105 g a.i. ha^{-1} applied alone or with adjuvants Ad-500 or Bio-enhancer at 400 mL ha^{-1} each and weedy check as a control treatment. Isoproturon at 175 g a.i. ha^{-1} + Bio-enhancer at 400 mL ha^{-1} was most effective treatment for control of *Melilotus indica, Anagallis arvensis, Phalaris minor* and *Fumaria indica* as it decreased the photosynthetic activity, fresh and dry biomass of these weeds. In case of wheat, highest productive tillers, plant height, 1000-grain weight, biological and grain yield were achieved with isoproturon at 175 g a.i. ha^{-1} + Bio-enhancer at 400 mL ha^{-1}. However, highest values of gas exchange parameters of wheat were observed where no herbicide was sprayed. It can be concluded that isoproturon at 175 g a.i. ha^{-1} + Bio-enhancer at 400 mL ha^{-1} might be a profitable approach to achieve optimal yield of wheat by causing the maximum suppression of these tested weeds. Moreover, the herbicide at reduced dose with adjuvants was not much effective in terms of weed control or increased yield.

Keywords: fresh and dry weight, gas exchange traits, growth and yield, herbicide doses, *Triticum aestivum* L., weed control.

RESUMO - Entre várias práticas de manejo de plantas daninhas, o controle químico delas é considerado o método mais efetivo. No entanto, a dose ideal e a combinação adequada de herbicidas com adjuvantes desempenham papel vital no controle de plantas daninhas em um nível aceitável e produzem o rendimento máximo da cultura. Um estudo de campo foi conduzido para investigar o efeito de pós-emergência do herbicida isoproturon sozinho ou com combinação de adjuvantes no trigo de inverno e suas plantas daninhas relevantes. As doses de herbicida foram isoproturon a 175 g i.a. ha^{-1}, isoproturon a 140 g i.a. ha^{-1} e isoproturon a 105 g i.a. ha^{-1}, aplicado sozinho ou com adjuvantes Ad-500 ou biopotenciador a 400 mL ha^{-1} cada, e a verificação de plantas daninhas como tratamento controle. Entre todos os tratamentos, isoproturon a 175 g i.a. ha^{-1} + biopotenciador a 400 mL ha^{-1} foi mais eficaz no controle de ***Melilotus indica*, *Anagallis arvensis*, *Phalaris minor*** *e* ***Fumaria indica****, pois ele reduziu a atividade fotossintética e a biomassa fresca e seca dessas plantas daninhas. No caso do trigo, os maiores perfilhos produtivos, altura da planta, peso de mil grãos e rendimento biológico e*

*** Corresponding author:**
<mmansoorjavaid@gmail.com>

Received: February 15, 2018
Approved: December 15, 2018

Planta Daninha 2020; v38:e020191561

[1] Department of Agronomy, College of Agriculture, University of Sargodha, Sargodha, 40100, Pakistan; [2] Department of Botany, University of Sargodha, Sargodha, 40100, Pakistan; [3] Institute of Horticultural Sciences, University of Agriculture, Faisalabad, Pakistan; [4] Department of Agronomy, BZU Bahadur Sub Campus, Layyah, Pakistan.

Doi: 10.1590/S0100-83582020380100024

de grãos foram obtidos com isoproturon a 175 g i.a. ha^{-1} + biopotenciador a 400 mL ha^{-1}, devido à supressão máxima de plantas daninhas. No entanto, observaram-se valores mais altos de parâmetros de troca de gás do trigo quando nenhum herbicida foi pulverizado. Conclui-se que o isoproturon a 175 g i.a. ha^{-1} + biopotenciador a 400 mL ha^{-1} pode ser uma abordagem rentável para obter o melhor rendimento de trigo, juntamente com a supressão máxima das plantas daninhas.

Palavras-chave: características de troca de gás, crescimento e rendimento, controle de ervas daninhas, peso fresco e seco, doses de herbicidas, *Triticum aestivum*.

INTRODUCTION

Wheat is among the most widely planted crops in the world. It secures top position in terms of area and production in Pakistan as compared to other cereals (Guarda et al., 2004; Rueda Ayala et al., 2011). Severe weed infestation is one of the major constraints hampering potential yield of wheat and causing 20-40% reduction in its yield (Ahmad and Shaikh, 2003). Losses due to weeds can be managed by different approaches such as manual, mechanical, allelopathic, biological and chemical. Among these methods, chemical weed control is the most improved method (Bibi et al., 2008). In cereals, particularly in wheat, different herbicides are utilized with chief mode of action of photosynthesis inhibition by interrupting normal functioning of chlorophyll and photosystems I and II by binding to quinine binding protein D-1 in thalakoid membrane and seizes electron transport chain (Naseer-ud-din et al., 2011). Isoproturon {3-(4- isopropyl phenyl)-1,1- dimethyl urea} is among the important phenyl related urea group and post-emergence herbicide mainly utilized to control annual, broad leaf and grasses weeds in wheat and other cereal crops (Chhokar et al., 2008) with primary mode of action of photosynthesis inhibition and chlorophyll lipid synthesis (Shehzad et al., 2012).

Herbicide efficacy is significantly decreased due to direct influence of factors like drift and surface tension, whereas it can be increased with addition of adjuvants (Adamczewski and Matysiak, 2005; Bernards et al., 2009). Adjuvants improve the biological activity and reduce surface tension which may help to reduce herbicide dose (Green and Cahill, 2003). Some adjuvants completely alter the chemical composition of herbicide or even cover the plant surface by keeping the herbicide in-contact with plant tissue hence increase herbicide penetration and binding ability to kill the target plant without damaging actual crop (Kudsk and Streibig, 1993; Hess and Foy, 2000). Several studies has demonstrated that adjuvants efficacy is dependent on the herbicide being used and the characteristics of target weed (Kieloch and Domaradzki, 2008; Gugaa et al., 2010; Kammler et al., 2010). Therefore, identification of appropriate adjuvant for specific weed species is primarily required to maximize herbicide performance. Singh et al. (2006) has reported that weeds are efficiently controlled when isoproturon is sprayed combined with surfactants. An appropriate adjuvant when combined efficiently can decrease the amount of herbicide applied and significantly reduces the total costs for weed control (Green, 2001; Monaco et al., 2002). When herbicides are applied as a tank mixture or combined with an adjuvant, they might be more efficacious and cost-effective in controlling weeds if the appropriate combinations are used (Monaco et al., 2002). However, a higher dose of isoproturon causes adverse effects on wheat productivity (Singh et al., 1998). Therefore, it is a dire need to select an appropriate dose of herbicide with suitable adjuvant that must suppress the weed growth along with optimum yield of crop. The key objective of presented research was to evaluate the effect of post-emergence application of isoproturon herbicide alone and with most suitable combination of adjuvant on photosynthetic attributes of wheat and their associated weeds.

MATERIALS AND METHODS

A field experiment was conducted during winter season, 2013-2014 at the Agronomic Research Area, College of Agriculture, University of Sargodha, Sargodha (31.41^{o}, Latitude N, 74.17^{o}, E Longitude and Altitude 194.4 m). The soil of experimental site was analyzed and found to be sandy clay loam with pH 8.2, organic matter content 0.90%, 0.55% nitrogen (N), 12 ppm available phosphorous (P) and 113 ppm available potassium (K). Experiment was laid out in Randomized Complete Block Design (RCBD) with four replications. Treatments were comprised of weedy check, isoproturon at 175 g a.i. ha^{-1}, isoproturon at 140 g a.i. ha^{-1}, isoproturon at 105 g a.i. ha^{-1}, isoproturon at 175 g a.i. ha^{-1} + Ad-500 at 400 mL ha^{-1}, isoproturon at 140 g a.i. ha^{-1} + Ad-500 at 400 mL ha^{-1}, isoproturon at 105 g a.i. ha^{-1} + Ad-500 at 400 mL ha^{-1}, isoproturon at 175 g a.i. ha^{-1} + Bio-enhancer at 400 mL ha^{-1}, isoproturon at 140 g a.i. ha^{-1} + Bio-enhancer at 400 mL ha^{-1}, isoproturon at 105 g a.i. ha^{-1} + Bio-enhancer at 400 mL ha^{-1}. Seed bed was prepared by cultivating the soil thrice with tractor mounted cultivator, each followed by planking. The plot size was 1.5 m × 3.5 m having row to row spacing 25 cm. Wheat variety PUNJAB-2011 was sown at the seed rate of 100 kg ha^{-1}, planted using a single-row hand-pulled seed drill. Recommended dose of nitrogen (N) from urea, phosphorus (P) from diammonium phosphate and potassium (K) from sulfate of potash was applied at the rate of 50, 34 and 25 kg/acre respectively. Complete dose of phosphorus and potassium and half of nitrogen was applied during seed bed preparation, while remaining nitrogen was applied at first irrigation. Recommended agronomic practices were kept same for each treatment. Spray solutions were prepared by adding isoproturon alone and with adjuvants in a plastic bottles containing tap water. Each dose of isoproturon was prepared separately. All herbicide treatments were applied with back pack knapsack sprayer equipped with flat fan nozzle after calibration. The sprayer was adjusted to deliver 250 L ha^{-1} solution at 3.2 km h^{-1}. Herbicide treatments were applied at two to four leaf stage of weeds. Data regarding number of weeds per plot was collected two times, first at 21 days after sowing and second at maturity. Other parameters including weeds plant height (cm), fresh weight (g) and dry weight (g) were recorded at maturity by using standard procedure. However, growth and yield related parameters of wheat like number of productive tillers (m^{-2}), number of none-productive tillers (m^{-2}), plant height (cm), number of grains/spike, 1000-grains weight (g), spike length (cm), biological yield (kg ha^{-1}), grain yield (kg ha^{-1}) were recorded at maturity following standard procedure. Harvest index (%) of wheat was calculated using following formula:

$$\text{Harvest index (\%)} = \frac{\text{Grain yield}}{\text{Biological yield}} \times 100$$

Gas exchange parameters

The net photosynthetic rate, transpiration rate and stomatal conductance for wheat and weeds were measured 3, 10 and 17 days after herbicide application. Gas exchange parameters were recorded using portable infrared gas analyzer (CI-340 Portable Photosynthesis System, CID Biosciences, USA) with some adjustments: mass flow rate 0.33 mol m^{-2} s^{-1}, atmospheric pressure 99.5 kPa, photosynthetically active radiation at leaf surface maximum up to 1393 µmol m^{-2} s^{-1}, water vapor pressure at outlet of leaf chamber ranged from 1.7-2.4 kPa and ambient air temperature in leaf chamber ranged from 23-34 ^{o}C. The data was recorded from fully expanded mature leaves in between 10:00 am to 12:00 pm.

Statistical analysis

The collected data was subjected to analysis of variance (ANOVA) technique and treatments means were compared using Tukey's (HSD) test at 5% probability level using Statistix 8.1 (Steel et al., 1997).

RESULTS AND DISSCUSSION

Effect of isoproturon on agronomic traits of wheat

Results regarding the effect of isoproturon with and without adjuvants on number of productive and non-productive tillers of wheat are described in Table 1. Highest productive tillers (375.2) and lowest non-productive tillers (18.5) of wheat were observed with the application of isoproturon at 175 g a.i. ha^{-1} + Bio-enhancer at 400 mL ha^{-1}. Minimum productive and maximum non-productive tillers were recorded in weedy check. Comparatively, isoproturon at 175 g a.i. ha^{-1} + Bio-enhancer at 400 mL ha^{-1} produced tallest wheat plants, whereas, minimum plant height (79.5 cm) was recorded with isoproturon at 105 g a.i. ha^{-1}. Spike length was significantly affected

Table 1 **-** Effect of Isoproturon with and without adjuvants on number of productive tillers (m^{-2}), number of non-productive tillers (m^{-2}), plant height (cm), spike length (cm) and number of grains per spike of wheat

Treatment	Number of productive tillers (m^{-2})	Number of non-productive tillers (m^{-2})	Plant height (cm)	Spike length (cm)	Number of grains per spike
T_1	299.2 g	43.5 a	83.5 f	8.5 e	54.5 j
T_2	365.0 c	20.2 de	91.5 c	11.5 bc	78.5 c
T_3	360.7 d	23.0 bc	85.5 e	10.5 cd	68.5 g
T_4	352.0 f	24.5 b	79.5 h	9.5 de	65.5 i
T_5	370.2 b	18.7 ef	93.5 b	12.5 ab	81.5 b
T_6	362.0 d	21.5 cd	87.5 d	11.5 bc	71.5 e
T_7	355.0 e	24.2 b	81.5 g	10.5 cd	67.5 h
T_8	375.2 a	18.5 f	95.5 a	13.5 a	84.0 a
T_9	365.5 c	21.5 cd	88.5 d	12.5 ab	73.5 d
T_{10}	355.2 e	23.5 b	82.5 fg	11.5 bc	69.5 f
HSD (0.05)	0.5	1.6	1.3	1.0	0.9

Means sharing the same letter in a column did not differ with each other at 5% (0.05) probability level. T_1 = Weedy check, T_2 = Isoproturon at 175 g a.i. ha^{-1}, T_3 = Isoproturon at 140 g a.i. ha^{-1}, T_4 = Isoproturon at 105 g a.i. ha^{-1}, T_5 = Isoproturon at 175 g a.i. ha^{-1} + Ad-500 at 400 mL ha^{-1}, T_6 = Isoproturon at 140 g a.i ha^{-1} + Ad-500 at 400 mL ha^{-1}, T_7 = Isoproturon at 105 g a.i. ha^{-1} + Ad-500 at 400 mL ha^{-1}, T_8 = Isoproturon at 175 g a.i. ha^{-1} + Bio-enhancer at 400 mL ha^{-1} , T_9 = Isoproturon at 140 g a.i. ha^{-1} + Bio-enhancer at 400 mL ha^{-1}, T_{10} = Isoproturon at 105 g a.i. ha^{-1} + Bio-enhancer at 400 mL ha^{-1}.

by exogenous application of isoproturon with and without adjuvants. Isoproturon dose at 175 g a.i. ha^{-1} + Bio-enhancer at 400 mL ha^{-1} produced maximum spike length. Results clearly demonstrates that reduced dose of isoproturon (105 g a.i. ha^{-1}) along with Bio-enhancer at 400 mL ha^{-1} gave similar spike length as that of full dose of isoproturon with and without adjuvants (Table 1).

There was significant effect of isoproturon with and without adjuvants on number of grains/spike of wheat (Table 1). Both adjuvants improved efficacy of isoproturon and produced higher number of grains/spike than isoproturon alone (Table 1). Maximum number of grains/spike (84) of wheat were observed with isoproturon at 175 g a.i. ha^{-1} + Bio-enhancer followed by that of isoproturon at 175 g a.i. ha^{-1} + Ad-500 at 400 mL ha^{-1}. Whereas, the weedy check produced lowest number of grains/spike compared to other herbicidal treatments. The 1000-grains weight of wheat varied significantly under various application of isoproturon with and without adjuvants (Table 2). The isoproturon at 175 g a.i. ha^{-1} with both adjuvants (Bio-enhancer and Ad-500 each at 400 mL ha^{-1}) significantly increased 1000-grains weight than weedy check. Combination of

Table 2 - Effect of isoproturon with and without adjuvants on 1000-grain weight (g), biological yield (kg ha^{-1}), grain yield (kg ha^{-1}) and harvest index (%) of wheat

Treatment	1000-grain weight (g)	Biological yield (kg ha^{-1})	Grain yield (kg ha^{-1})	Harvest index (%)
T_1	35.0 f	5923.8 i	2285.7 h	39.5 h
T_2	42.5 c	7276.8 e	2476.1 c	48.0 de
T_3	40.5 d	7066.6 f	2285.7 f	46.5 f
T_4	38.5 e	6685.7 h	2285.7 f	44.5 g
T_5	44.5 b	7638.0 b	2666.6 b	50.0 b
T_6	42.5 c	7352.3 d	2476.1 d	48.5 cd
T_7	40.5 d	6971.4 g	2285.7 f	47.5 e
T_8	45.5 a	7828.5 a	2666.6 a	51.5 a
T_9	44.5 b	7542.8 c	2476.1 c	50.0 b
T_{10}	42.5 c	7047.6 f	2285.7 f	49.0 c
HSD (0.05)	0.4	4.4	1.3	0.7

Means sharing the same letter in a column did not differ with each other at 5% (0.05) probability level. T_1 = Weedy check, T_2 = Isoproturon at 175 g a.i. ha^{-1}, T_3 = Isoproturon at 140 g a.i. ha^{-1}, T_4 = Isoproturon at 105 g a.i. ha^{-1}, T_5 = Isoproturon at 175 g a.i. ha^{-1} + Ad-500 at 400 mL ha^{-1}, T_6 = Isoproturon at 140 g a.i ha^{-1} + Ad-500 at 400 mL ha^{-1}, T_7 = Isoproturon at 105 g a.i. ha^{-1} + Ad-500 at 400 mL ha^{-1}, T_8 = Isoproturon at 175 g a.i. ha^{-1} + Bio-enhancer at 400 mL ha^{-1}, T_9 = Isoproturon at 140 g a.i. ha^{-1} + Bio-enhancer at 400 mL ha^{-1}, T_{10} = Isoproturon at 105 g a.i. ha^{-1} + Bio-enhancer at 400 mL ha^{-1}.

Bio-enhancer and isoproturon is more effective as compared to Ad-500, as Bio-enhancer at 400 mL ha^{-1} with reduced dose of isoproturon (140 g a.i. ha^{-1}) gave similar 1000-grain weight to that of full dose of isoproturon (175 g a.i. ha^{-1}) with Ad-500 at 400 mL ha^{-1}.

All herbicide treatments produced more biological yield as compared to weedy check. Isoproturon at 175 g a.i. ha^{-1} + Bio-enhancer at 400 mL ha^{-1} produced highest biological yield compared to other treatments. However, similar biological yield was recorded with isoproturon at 140 g a.i. ha^{-1} and isoproturon at 105 g a.i. ha^{-1} + Bio-enhancer at 400 mL ha^{-1} (Table 2). Regarding grain yield, wheat responded differently to isoproturon applied with and without adjuvants (Table 2). Highest grain yield (2666.6 kg ha^{-1}) of wheat was observed with isoproturon at 175 g a.i. ha^{-1} with combination of either adjuvant (Ad-500 or Bio-enhancer) at 400 mL ha^{-1}. However, minimum grain yield (2285.7 kg ha^{-1}) was recorded in weedy check followed by that of isoproturon at 140 g and 105 g a.i. ha^{-1} and isoproturon at 105 g a.i. ha^{-1} with each adjuvant at 400 mL ha^{-1}. Data regarding effect of isoproturon with and without adjuvants on harvest index of wheat is presented in Table 2. Maximum harvest index (51.5%) of wheat was observed with isoproturon at 175 g a.i. ha^{-1} + Bio-enhancer at 400 mL ha^{-1}. Data stated that full dose of isoproturon at 175 g a.i. ha^{-1} + Ad-500 at 400 mL ha^{-1} and reduced dose of isoproturon (140 g a.i. ha^{-1}) along with Bio-enhancer at 400 mL ha^{-1} gave similar harvest index (Table 2).

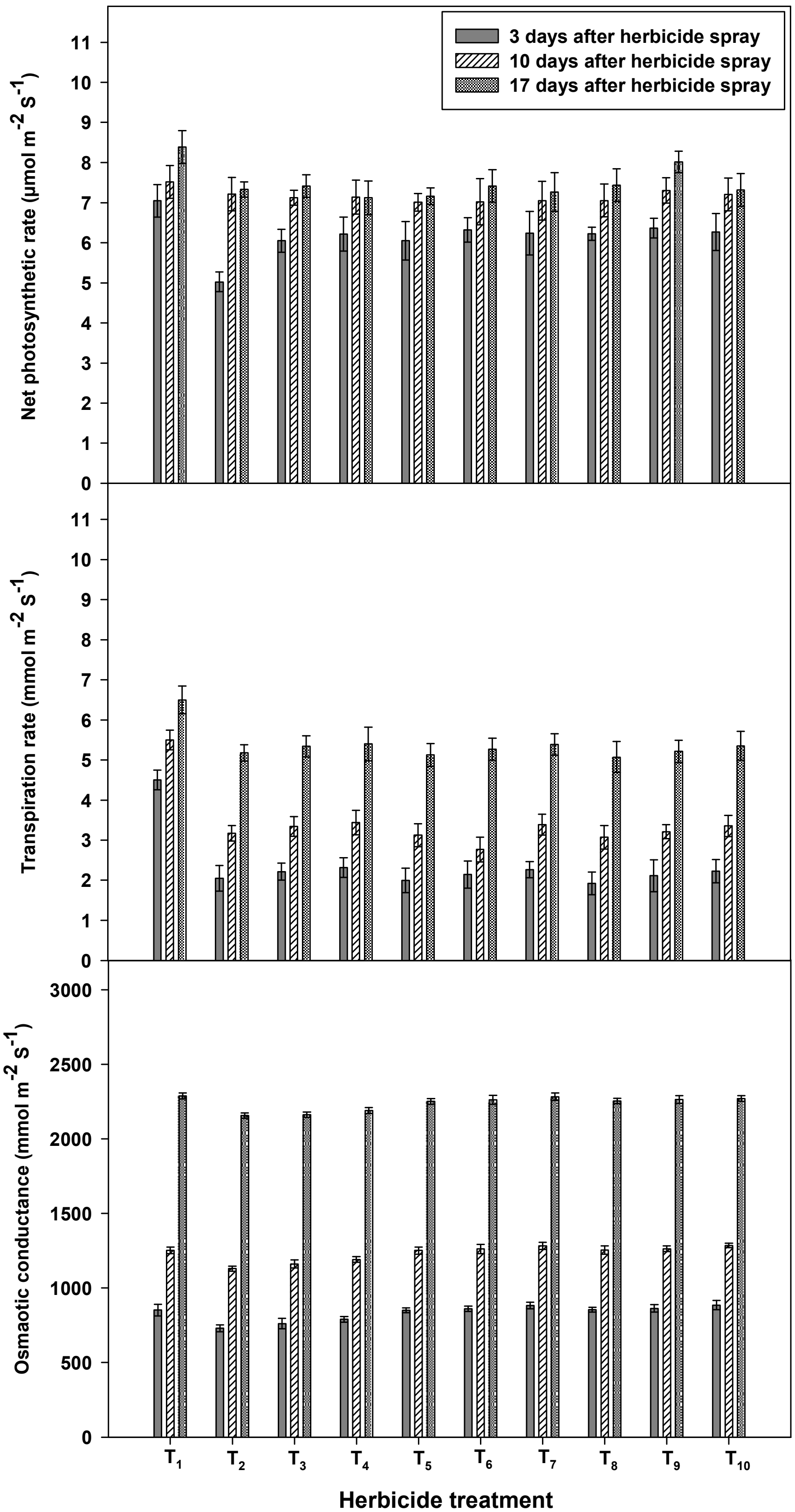
Effect of isoproturon on physiological parameters of wheat

Data regarding net photosynthetic rate of wheat after 3, 10 and 17 days of post-emergence herbicide application of isoproturon alone and with adjuvants is shown in Figure 1. Among all treatments, weedy check produced maximum photosynthetic rate after 3, 10 and 17 days of herbicide spray. Whereas in all herbicidal applications, lowest photosynthetic rate (7.13 µmol m^{-2} s^{-1}) of wheat was recorded with isoproturon at 175 g a.i. ha^{-1} + Bio-enhance at 400 mL ha^{-1} after 17 days of herbicidal spray followed by 10 and 3 days after herbicidal spray with the same treatment. After 3, 10 and 17 days of herbicide applications, transpiration rate of wheat enhanced progressively with passage of time (Figure 1). Highest transpiration rate was observed in weedy check after that maximum transpiration rate (5.40 µmol m^{-2} s^{-1}) was recorded with lowest dose of isoproturon at 105 g a.i. ha^{-1} without adjuvants followed by isoproturon at 105 g a.i. ha^{-1} + Ad-500 at 400 mL ha^{-1} after 17 days of herbicide application. However, lowest transpiration rate (5.07 µmol m^{-2} s^{-1}) was observed with isoproturon at 175 g a.i. ha^{-1} + Bio-enhance at 400 mL ha^{-1} after 17 days of herbicidal spray. Stomatal conductance enhanced significantly after 17 day of herbicidal spray than 3 and 10 days after spray (Figure 1). Among all treatments, maximum stomatal conductance (2287 µmol m^{-2} s^{-1}) was recorded in weedy check. In all intervals of herbicidal applications, isoproturon at 175 g a.i. ha^{-1} + Bio-enhancer at 400 mL ha^{-1} recorded the minimum stomatal conductance of wheat (Figure 1).

Effect of isoproturon on growth parameters of weeds

Effect of post-emergence herbicide isoproturon alone and with adjuvants on fresh and dry weight of all four weeds *Melilotus indica, Anagallis arvensis, Phalaris minor* and *Fumaria indica* resulted in lowest fresh and dry weight as compared to weedy check (Table 3). Maximum fresh and dry weight of four weeds was observed in weedy check. Whereas, isoproturon at 175 g a.i. ha^{-1} + Bio-enhancer at 400 mL ha^{-1} produced minimum fresh weight of 37.5 g, 16.5 g and 16.5 g in *M. indica, A. arvensis* and *F. indica,* respectively. However, minimum fresh weight (37.5 g) was measured from *P. minor* where isoproturon at 140 g a.i. ha^{-1} + Bio-enhancer at 400 mL ha^{-1} were sprayed (Table 3). In case of dry weight of weeds, isoproturon at 175 g a.i. ha^{-1} + Bio-enhancer at 400 mL ha^{-1} produced minimum dry weight of 7.5, 8, 19.5 and 7.5 g of *M. indica, A. arvensis, P. minor* and *F. indica*, respectively.

Results regarding number of weeds of all four species (*M. indica, A. arvensis, P. minor* and *F. indica*) after 21 days of application of isoproturon with and without adjuvants are presented in Table 4. Results showed that maximum number of weeds (54.4) was measured for *M. indica* followed by *A. arvensis* (30.5), *P. minor* (7.5) and *F. indica* (12.5) in weedy check treatment while, isoproturon at 175 g a.i. ha^{-1} + Bio-enhancer at 400 mL ha^{-1} gave minimum number of *M. indica* and *F. indica* weeds. However, minimum number of *A. arvensis* (7.5) weeds was recorded with



T_1 = Weedy check, T_2 = Isoproturon at 175 g a.i. ha^{-1}, T_3 = Isoproturon at 140 g a.i. ha^{-1}, T_4 = Isoproturon at 105 g a.i. ha^{-1}, T_5 = Isoproturon at 175 g a.i. ha^{-1} + Ad-500 at 400 mL ha^{-1}, T_6 = Isoproturon at 140 g a.i. ha^{-1} + Ad-500 at 400 mL ha^{-1}, T_7 = Isoproturon at 105 g a.i. ha^{-1} + Ad-500 at 400 mL ha^{-1}, T_8 = Isoproturon at 175 g a.i. ha^{-1} + Bio-enhancer at 400 mL ha^{-1}, T_9 = Isoproturon at 140 g a.i. ha^{-1} + Bio-enhancer at 400 mL ha^{-1}, T_{10} = Isoproturon at 105 g a.i. ha^{-1} + Bio-enhancer at 400 mL ha^{-1}.

Figure 1 - Effect of Isoproturon with and without adjuvants on net photosynthetic rate, transpiration rate and stomatal conductance of wheat at 3, 10 and 17 days after herbicide spray.

Table 3 **-** Effect of isoproturon with and without adjuvants on fresh and dry weight (g) of four weeds (*Melilotus indica* L., *Anagallis arvensis* L., *Phalaris minor* L., *Fumaria indica* L.) growing in wheat (*Triticum aestivum* L.)

Treatment	Fresh weight (g)				Dry weight (g)			
	Melilotus indica	*Anagallis arvensis*	*Phalaris minor*	*Fumaria indica*	*Melilotus indica*	*Anagallis arvensis*	*Phalaris minor*	*Fumaria indica*
T_1	180.5 a	140.5 a	312.5 a	140.5 a	49.5 a	59.5 a	147.5 a	49.5 a
T_2	40.5 d	17.2 cde	52.5 bcd	17.2 cde	8.5 e	9.5 d e	22.5 f	8.5 e
T_3	42.5 c	22.5 bc	57.5 bcd	22.5 bc	10.5 c	10.5 c	26.5 c	10.5 c
T_4	44.5 b	24.5 b	60.5 b	24.5 b	12.5 b	11.5 b	29.5 b	12.5 b
T_5	38.5 f	16.5 cde	49.5 bcd	16.5 cde	8.5 e	8.5 fg	21.5 g	8.5 e
T_6	41.0 d	20.5 bcde	53.5 bc	20.5 bcde	9.5 d	9.5 de	24.5 d	9.5 d
T_7	42.0 c	21.5 bcde	57.5 bcd	21.5 bcd	10.5 c	10.5 c	26.5 c	10.5 c
T_8	37.5 g	16.5 de	42.5 cd	16.5 cde	7.5 f	8.0 g	19.5 h	7.5 f
T_9	38.5 f	17.5 cde	37.5 d	18.5 cde	8.5 e	9.0 ef	21.5 g	8.5 d
T_{10}	39.5 e	19.5 cde	52.5 bcd	19.5 cde	9.5 d	10.0 cd	23.5 e	9.5 d
HSD (0.05)	0.59	4.0	15.3	4.0	0.8	0.6	0.8	0.8

Means sharing the same letter in a column did not differ with each other at 5% (0.05) probability level. T_1 = Weedy check, T_2 = Isoproturon at 175 g a.i. ha^{-1}, T_3 = Isoproturon at 140 g a.i. ha^{-1}, T_4 = Isoproturon at 105 g a.i. ha^{-1}, T_5 = Isoproturon at 175 g a.i. ha^{-1} + Ad-500 at 400 mL ha^{-1}, T_6 = Isoproturon at 140 g a.i ha^{-1} + Ad-500 at 400 mL ha^{-1}, T_7 = Isoproturon at 105 g a.i. ha^{-1} + Ad-500 at 400 mL ha^{-1}, T_8 = Isoproturon at 175 g a.i. ha^{-1} + Bio-enhancer at 400 mL ha^{-1}, T_9 = Isoproturon at 140 g a.i. ha^{-1} + Bio-enhancer at 400 mL ha^{-1}, T_{10} = Isoproturon at 105 g a.i. ha^{-1} + Bio-enhancer at 400 mL ha^{-1}.

Table 4 **-** Effect of isoproturon with and without adjuvants on number of weeds (*Melilotus indica* L., *Anagallis arvensis* L., *Phalaris minor* L., *Fumaria indica* L.) at 21 days after herbicide application and at harvest of wheat (*Triticum aestivum* L.)

Treatment	Number of weeds 21 days after treatment				Number of weeds at harvest			
	Melilotus indica	*Anagallis arvensis*	*Phalaris minor*	*Fumaria indica*	*Melilotus indica*	*Anagallis arvensis*	*Phalaris minor*	*Fumaria indica*
T_1	54.5 a	30.5 a	7.5 a	12.5 a	57.2 a	22.5 a	5.5 a	12.5 a
T_2	17.5 f	7.5 d	2.5 bc	4.5 d	9.5 de	0.0 d	1.5 bc	0.0 d
T_3	23.5 d	9.5 bc	3.5 b	5.5 c	15.5 bc	1.5 bc	3.2 b	1.5 bc
T_4	27.5 b	10.5 b	1.5 c	6.5 b	19.5 b	2.5 b	1.7 bc	2.5 b
T_5	15.5 g	7.5 d	2.5 bc	3.5 e	7.5 ef	0.0 d	2.5 bc	0.0 d
T_6	20.5 e	8.5 cd	1.5 c	4.5 d	12.5 cd	0.5 cd	1.7 bc	0.5 cd
T_7	25.5 c	9.5 bc	2.5 bc	5.5 c	17.5 b	1.5 bc	2.2 bc	1.5 bc
T_8	12.5 h	7.5 d	1.5 c	2.5 f	4.5 f	0.0 d	1.7 bc	0.0 d
T_9	23.5 d	8.5 cd	1.5 c	3.5 e	15.5 bc	0.5 cd	1.2 c	0.3 cd
T_{10}	22.5 d	9.0 c	2.5 bc	4.5 d	15.5 bc	0.4 cd	3.0 bc	0.5 cd
HSD (0.05)	1.6	1.3	1.4	0.8	4.9	1.04	0.8	0.8

Means sharing the same letter in a column did not differ with each other at 5% (0.05) probability level. T_1 = Weedy check, T_2 = Isoproturon at 175 g a.i. ha^{-1}, T_3 = Isoproturon at 140 g a.i. ha^{-1}, T_4 = Isoproturon at 105 g a.i. ha^{-1}, T_5 = Isoproturon at 175 g a.i. ha^{-1} + Ad-500 at 400 mL ha^{-1}, T_6 = Isoproturon at 140 g a.i ha^{-1} + Ad-500 at 400 mL ha^{-1}, T_7 = Isoproturon at 105 g a.i. ha^{-1} + Ad-500 at 400 mL ha^{-1}, T_8 = Isoproturon at 175 g a.i. ha^{-1} + Bio-enhancer at 400 mL ha^{-1}, T_9 = Isoproturon at 140 g a.i. ha^{-1} + Bio-enhancer at 400 mL ha^{-1}, T_{10} = Isoproturon at 105 g a.i. ha^{-1} + Bio-enhancer at 400 mL ha^{-1}.

isoproturon at 175 g a.i. ha^{-1} sprayed alone and with both adjuvants (Ad-500 or Bio-enhancer) each at 400 mL ha^{-1}. Whereas, in case of *P. minor* minimum number of weeds (1.5) were recorded with isoproturon at 105 g a.i. ha^{-1}, isoproturon at 140 g a.i. ha^{-1} with both adjuvants each at 400 mL ha^{-1}, isoproturon at 175 g a.i. ha^{-1} + Bio-enhancer at 400 mL ha^{-1} (Table 4).

At harvesting, maximum number of weeds were recorded for all four weeds in weedy check. However, effect of isoproturon with and without adjuvants was different for minimum number of weeds at harvest (Table 4). In case of *M. indica* minimum weeds (4.5) were recorded with isoproturon at 140 g a.i. ha^{-1} and isoproturon at 175 g a.i. ha^{-1} + Bio-enhancer at 400 mL ha^{-1}. At harvest, *A. arvensis* and *F. indica* showed similar trend and both weeds were fully controlled in plots where isoproturon at 175 g a.i. ha^{-1} was sprayed alone and in combination with both adjuvants (Bio-enhancer + Ad-500) at 400 mL ha^{-1}. However, isoproturon at reduced dose (105 g a.i. ha^{-1}) with Bio-enhancer 400 mL ha^{-1} resulted in similar number of *P. minor* weeds at harvest to that of full dose (175 g a.i. ha^{-1}) without adjuvants.

Efficacy of isoproturon with and without adjuvants on height of all four weeds (*M. indica, A. arvensis, P. minor* and *F. indica*) was found significantly different (Table 5). Maximum plant height of *M. indica* (63.5 cm), *A. arvensis* (39.5), *P. minor* (80.2 cm) and *F. indica* (57.75 cm) was recorded in weedy check. Whereas, isoproturon at 175 g a.i. ha^{-1} + Bio-enhancer at 400 mL ha^{-1} gave plant heights of 13.5, 2.5, 22.5 and 11.25 cm in *M. indica, A. arvensis, P. minor* and *F. indica* respectively which was minimum among all treatments. Isoproturon at 105 g a.i. ha^{-1} resulted in highest plant height in all tested weeds after weedy check compared to all other treatments (Table 5).

Table 5 - Effect of isoproturon with and without adjuvants on plant height of weeds (*Melilotus indica* L., *Anagallis arvensis* L., *Phalaris minor* L., *Fumaria indica* L.) of wheat (*Triticum aestivum* L.)

Treatment	Weed plant height (cm)			
	Melilotus indica	*Anagallis arvensis*	*Phalaris minor*	*Fumaria indica*
T_1	63.5 a	39.5 a	80.2 a	57.7 a
T_2	15.5 g	4.5 e	25.5 ef	14.2
T_3	21.5 d	6.5 bc	31.5 cd	20.0 bc
T_4	23.5 b	7.5 b	53.0 b	22.5 b
T_5	14.5 h	3.5 ef	23.0 f	13.0 f
T_6	19.5 e	5.5 cd	28.5 de	17.5 cde
T_7	22.5 c	6.5 bc	30.5 cd	20.5 bc
T_8	13.5 i	2.5 f	22.5 f	11.2 f
T_9	18.5 f	4.5 de	34.5 c	16.5 de
T_{10}	21.5 d	5.5 cd	29.5 de	19.5 bcd
HSD (0.05)	0.7	1.4	4.0	3.36

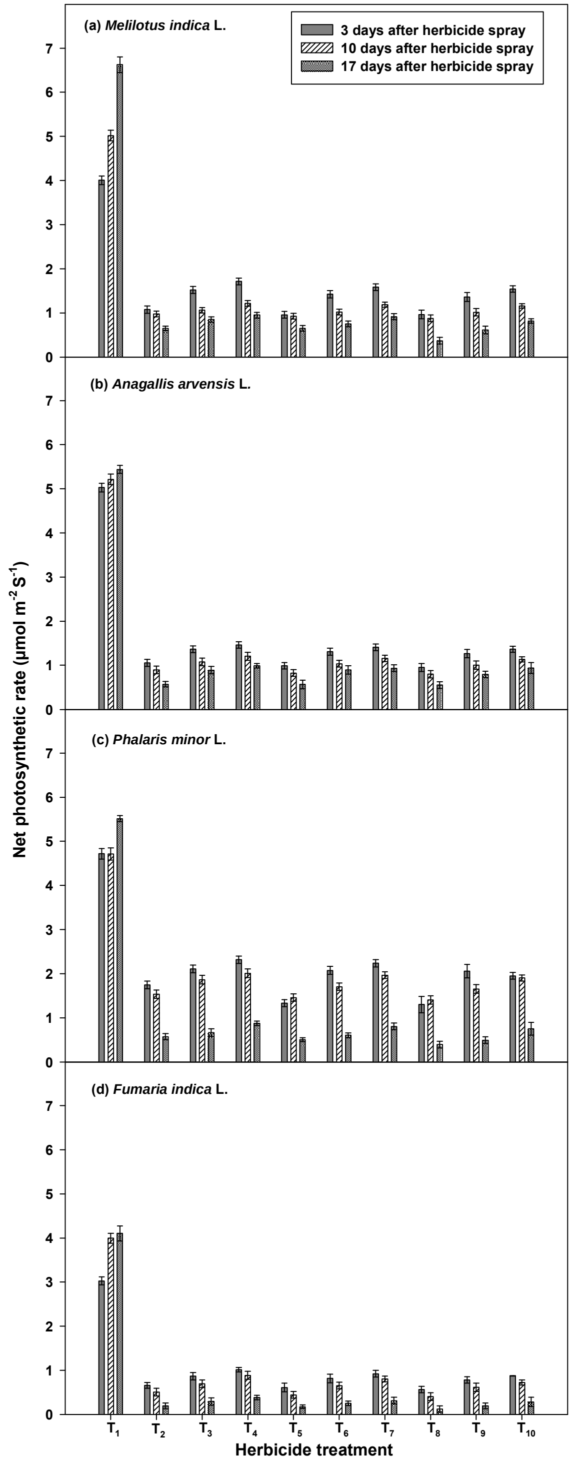
Means sharing the same letter in a column did not differ with each other at 5% (0.05) probability level. T_1 = Weedy check, T_2 = Isoproturon at 175 g a.i. ha^{-1}, T_3 = Isoproturon at 140 g a.i. ha^{-1}, T_4 = Isoproturon at 105 g a.i. ha^{-1}, T_5 = Isoproturon at 175 g a.i. ha^{-1} + Ad-500 at 400 mL ha^{-1}, T_6 = Isoproturon at 140 g a.i ha^{-1} + Ad-500 at 400 mL ha^{-1}, T_7 = Isoproturon at 105 g a.i. ha^{-1} + Ad-500 at 400 mL ha^{-1}, T_8 = Isoproturon at 175 g a.i. ha^{-1} + Bio-enhancer at 400 mL ha^{-1}, T_9 = Isoproturon at 140 g a.i. ha^{-1} + Bio-enhancer at 400 mL ha^{-1}, T_{10} = Isoproturon at 105 g a.i. ha^{-1} + Bio-enhancer at 400 mL ha^{-1}.

Effect of isoproturon on physiological parameters of weeds

All herbicide treatments with and without adjuvants impart significant impact on all weeds by reducing their photosynthetic rate as compared to weedy check after 3, 10 and 17 days of herbicidal spray (Figure 2). In comparison among days of herbicide application, lowest photosynthesis rate of all four weeds was observed after 17 days of herbicide application. Minimum photosynthetic rate in *M. indica* (0.612 µmol m^{-2} s^{-1}), *A. arvensis* (0.552 µmol m^{-2} s^{-1}), *P. minor* (0.395 µmol m^{-2} s^{-1}), and *F. indica* (0.125 µmol m^{-2} s^{-1}) was recorded with isoproturon at 175 g a.i. ha^{-1} + Bio-enhancer at 400 mL ha^{-1} followed by isoproturon at 175 g a.i. ha^{-1} + Ad-500 at 400 mL ha^{-1} after 17 days of herbicide application. However, in weedy check, highest rate of photosynthesis was recorded in all weeds after 3, 10, and 17 days of herbicide spray.

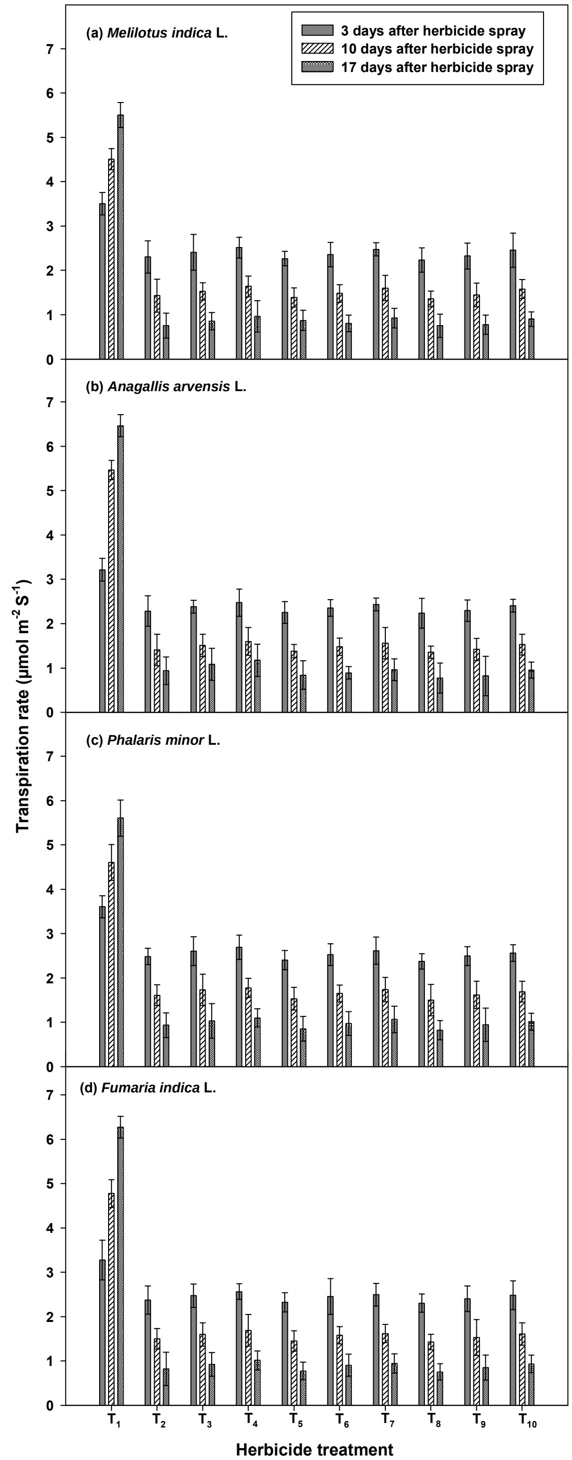
Transpiration rate was found maximal in weedy check when measured 3, 10 and 17 days after herbicide spray (Figure 3). Data showed that post-emergence spray of isoproturon with and without adjuvants reduced the transpiration rate of all four weeds (*M. indica, A. arvensis*, *P. minor*, and *F. indica*) after 3, 10 and 17 days of application. Whereas, isoproturon at 175 g a.i. ha^{-1} + Bio-enhancer at 400 mL ha^{-1} lowered the transpiration rate significantly in studied weeds after 17 days of herbicide spray than 3 and 10 days. However, after 3 days of herbicidal application, minimum transpiration rate (2.32 µmol m^{-2} s^{-1}) was recorded with isoproturon at 175 g a.i. ha^{-1} + Ad-500 at 400 mL ha^{-1} in *F. indica* than others weeds (Figure 3).

Effect of isoproturon with and without adjuvants on stomatal conductance of all four weeds (*M. indica, A. arvensis, P. minor* and *F. indica*) resulted in lowest rate of stomatal conductance when compared with that of weedy check (Figure 4). In *M. indica*, after 3, 10 and 17 days of herbicidal treatments, lowest stomatal conductance were observed with isoproturon at 175 g a.i. ha^{-1} + Bio-enhancer at 400 mL ha^{-1}. In case of *A. arvensis, F. indica* and *P. minor,* minimal stomatal conductance was recorded with isoproturon at 175 g a.i. ha^{-1} with both adjuvants each at 400 mL ha^{-1} after 3, 10 and 17 days of herbicide treatments. Whereas, highest stomatal conductance was recoded in weedy check after 17 days of herbicide spray in all four weeds.



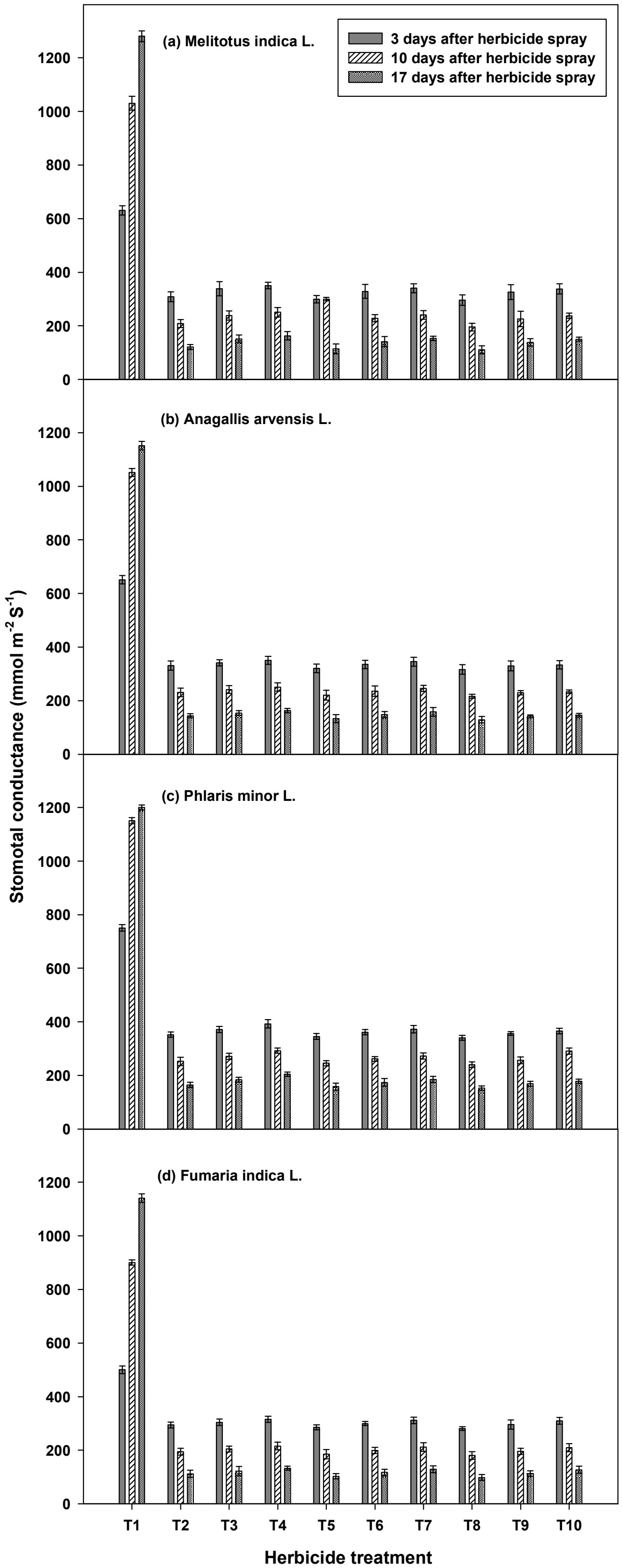
T_1 = Weedy check, T_2 = Isoproturon at 175 g a.i. ha^{-1}, T_3 = Isoproturon at 140 g a.i. ha^{-1}, T_4 = Isoproturon at 105 g a.i. ha^{-1}, T_5 = Isoproturon at 175 g a.i. ha^{-1} + Ad-500 at 400 mL ha^{-1}, T_6 = Isoproturon at 140 g a.i. ha^{-1} + Ad-500 at 400 mL ha^{-1}, T_7 = Isoproturon at 105 g a.i. ha^{-1} + Ad-500 at 400 mL ha^{-1}, T_8 = Isoproturon at 175 g a.i. ha^{-1} + Bio-enhancer at 400 mL ha^{-1}, T_9 = Isoproturon at 140 g a.i. ha^{-1} + Bio-enhancer at 400 mL ha^{-1}, T_{10} = Isoproturon at 105 g a.i. ha^{-1} + Bio-enhancer at 400 mL ha^{-1}.

Figure 2 - Effect of isoproturon with and without adjuvants on net photosynthetic rate of *Melilotus indica* L. (A), *Anagallis arvensis* L. (B), *Phalaris minor* L.(C), *Fumaria indica* L.(D) at 3, 10 and 17 days after herbicide spray.



T_1 = Weedy check, T_2 = Isoproturon at 175 g a.i. ha^{-1}, T_3 = Isoproturon at 140 g a.i. ha^{-1}, T_4 = Isoproturon at 105 g a.i. ha^{-1}, T_5 = Isoproturon at 175 g a.i. ha^{-1} + Ad-500 at 400 mL ha^{-1}, T_6 = Isoproturon at 140 g a.i. ha^{-1} + Ad-500 at 400 mL ha^{-1}, T_7 = Isoproturon at 105 g a.i. ha^{-1} + Ad-500 at 400 mL ha^{-1}, T_8 = Isoproturon at 175 g a.i. ha^{-1} + Bio-enhancer at 400 mL ha^{-1}, T_9 = Isoproturon at 140 g a.i. ha^{-1} + Bio-enhancer at 400 mL ha^{-1}, T_{10} = Isoproturon at 105 g a.i. ha^{-1} + Bio-enhancer at 400 mL ha^{-1}.

Figure 3 - Effect of isoproturon with and without adjuvants on transpiration rate of *Melilotus indica* L. (A), *Anagallis arvensis* L. (B), *Phalaris minor* L.(C), *Fumaria indica* L.(D) at 3, 10 and 17 days after herbicide spray.



T_1 = Weedy check, T_2 = Isoproturon at 175 g a.i. ha^{-1}, T_3 = Isoproturon at 140 g a.i. ha^{-1}, T_4 = Isoproturon at 105 g a.i. ha^{-1}, T_5 = Isoproturon at 175 g a.i. ha^{-1} + Ad-500 at 400 mL ha^{-1}, T_6 = Isoproturon at 140 g a.i ha^{-1} + Ad-500 at 400 mL ha^{-1}, T_7 = Isoproturon at 105 g a.i. ha^{-1} + Ad-500 at 400 mL ha^{-1}, T_8 = Isoproturon at 175 g a.i. ha^{-1} + Bio-enhancer at 400 mL ha^{-1}, T_9 = Isoproturon at 140 g a.i. ha^{-1} + Bio-enhancer at 400 mL ha^{-1}, T_{10} = Isoproturon at 105 g a.i. ha^{-1} + Bio-enhancer at 400 mL ha^{-1}.

Figure 4 - Effect of isoproturon with and without adjuvants on stomatal conductance of *Melilotus indica* L. (A), *Anagallis arvensis* L. (B), *Phalaris minor* L.(C), *Fumaria indica* L.(D) at 3, 10 and 17 days after herbicide spray.

Figure 4 showed decreasing (isoproturon with and without adjuvants) and increasing (weedy check) trend of stomatal conductance after 3, 10 and 17 days of herbicidal treatments.

To increase the growth and yield of wheat, it is important to apply herbicides at optimum rate and right time while maintaining weed control at an acceptable level and also protecting crop from herbicide injury. Our results showed that wheat produced maximum number of productive tillers (m^{-2}) and minimum non-productive tillers where maximum weed control was achieved. This might be due to addition of adjuvants that increased efficacy of herbicides either at full or reduced dose as well as reduced competition of wheat plants with weeds for utilization of available resources at their maximum level. Tank mixture adjuvant provided better control of major weeds species than herbicide use alone or low dose with adjuvants that resulted in increased space and nutrients availability to crops which ultimately increased productive tillers and reduced non-productive tillers (Kierzek and Adamczewski, 2008). According to Khalil et al., (2010) carfentrazone-ethyl + isoproturon gave maximum number of spike bearing tillers (m^{-2}) than clodinafop propargyl + bromoxynil octanovate + heptanovate ester. Growth parameters such as plant height and biological yield were increased with herbicide application because of low competition between weeds and wheat plants for nutrients, light, space and water that enhance nutrient use efficiency of wheat plants. Presented results are in agreement with those of Naseer-ud-Din et al. (2011) who revealed that *F. indica*, *M. indica* and *Rumex dentatus* density significantly decreased by different herbicides compared with control. Bromoxynil + MCPA at 0.49 kg a.i. ha^{-1} as post emergence application was most effective in controlling *F. indica, M. indica* and *R. dentatus* with maximum mortality at 30 and 60 days after spray without being phytotoxic to wheat. Number of grains/spike, spike length, 1000-grains weight and grain yield was enhanced by application of isoproturon with and without adjuvants not only due to more availability of nutrients but also increased transportation of photosynthates, protein synthesis from source to sink. According to Rahman et al. (2000) spike length can be the reason for increasing number of grains/spike. Our results indicated that addition of Bio-enhancer to isoproturon increased the efficacy of isoproturon at full dose in terms of number of grains per spike when compared with addition of Ad-500 or without adjuvant. The higher number of grains per spike might be due to least competition of weeds and maximum production of photosynthates by wheat plant that shifted into the reproductive organs. Our findings are in accordance with Ashrafi (2009) who studied the effect of bromoxynil + MCPA, isoproturon and triasulfuron on yield and yield components of wheat in which it was concluded that herbicide application significantly increased the yield components of wheat when compared with weedy check. Our results are also in agreement to Woznica and Idziak (2010) who revealed that sequential application of herbicide mixtures with adjuvants enhanced maize grain and biological yield. According to Cheema et al. (2006) excellent weed control and maximum grain yield was recorded from Puma Super 75 EW at 1.25 L ha^{-1} + buctril super 60 EC at 750 mL ha^{-1} followed by isoproturon at 2 kg ha^{-1} having statistically at par grain yield. Usman and Khan (2009) also revealed that herbicides significantly improved harvest index over weedy check. In our study, gaseous exchange parameters of wheat including net photosynthesis, transpiration rate, and stomatal conductance increased in weedy check than all herbicide applications after 3, 10 and 17 days of herbicidal application. After weedy check, lower doses of isoproturon with both adjuvants (Bio-enhancer + Ad-500) at 400 mL ha^{-1} produced highest gaseous exchange parameters after 17 days of herbicide spray that might be due to the fact that all herbicide treatments not only affected weeds but also the wheat plants at earlier stage of spray however, lower doses of isoproturon imparted less impact on wheat. This might be due to stomotal closure at early stage of herbicide spray that reduced CO_2 uptake under herbicide application. Early reports revealed that herbicides has a direct impact on photosynthetic activity by disrupting all major components of photosynthesis including carbon reduction cycle, thylakoid electron transport, stomatal control of the CO_2 supply and cholorophyll activity (Naseer-ud-Din et al., 2011; Vandoorne et al., 2012; Shukla et al., 2015). Different post-emergence herbicides has been used to control weeds but it is documented that application of post-emergence herbicide with adjuvants was found to be more effective in controlling the weeds (Naseer-ud-Din et al., 2011). From findings of this study it could be concluded that weed plant height, number of weeds after 21 days, number of weeds at harvest and weeds biomass in terms of their fresh and dry weight was decreased significantly by all doses of herbicidal spray but application of herbicide with adjuvants reduced all above mentioned traits to greater extent. The more decrease in above traits with inclusion of adjuvants among all other treatments might be due to enhancement in efficiency of isoproturon with addition of adjuvants. According to Harbour et al. (2003), efficacy of herbicides such as bromoxynil, glyphosate and 2, 4-D with adjuvants (Allinol 810-60, MON 0818 and Oxysorbic 20) against kochia (*Bassia scoparia*) and Russian thistle (*Salsola tragus*) provided better control of weeds as compared to herbicide alone. In view of our findings, physiological parameters such as net photosynthesis rate, transpiration rate, and stomatal conductance of all four weeds were significantly reduced to a greater extent by all herbicidal spray measured after 3, 10 and 17 days of application in comparison with weedy check. However, among all herbicidal applications, isoproturon with adjuvants decreased the net photosynthesis, transpiration rate, and stomatal conductance in all four weeds (*M. indica, A. arvensis*, *P. minor*, and *F. indica*) after 17 days of herbicide application compared to others treatments. Significant reduction in above mentioned physiological parameters in all weeds was probably due to herbicide application with adjuvants that enhanced the effectiveness of herbicide and isoproturon which disturbed the activity of chlorophyll and photosystems I and II by binding to quinine binding protein D-1 in thalakoid membrane in plant and effect electron transport chain (Naseer-ud-Din et al., 2011). According to Shehzad et al. (2012), herbicide control weeds by inhibiting their photosynthesis, chlorophyll, lipid synthesis and seedling growth. Adding adjuvants allow the applicator to customize the tank formulation for each particular situation. In many situations, adding an adjuvant can significantly enhance herbicide's effect by affecting different biochemical processes of target plants (weeds) that cause reduction in gaseous parameters (Kudsk and Streibig, 1993; Green, 2001; Brecke and Stephenson, 2006).

In conclusion, isoproturon at 175 g a.i. ha^{-1} with both adjuvants (Ad-500 and Bio-enhancer) each at 400 mL ha^{-1} was more effective in reducing photosynthetic parameters of weeds than all other herbicide treatments and caused maximum reduction in photosynthetic parameters of weeds. Moreover, maximum wheat growth and yield as well as weed control was also achieved with this treatment.

REFERENCES

Adamczewski K, Matysiak R The effects and benefits of adjuvants used with sulfonyl urea herbicides. Prog Plant Prot. 2005;45:17-24.

Ahmad R, Shaikh AS. Common weeds of wheat and their control. Pak J Water Res. 2003;1:71-73.

Ashrafi Z. Study effects of planting methods and tank mixed herbiciedes on weeds controlling and wheat yield. J Agric Sci. 2009;1:101-111

Bernards ML, Penner D, Michael J, Zollinger R, Rhode A, Dean SW. Imazapyr absorption and translocation in northern red oak and red maple as affected by herbicide formulation and the adjuvant methylated seed oil. J ASTM Int. 2009;6(6):1-10.

Bibi S, Marwat KB, Hassan G, Khan NM. Effect of herbicides and wheat population on control of weeds in wheat. Pak J Weed Sci Res. 2008;14(3-4):111-20.

Brecke BJ, Stephenson DO. Weed control in cotton (*Gossypium hirsutum*) with post emergence applications of trifloxysulfuron-sodium. Weed Technol. 2006;20(2):377-83.

Cheema MS, Akhtar M, Iqbal MS. Performance of different herbicides in wheat under irrigated conditions of southern Punjab, Pakistan. Pak J Weed Sci Res. 2006;12:53-59.

Chhokar R, Singh S, Sharma R. Herbicides for control of isoproturon-resistant Littleseed Canarygrass (*Phalaris minor*) in wheat. Crop Prot. 2008;27(3-5):719-26.

Green JM, Cahill WR. Enhancing the biological activity of nicosulfuron with pH adjusters. Weed Technol. 2003;17(2):338-45.

Green JM. Herbicide adjuvants. Presented at the UC Davis. WRIC Weed Science School, September 26–28. Woodland: 2001.

Guarda G, Padovan S, Delogu G. Grain yield, nitrogen-use efficiency and baking quality of old and modern Italian bread-wheat cultivars grown at different nitrogen levels. Eur J Agron. 2004;21:181-92.

Gugaa M, Zarzecka K, Zadrozniak B. An effect of adjuvants on potato yielding and limiting weed infestation in potato stands. Biu Inst Hod Aklimat Ros. 2010;255:47-57.

Harbour JD, Messersmith CG, Ramsdale BK. Surfactants affect herbicides on kochia (*Kochia scoparia*) and russian thistle (*Salsolai berica*). Weed Sci. 2003;51:430-4.

Hess FD, Foy CL. Interaction of surfactants with plant cuticles. Weed Technol. 2000;14:807-13.

Kammler KJ, Walters SA, Young BG. Effects of adjuvants, halosulfuron, and grass herbicides on Cucurbita spp. Injury and grass control. Weed Technol. 2010;24:147-52.

Khalil MF, Hassan G, Hussain Z, Shah NH, Khan MM. Effect of individual and tank mixed herbicides on yield of wheat crop. Pak J Weed Sci Res. 2010;16:89-96.

Kieloch R, Domaradzki K. The abiotic factors affecting the effectiveness of herbicides. Fragmenta Agron. 2008;25:61-70.

Kierzek R, Adamczewski K. Activity of selected herbicide mixtures in maize. Progress Plant Prot. 2008;48:1146-9.

Kudsk P, Streibig JC. Formulation and adjuvants. In: Strigib JC, Kudsk P, editors. Herbicide Bioassays. Boca Raton: CRC Press; 1993. p.99-116.

Monaco TJ, Weller SJ, Ashton FM. Weed science: Principles and practices. 4th ed. New York: John Wiley and Sons; 2002.

Naseer-ud-Din GM, Shehzad MA, Nasarullah HM. Efficacy of various pre and post-emergence herbicides to control weeds in wheat. Pak J Agric Sci. 2011;48:185-90.

Rahman L, Sakuratoni E, Uddiu T. Ecological adoption of chickpea to water stress. Legume Res. 2000;23:145-200.

Rueda Ayala V, Rasmussen J, Gerhards R, Fournaise NE. The influence of post emergence weed harrowing on selectivity, crop recovery and crop yield in different growth stages of winter wheat. Weed Res. 2011;51(1):478-88.

Shehzad MA, Maqsood M, Anwar-ul-Haq M, Niaz A. Efficacy of various herbicides against weeds in wheat (*Triticum aestivum* L.). Afr J Biotechnol. 2012;11(4):791-9.

Shukla N, Awasthi RP, Rawat L, Kumar J. Seed biopriming with drought tolerant isolates of *Trichoderma harzianum* promote growth and drought tolerance in *Triticum aestivum*. Ann App Bio. 2015;166(2):171-182.

Singh S, Kirkwood RC, Marshall G. Effect of ABT on the activity and rate of degradation of isoproturon in susceptible and resistant biotypes of *Phalaris minor* and in wheat. Pestic Sci. 1998;53:123-132.

Singh R, Dhiman SEN, Rana NS, Kumar S. Efficacy of dicamba alone and in combination with isoproturon on wheat (*Triticum aestivum*) and associated weeds. Indian J Agron. 2006;51(2):139-41.

Steel RGD, Torrie JH, Dicky D. Principles and procedures of statistics. Multiple comparisons. 3rd ed. New York: McGraw Hill Book; 1997. p.178-98.

Usman K, Khan M. Economic evaluation of weed management through tillage, herbicides and hand weeding in irrigated wheat. Pak J Weed Sci Res. 2009;15:199-208.

Vandoorne B, Mathieu AS, van den Ende W, Vergauwen R, Périlleux C, Javaux M, et al. Water stress drastically reduces root growth and inulin yield in *Cichorium intybus* (var. sativum) independently of photosynthesis. J Exp Bot. 2012;63(12):4359-4373.

Woznica Z, Idziak R. Influence of herbicide application timings, rates and adjuvant type on weed control and yield of maize grown for forage. Acta Sci Polon Agric. 2010;9:77-84.