

**WEED GROWTH, HERBICIDE EFFICACY INDICES, CROP GROWTH AND YIELD OF WHEAT ARE MODIFIED BY HERBICIDE AND CULTIVAR INTERACTION**

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**ABSTRACT**

*Weeds pose serious threat to wheat productivity, and chemical means are usually employed to combat weed menace in field crops. A field study was undertaken at Agronomy Research Farm, University of Agriculture, Faisalabad, Pakistan during Rabi 2011-12 to appraise the efficacy of some broad-spectrum herbicides against weed growth, and their influence on growth and yield of wheat. Three commonly available broad-spectrum herbicides i.e. pyaxosulam, iodosulfuron + mesosulfuran-methyle and isoproturon + carfentrazone ethyl ester at 14.4, 14.4 and 1000 g a.i. ha<sup>-1</sup> were applied as early post-emergence application (30 DAS) in three cultivars viz., Sehar-2006, Lasani-2008 and AARI-2011. A tank mixture comprising of graminicide pinoxaden at 41.25 g a.i. ha<sup>-1</sup> and broadleaf weedicide bromoxynil at 225 g a.i. ha<sup>-1</sup> + MCPA at 225 g a.i. ha<sup>-1</sup> was also included. Weed free and weedy check (control) plots were included for comparison. The experiment was replicated thrice in a randomized complete block design following factorial arrangement. Net plot size was 7 × 2.25 m<sup>2</sup>. Data regarding weed growth, treatment efficacy, wheat growth and yield was recorded following standard procedures. Weed density was significantly affected by the interaction of wheat cultivars and herbicides; however, this interaction was non-significant for weed biomass at both 60 and 90 DAS. Differences among cultivars were pronounced even in weedy check and wheat cultivar Sehar-2006 experienced less weed infestation in terms of density and biomass. Application of isoproturon + carfentrazone ethyl ester produced over 90% suppression in weed density and biomass along with minimum weed and weed persistence indices and maximum herbicide efficiency. Significant improvements in wheat growth and grain yield were realized by various weed control treatments. Among herbicides, isoproturon + carfentrazone ethyl ester proved*

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to the best as it attained highest grain yield ( $4.72 \text{ t ha}^{-1}$ ) of cultivar Sehar-2006.

**Key words:** Efficiency indices, grain yield, herbicides, weed density and biomass, wheat growth attribute.

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## INTRODUCTION

Wheat (*Triticum aestivum* L.) is a principal cereal crop of Pakistan and country's food security largely depends on its efficient production and utilization. Wheat is the main preceding crop after rice and cotton in wheat based cropping systems. During 2011-12, it was cultivated on an area of 8.65 million ha, which produced 23.5 million tons of wheat with a national average yield of  $2713 \text{ kg ha}^{-1}$  (Anonymous, 2013). Despite availability of superior wheat genotypes, average national wheat yield is still stagnant. A number of biotic and abiotic factors pose threat to higher wheat productivity under field conditions. Among these, weeds are the serious biological constraint. Weeds compete with wheat for growth resources, and can inflict huge loss of quantity and quality of final produce (Khaliq *et al.*, 2011). Weed infestation can reduce wheat grain yield by 48-52% (Khan and Haq, 2002). Nevertheless, magnitude of weed related yield loss may vary from place to place due to variable weed flora, climatic and edaphic conditions, and crop management practices. There is ever-growing consensus that genotypic variation responsible for weed tolerance can be exploited as an integral component of integrated weed management program (Mahajan *et al.*, 2013). Competitive ability of any crop cultivar can be judged by its ability to prosper and thrive under weedy conditions (Mahajan and Chauhan, 2011). As a rule of thumb, weed density and biomass will be less in a weed competitive crop cultivar (Mahajan *et al.*, 2004). A cultivar that is competitive against weeds can have definite yield advantage over less competitive cultivars especially under weedy conditions. The degree of competition offered by a crop cultivar can also influence the level of weed control that can be achieved with herbicides (Lemerle *et al.*, 1996). Morphophysiological differences among crop cultivars might account for this variation. Recently, Mahajan and Chauhan (2013) emphasized on the significance of crop cultivars in managing recalcitrant weed flora. In recent past, a number of high yielding wheat cultivars have been released. With data available regarding their yield potential and yield

contributing traits, information regarding their weed competitive ability is entirely lacking. Thus newly evolved wheat cultivars require field assessment of their weed competitive ability as an important area of research.

Mostly cultural, mechanical and chemical methods are used to control weeds in wheat fields, with each method having its own pros and cons. Over years, advent of new herbicide molecules has revolutionized crop production and contemporary agriculture relies primarily on synthetic herbicides to combat weed menace. Despite the criticism received from various scientific communities, herbicides are still most efficient, quick and cost-effective means of securing crop yields against weeds. A number of herbicides with contrasting mode of action, target flora and spectrum of activity are available locally to wheat growers (Ashiq *et al.*, 2003). Weed communities are floristically diverse in irrigated wheat fields and usually comprise of both grassy and broadleaf weeds. Hence, the use of herbicide that can simultaneously tackle both types of weeds seems obligate. It is hypothesized that different wheat cultivars may experience variable weed infestation levels under field condition and can alter herbicide efficacy. Keeping in view the significance of weeds as a yield limiting factor in wheat production, a study was planned to appraise efficacy of some broad-spectrum herbicides against weed flora and their influence on growth and yield of some newly released wheat cultivars.

## **MATERIALS AND METHODS**

### **Site description**

The proposed study was undertaken at Agronomy Research Farm, University of Agriculture, Faisalabad, Pakistan. The soil belongs to Lyallpur soil series (Aridisol-fine-silty, mixed, hyperthermic Ustalfic, Haplargid in USDA classification and Haplic Yermosols in FAO classification). Due to high evapotranspiration, Faisalabad features a semi-arid climate with mean annual rainfall of about 200 mm. The soil of the experimental site was a sandy clay loam with proportion of sand, silt and clay as 53.25, 20.55 and 26.20%. Soil pH and EC was 7.6 and 0.85 dSm<sup>-1</sup>, respectively. The organic matter, total nitrogen, available phosphorus and potassium were 0.66%, 0.06%, 14 mg kg<sup>-1</sup> and 185 mg kg<sup>-1</sup>, respectively. The Bulk density and cation exchange capacity was 1.40 g cm<sup>-3</sup> and 4.1 cmol<sub>c</sub> kg<sup>-1</sup>.

### **Experimentation**

Seed of wheat cultivars, i.e, Sehar-2006, Lasani-2008 and AARI-2011 was obtained from Wheat Research Institute, Ayub Agriculture Research Institute, Faisalabad. Seed was surface sterilized with fungicide prior to sowing. For all treatments, healthy and graded seed was used. A field vacated after rice crop was selected where

previous history showed heavy weed infestation. A seedbed of fine tilth was prepared by cultivating the soil thrice with a tractor mounted plough followed by planking each time. The wheat crop was sown on December 10<sup>th</sup>, 2011 with the help of a single row hand drill in 22.5 cm spaced crop rows using a seed rate of 125 kg ha<sup>-1</sup>. A fertilizer dose of 120: 65: 45 kg ha<sup>-1</sup> (N: P: K) in the form of urea (46% N), diammonium phosphate (46% P<sub>2</sub>O<sub>5</sub> and 18% N) and sulfate of potash (50% K<sub>2</sub>O) was used. All the potassium and phosphatic fertilizer and one-third of the nitrogen was applied as basal dose at the time of sowing. The remaining nitrogen was top dressed in two equal splits at tillering and booting, respectively. All other practices except those under study were kept uniform for all treatments.

The experiment was laid out in a randomized complete block design with factorial arrangement having three replications. Net plot size was 7 × 2.25 m<sup>2</sup>. The experiment comprised of three wheat cultivars viz., Sehar-2006, Lasani-2008 and AARI-2011, and five herbicides. i.e, Pallas 450D (pyaxosulam) @ 14.4 g a.i. ha<sup>-1</sup>, Atlantis 3.6WG (iodosulfuron + mesosulfuran-methyl) @ 14.4 g a.i. ha<sup>-1</sup>, Affinity 50WP (isoproturon + carfentrazone ethyl ester) @ 1000 g a.i. ha<sup>-1</sup>, and a herbicide tank mixture containing Axial 0.5EC (pinoxaden) @ 41.25 g a.i. ha<sup>-1</sup> and Buctril Super 60EC (bromoxynil+ MCPA) @ 225 g a.i. ha<sup>-1</sup>. For each wheat cultivar, weedy check and weed free plots were maintained as control and positive control, respectively. Herbicides were applied to their respective plots on a fog free, sunny day as per treatment plan on 30 days after sowing (DAS) after first irrigation. A Knapsack sprayer fitted with a flat fan nozzle at a spray pressure of 230 KPa was used for herbicide application. Before spraying, volume of spray solution (330 L ha<sup>-1</sup>) was calibrated using water. To prevent herbicide drift to adjacent plots and avoid masking of treatment effect, plastic sheet cover was used as barrier while spraying. Field plots were separated from each other by 0.5 m wide field bunds. Irrigation was applied at tillering, jointing, booting, anthesis and grain filling stages.

### **Observations and data analyses**

Data regarding weed density were taken at 60 and 90 DAS from two randomly placed quadrats (50 × 50 cm<sup>2</sup>) from each plot. Weeds were clipped off above the soil surface and individual weed counts were made. Those were sun dried for several days and then placed in an oven at 70°C for 72 h. Weeds were then weighed to record dry biomass on a digital electronic balance (TX-323L, Shimadzu, Japan). From this data, total weed density and biomass were computed and are expressed as m<sup>-2</sup> and g m<sup>-2</sup> basis, respectively. Data on weed count and dry weights were used to compute different

efficiency indices using the formulae of Misra and Misra (1997) as under;

**Weed index (WI)**

$$WI = \frac{X - Y}{X} \times 100$$

where X and Y are the yields of weed free and herbicide-treated plots, respectively.

**Weed persistence index (WPI)**

$$WPI = \frac{\text{Dry matter of weeds in treated plots}}{\text{Dry matter of weeds in control}} \times \frac{\text{Weed count in control}}{\text{Weed count in treated plots}}$$

**Herbicide efficiency index (HEI)**

$$HEI = \frac{YT}{YC} \times 100 \quad / \quad \frac{DMT}{DMC} \times 100$$

where YT and YC were yields of treated and control plots respectively, while DMT and DMC are weed dry matter in treatment and control, respectively.

A 0.5 m long crop strip was harvested with fortnight interval leaving appropriate borders and dissected into respective plant fraction (stem, leaves, spike etc.). Each plant fraction was weighed separately. A 2 g sub sample was used to record leaf area (Model Licor-3100). Harvested crop material was oven dried as in case of weeds and dry matter accumulated at each successive interval was recorded. Different growth attributes were then computed using the formulae of Watson (1947) and Hunt (1978). At physiological maturity, crop was manually harvested on May 5<sup>th</sup>, 2012 from an area of 4 × 0.9 m<sup>2</sup>. Harvested crop was tied into bundles and allowed to sun-dry for a week. Produce of each crop was threshed on a small-scale thresher built for research purpose. After threshing, grain yield was recorded for each plot and is expressed as t ha<sup>-1</sup>. The data on weed density, dry biomass and crop yield was statistically analyzed following Fisher's analysis of variance technique. Differences among treatment means were chalked out using LSD test at 5% probability level. Graphical representation of the data and regression analyses were carried out using MS-Excel.

## RESULTS AND DISCUSSION

### Weed growth

Weed flora of the experimental site comprised of wild oat (*Avena fatua* L.), canary grass (*Phalaris minor* Retz.), swine cress (*Coronopus didymus* L. Sm.), broadleaf dock (*Rumex dentatus* L.), field bind weed (*Convolvulus arvensis* L.) and blue pimpernel

(*Anagallis arvensis* L.). Interactive ( $p \leq 0.05$ ) effect of various herbicide treatments with wheat cultivars was significant regarding weed density. Differences in weed density owing to wheat cultivars were more pronounced in control (weedy check) plots than herbicide treated plots. In control, wheat cultivar AARI-2011 experienced maximum weed density (107.67 and 130.17  $m^{-2}$ ), whereas minimum (72.67 and 92.67  $m^{-2}$ ) was recorded for Sehar-2006 at 60 DAS and 90 DAS, respectively. Among herbicide treatments, isoproturon+carfentrazone ethyl ester @ 1000 g a.i.  $ha^{-1}$  produced minimum weed density in all wheat cultivars at both 60 and 90 DAS [Fig. 1 (a,b)]. This treatment remained statistically at par ( $p \leq 0.05$ ) with tank mixture of pinoxaden @ 41.25 g a.i.  $ha^{-1}$  and bromoxynil+MCPA @ 225 g a.i.  $ha^{-1}$  at 60 DAS regarding weed density. Influence of various herbicide treatments [Fig. 2 (a,b)] and wheat cultivars (Fig. 3) was significant ( $p \leq 0.05$ ) regarding weed biomass while their interactive effect was non-significant. Maximum suppression (93%) in weed biomass at both 60 and 90 DAS was recorded with isoproturon+carfentrazone ethyl ester @ 1000 g a.i.  $ha^{-1}$ . Tank mixture of pinoxaden @ 41.25 g a.i.  $ha^{-1}$  and bromoxynil+MCPA @ 225 g a.i.  $ha^{-1}$  could be ranked at second position regarding weed biomass suppression magnitude (85 and 86%) at 60 DAS and 90 DAS, respectively [Fig. 2 (a,b)]. Influence of wheat cultivars on weed biomass was non-significant at 60 DAS, nonetheless at 90 DAS wheat cultivar Sehar-2006 showed 16 and 14% less weed biomass than Lasani-2008 and AARI-2011 (Fig. 3).

The reduction in weed density and dry biomass over control under herbicide treated plots is due to their phytotoxic effect. The results pertaining to weed density reduction were evenly reflected in the form of weed biomass suppression. Minimum weed density and biomass in isoproturon+carfentrazone ethyl ester plots are presumably due to control of both grassy and broadleaf weeds especially at the early growth stages. A narrow spectrum activity especially against grassy weeds (data not shown) rendered pyroxsulam less effective than rest of the herbicide treatments. Variation among wheat cultivars for weed density might be due to morpho-physiological divergence that accounted for variable weed competitiveness and hence weed infestation levels in control plots. The reduction in weed density and biomass in wheat crop under the influence of efficient herbicide treatments is in line with the findings of Zand *et al.* (2010) and Das and Yaduraju (2012).

### **Weed and herbicide efficiency indices**

Weed index is an ideal parameter to describe yield loss caused by weed infestation in comparison with weed free plots (Suria *et al.*, 2011). It reflects the effectiveness of applied herbicide in securing yield loss against weed competition and a lower value of weed index

means high herbicide efficiency. Regarding weed index, main effect of weed control treatments and wheat cultivars was significant ( $p \leq 0.05$ ) while their interactive effect was non-significant ( $p \leq 0.05$ ) [Figure 4 (a,b)]. Application of isoproturon+carfentrazone ethyl ester @ 1000 g a.i. ha<sup>-1</sup> recorded lowest weed index than rest of the herbicide treatments. AARI-2011 despite of its less weed competitive ability and heavy weed infestation, showed lower weed index presumably due to lower grain yield in weed free treatment. Weed persistence and herbicide efficiency indices express the tolerance of weeds to different herbicide treatments as well as their efficiency to eradicate the weeds. A lower WPI and higher HEI value is required for efficient weed management. Interactive effect of herbicides with wheat cultivars was significant for WPI (Fig. 5). Iodosulfuron+mesosulfuron methyl @ 14.4 g a.i. ha<sup>-1</sup> application to plots sown with wheat cultivars Lasani-2008 recorded lowest WPI and was statistically similar to that achieved with isoproturon+carfentrazone ethyl ester and tank mixture of pinoxaden with bromoxynil+MCPA in same wheat cultivar. Application of various herbicides to AARI-2011 resulted in relatively higher WPI than rest of the wheat cultivars. Regarding HEI, only the effect of herbicide treatment was significant and isoproturon+carfentrazone ethyl ester @ 1000 g a.i. ha<sup>-1</sup> produced significantly higher HEI than rest of the herbicides (Fig. 6). These results corroborate the findings of Khaliq *et al.* (2011) who documented the lower WPI and higher HEI efficiency indices due to herbicide application in wheat.

### **Crop growth**

Different weed control treatments depicted a positive influence on wheat growth and development. Leaf area index (LAI) showed periodic increase and reached its maximum value at 75 DAS and dropped thereafter. Maximum value of LAI (7.87) was recorded for weed free treatment as against lower observed for control treatment. Application of isoproturon+carfentrazone ethyl ester @ 1000 g a.i. ha<sup>-1</sup> was the second effective treatment in this regard. Nevertheless, rest of the herbicides behaved statistically alike regarding LAI (Fig. 7). Crop growth rate was maximum between 75-90 days and showed a sharp decline afterwards. Maximum crop growth rate (20.94 g m<sup>-2</sup> day<sup>-1</sup>) was realized for weed free treatment while lowest (14.61 g m<sup>-2</sup> day<sup>-1</sup>) was recorded for control (Fig. 8a). Among herbicide treatments, higher crop growth rate (19.50 g m<sup>-2</sup> day<sup>-1</sup>) was achieved by the application of isoproturon+carfentrazone ethyl ester @ 1000 g a.i. ha<sup>-1</sup>. It was closely followed (18.52 g m<sup>-2</sup> day<sup>-1</sup>) by tank mixture of pinoxaden with bromoxynil+MCPA. Wheat cultivar Sehar-2006 and Lasani-2008 exhibited maximum (19.08 g m<sup>-2</sup> day<sup>-1</sup>) and minimum (17.34 g m<sup>-2</sup> day<sup>-1</sup>) crop growth rates, respectively (Fig. 8b). Leaf area duration (LAD) showed temporal increase and weed free treatment

accumulated more (275.05 days) LAD than rest of the treatments owing to its more LAI (Fig. 9). Isoproturon+carfentrazone ethyl ester was equally effective (271.55 days) in promoting LAD. Rest of the herbicide treatments reflected lower LAD.

Wheat crop kept free of weeds showed maximum dry matter accumulation ( $924.55 \text{ g m}^{-2}$ ) (Fig. 10a). It was followed by treatment receiving application of isoproturon+carfentrazone ethyl ester ( $841.71 \text{ g m}^{-2}$ ) and tank mixture of pinoxaden with bromoxynil+MCPA ( $751.20 \text{ g m}^{-2}$ ), respectively. Wheat cultivar Sehar-2006 accumulated more dry matter than Lasani-2008 and AARI-2011 (Fig. 10b). Improvements in various growth attributes of the wheat crop over control under the influence of weed control treatments suggest their effectiveness in lessening weed-crop competition, and hence resulting in better crop growth. Higher LAI particularly early in the growing season resulted from different herbicide treatments might have led to higher dry matter accumulation on account of higher radiation interception over a prolonged period of time as evident by higher LAD. Better resource acquisition and utilization might have contributed to prompt growth and more dry matter accumulation by wheat plants.

### **Wheat grain yield**

Grain yield response of wheat cultivars to various weed control treatments varied due to the significant interaction between these two factors (Fig. 11). Cultivar differences were pronounced even in weedy check where Sehar-2006 recorded significantly higher (18 and 18.5%) grain yield than Lasani-2008 and AARI-2011, respectively. Same was true for the weed free plots. All the weed control treatments gained significant yield improvements over control. Application of isoproturon+carfentrazone ethyl ester @  $1000 \text{ g a.i. ha}^{-1}$  to plots sown with wheat cultivar Sehar-2006 produced maximum grain yield ( $4.72 \text{ t ha}^{-1}$ ) that was 24.86% and 9.77% higher in Lasani-2008 and AARI-2011 in response to same herbicide treatment. Generally, yield advantages realized with various herbicides were greater for Sehar-2006 and lower for Lasani-2008 (Fig. 11).

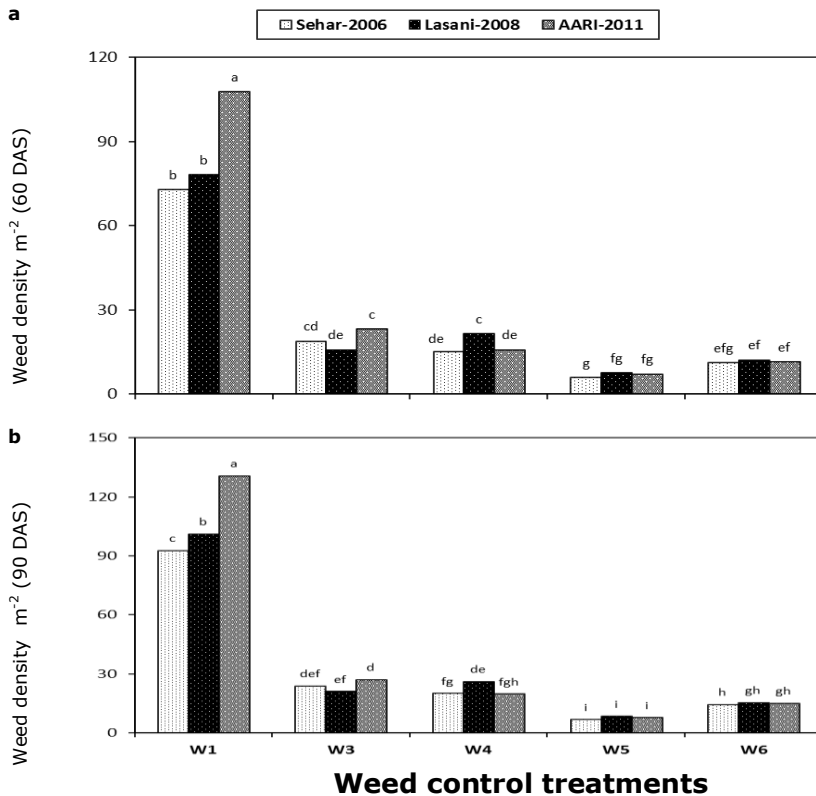
Regression analyses revealed that wheat grain yield of all the three cultivars was negatively associated with weed density and biomass and over 80% variation in wheat grain yield of Sehar-2006 and Lasani-2008 cultivars was due to weed density and biomass. However, approximately 90% variation was explained by weed density and biomass for AARI-2011 (Fig. 12). Higher grain yield in herbicide treated plots may be an outcome of efficient weed control achieved there. These results are in conformation with those of Baghestani *et al.* (2008), Chhokar *et al.* (2008) and Santos (2009) who reported that herbicides offer sizeable increase in crop productivity corresponding to their weed control spectrum. Negative correlation of wheat yield with



weed density and biomass reflects negative implications of weed competition on final yield. Khaliq *et al.* (2011) also reported that wheat yields were negatively correlated with weed growth.

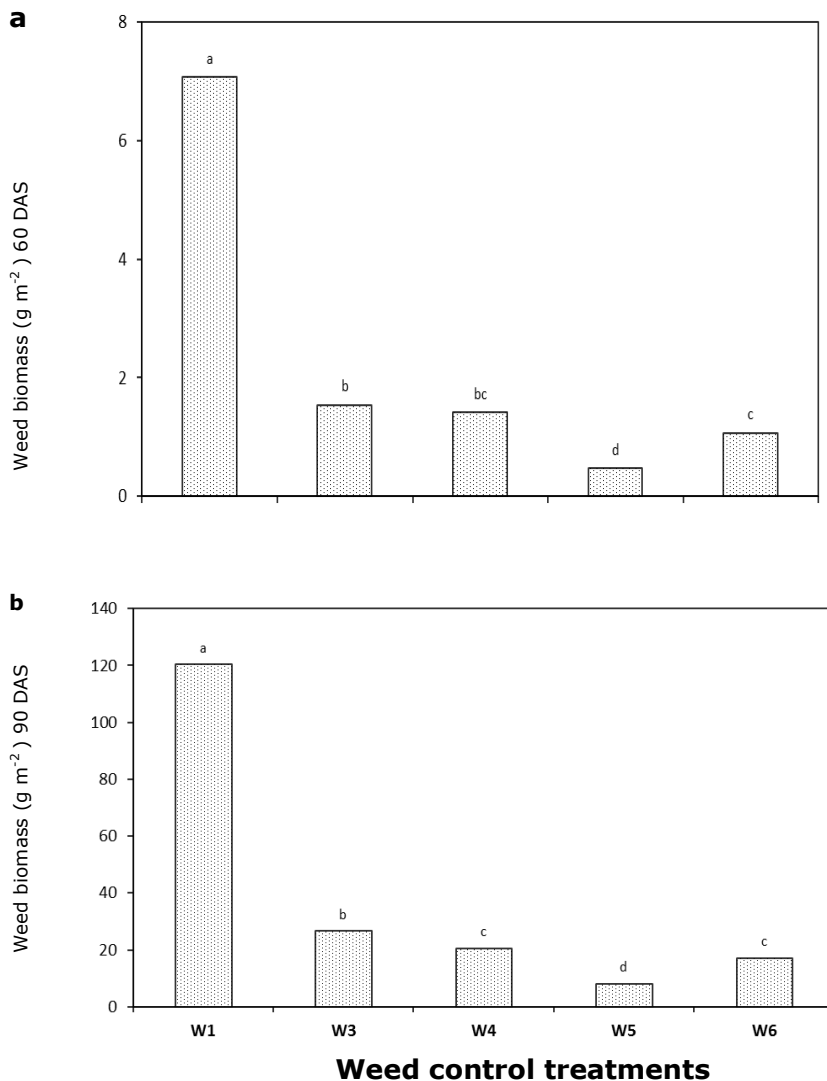
**CONCLUSION**

The present study concluded that post-emergence application of isoproturon+carfentrazone ethyl ester @ 1000 g a.i. ha<sup>-1</sup> was an effective weed control tactic in irrigated wheat. Sehar-2006 was better than rest of the wheat cultivars regarding its weed competitive ability and final yield. It is therefore suggested that isoproturon+carfentrazone ethyl ester application to wheat cultivar Sehar-2006 can tackle recalcitrant weed flora much efficiently, thus securing wheat yields against weed infestation.



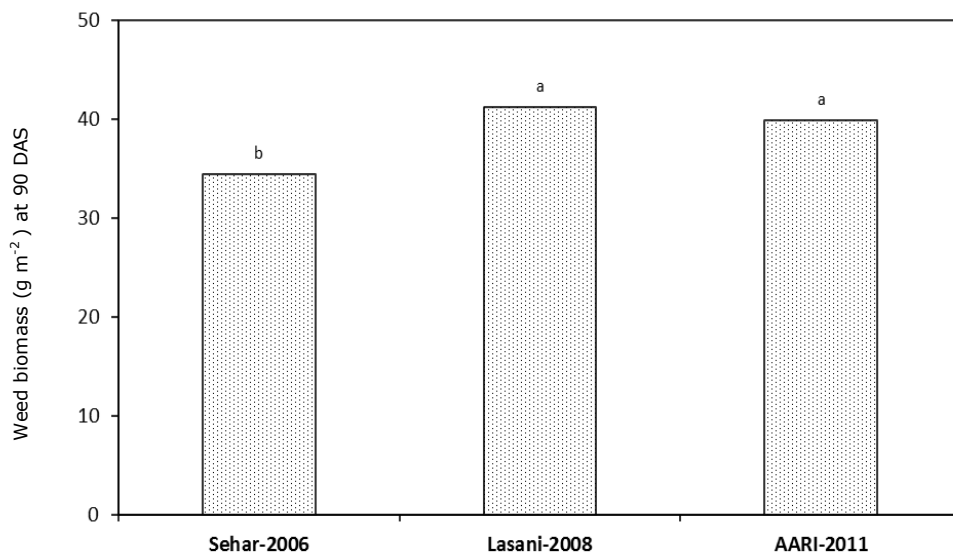
**Figure 1.** Influence of different weed control treatments on total weed density (m<sup>-2</sup>) at (a) 60 DAS and (b) 90 DAS in three wheat cultivars. W<sub>1</sub>: Control (weedy check), W<sub>3</sub>: Pyaxosulam at 14.4 g a.i. ha<sup>-1</sup>, W<sub>4</sub>: Iodosulfuron + mesosulfuron-methyl at 14.4 g a.i. ha<sup>-1</sup>, W<sub>5</sub>: Isoproturon + carfentrazone ethyl ester at 1000 g a.i. ha<sup>-1</sup>, W<sub>6</sub>:

Pinoxaden at 41.25 g a.i. ha<sup>-1</sup> + Bromoxynil at 225 g a.i. ha<sup>-1</sup> + MCPA at 225 g a.i. ha<sup>-1</sup>. Means with different letters differ significantly at 5% probability level by LSD test. Critical value for comparison for interaction is (a) 9.647 and (b) 10.030.



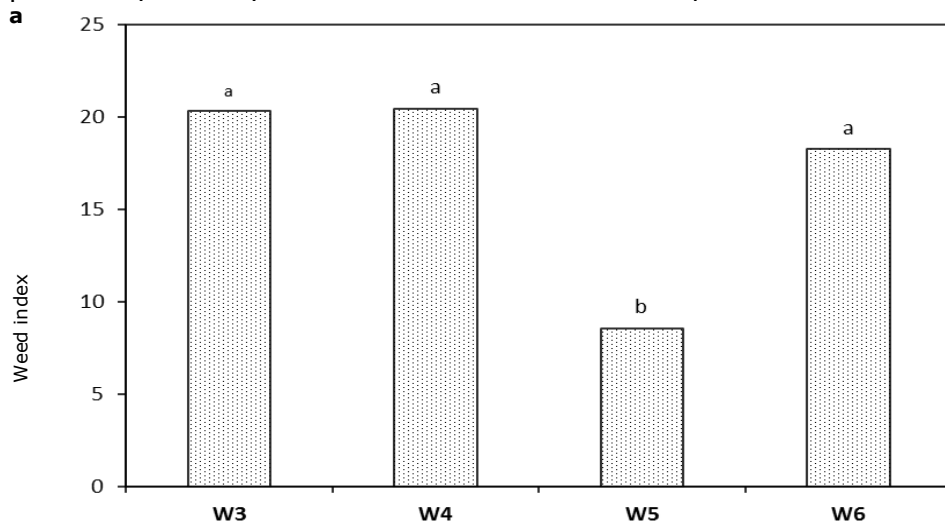
**Figure 2.** Influence of different weed control treatments on total weed biomass (g m<sup>-2</sup>) at (a) 60 DAS and (b) 90 DAS in three wheat cultivars. W<sub>1</sub>: Control, W<sub>3</sub>: Pyaxosulam at 14.4 g a.i. ha<sup>-1</sup>, W<sub>4</sub>: Iodosulfuron + mesosulfuron-methyl at 14.4 g a.i. ha<sup>-1</sup>, W<sub>5</sub>: Isoproturon + carfentrazone ethyl ester at 1000 g a.i. ha<sup>-1</sup>, W<sub>6</sub>: Pinoxaden at 41.25 g a.i. ha<sup>-1</sup> + Bromoxynil at 225 g a.i. ha<sup>-1</sup> + MCPA

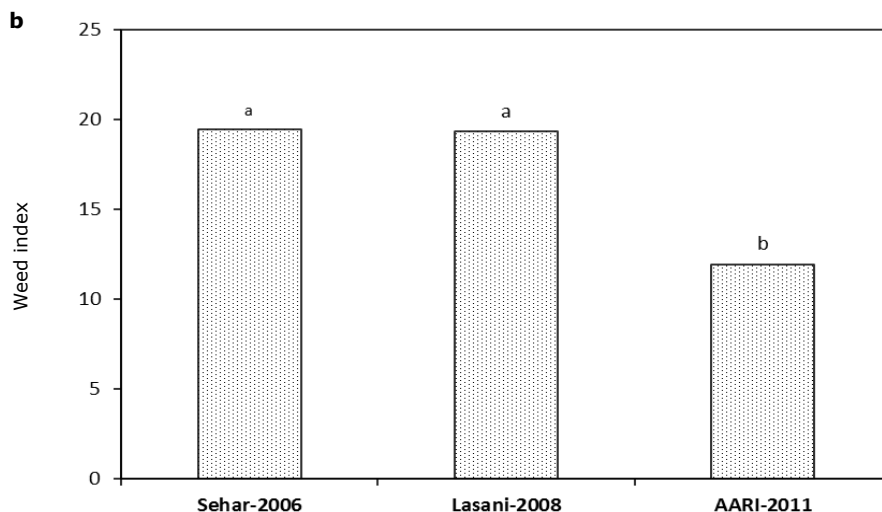
at 225 g a.i. ha<sup>-1</sup>. Means with different letters differ significantly at 5% probability level by LSD test. Critical value for comparison for weed control treatments is (a) 0.399 and (b) 6.044.



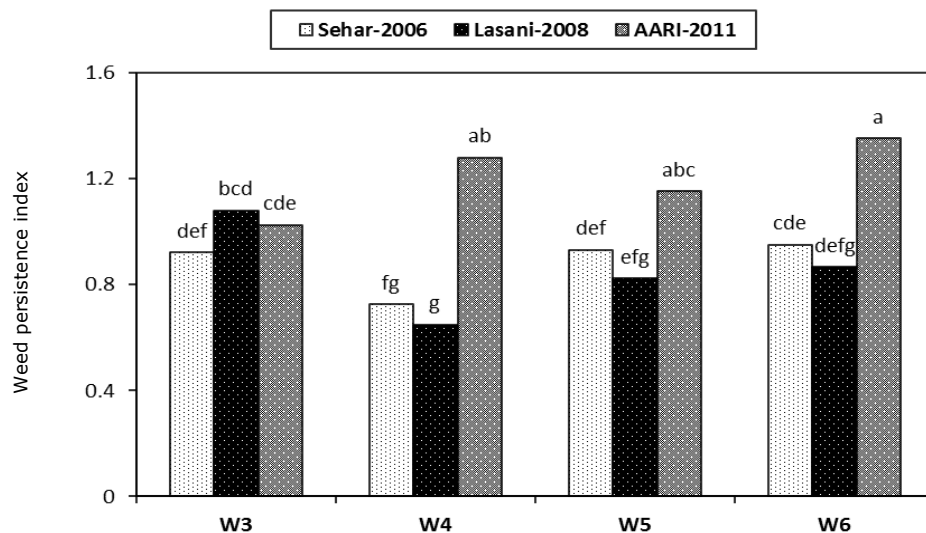
**Wheat cultivars**

**Figure 3.** Influence of wheat cultivars on total weed biomass (g m<sup>-2</sup>) at 90 DAS. Means with different letters differ significantly at 5% probability level by LSD test. Critical value for comparison is 4.682.



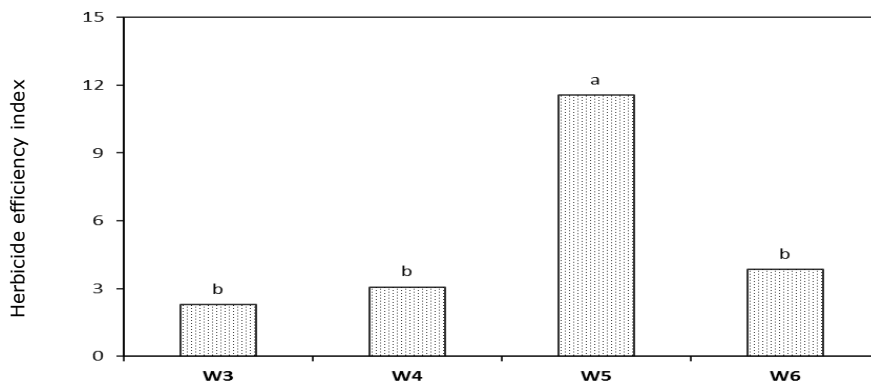


**Figure 4.** Influence of different (a) weed control treatments and (b) wheat cultivars on weed index. W<sub>3</sub>: Pyaxosulam at 14.4 g a.i. ha<sup>-1</sup>, W<sub>4</sub>: Iodosulfuron + mesosulfuron-methyl at 14.4 g a.i. ha<sup>-1</sup>, W<sub>5</sub>: Isoproturon + carfentrazone ethyl ester at 1000 g a.i. ha<sup>-1</sup>, W<sub>6</sub>: Pinoxaden at 41.25 g a.i. ha<sup>-1</sup> + Bromoxynil at 225 g a.i. ha<sup>-1</sup> + MCPA at 225 g a.i. ha<sup>-1</sup>. Means with different letters differ significantly at 5% probability level by LSD test. Critical value for comparison for weed control treatments and wheat cultivars is (a) 3.552 and (b) 3.077.

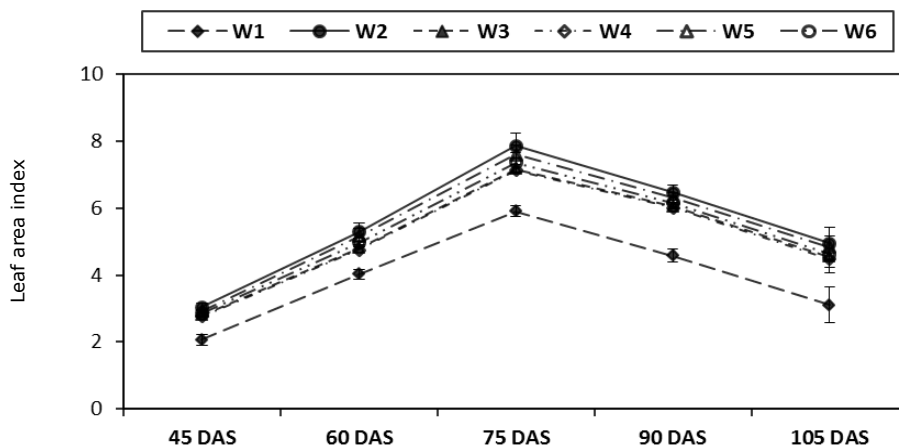


**Figure 5.** Influence of different weed control treatments on weed persistent index in three wheat cultivars. W<sub>3</sub>: Pyaxosulam at 14.4 g a.i.

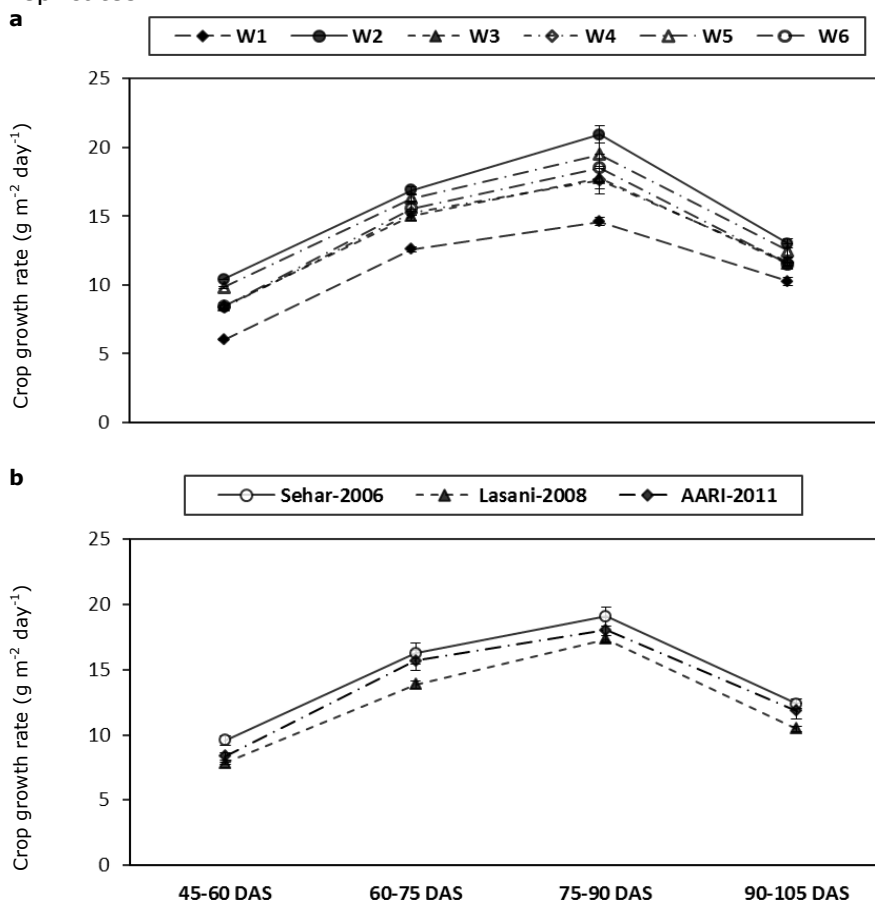
ha<sup>-1</sup>, W<sub>4</sub>: Iodosulfuron + mesosulfuron-methyl at 14.4 g a.i. ha<sup>-1</sup>, W<sub>5</sub>: Isoproturon + carfentrazone ethyl ester at 1000 g a.i. ha<sup>-1</sup>, W<sub>6</sub>: Pinoxaden at 41.25 g a.i. ha<sup>-1</sup> + Bromoxynil at 225 g a.i. ha<sup>-1</sup> + MCPA at 225 g a.i. ha<sup>-1</sup>. Means with different letters differ significantly at 5% probability level by LSD test. Critical value for comparison for interaction is 0.225.



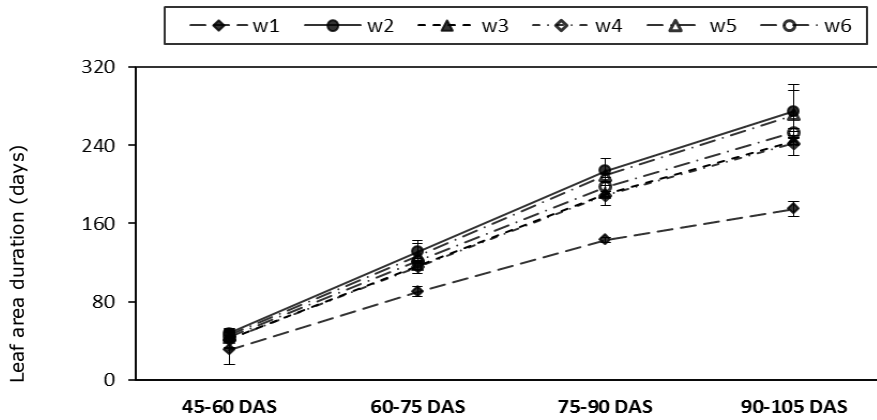
**Figure 6.** Influence of different weed control treatments on herbicide efficiency index in wheat. W<sub>3</sub>: Pyaxosulam at 14.4 g a.i. ha<sup>-1</sup>, W<sub>4</sub>: Iodosulfuron + mesosulfuron-methyl at 14.4 g a.i. ha<sup>-1</sup>, W<sub>5</sub>: Isoproturon + carfentrazone ethyl ester at 1000 g a.i. ha<sup>-1</sup>, W<sub>6</sub>: Pinoxaden at 41.25 g a.i. ha<sup>-1</sup> + Bromoxynil at 225 g a.i. ha<sup>-1</sup> + MCPA at 225 g a.i. ha<sup>-1</sup>. Means with different letters differ significantly at 5% probability level by LSD test. Critical value for comparison for weed control treatments is 1.739.



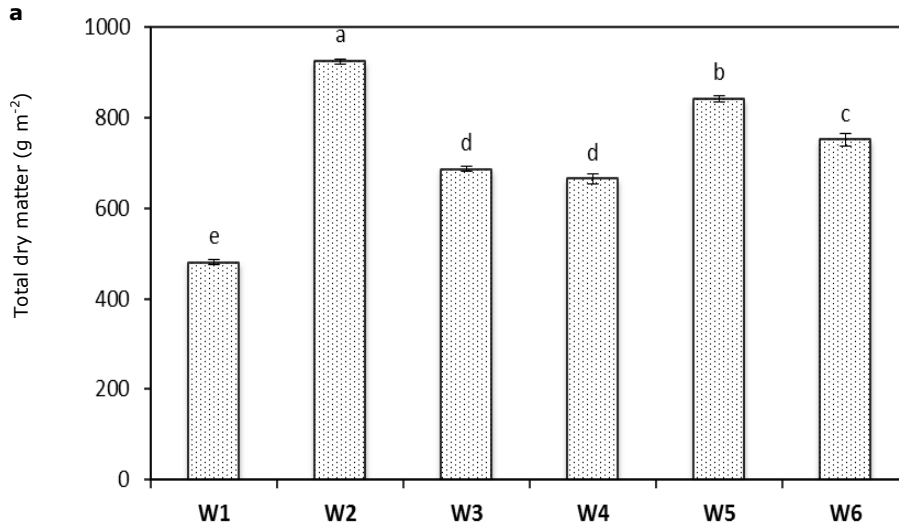
**Figure 7.** Influence of different weed control treatments on leaf area index. W<sub>1</sub>: Control, W<sub>2</sub>: Weed free, W<sub>3</sub>: Pyaxosulam at 14.4 g a.i. ha<sup>-1</sup>, W<sub>4</sub>: Iodosulfuron + mesosulfuron-methyl at 14.4 g a.i. ha<sup>-1</sup>, W<sub>5</sub>: Isoproturon + carfentrazone ethyl ester at 1000 g a.i. ha<sup>-1</sup>, W<sub>6</sub>: Pinoxaden at 41.25 g a.i. ha<sup>-1</sup> + Bromoxynil at 225 g a.i. ha<sup>-1</sup> + MCPA at 225 g a.i. ha<sup>-1</sup>. Vertical bars above means denote  $\pm$ S.E of three replicates.

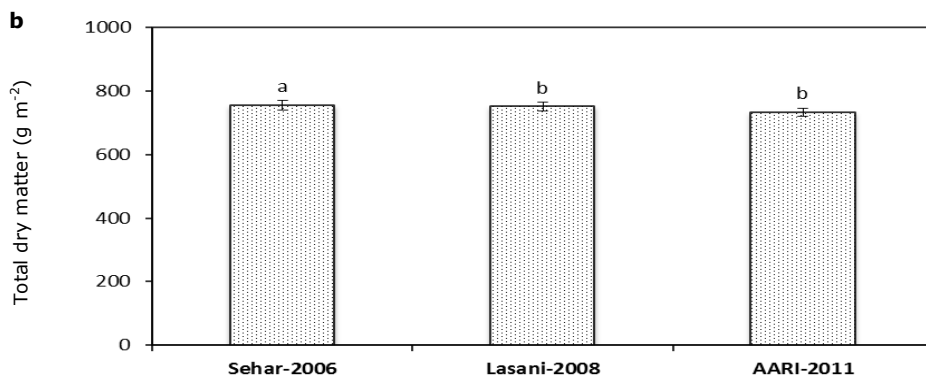


**Figure 8.** Influence of different (a) weed control treatments and (b) wheat cultivars on crop growth rate (g m<sup>-2</sup> day<sup>-1</sup>). W<sub>1</sub>: Control, W<sub>2</sub>: Weed free, W<sub>3</sub>: Pyaxosulam at 14.4 g a.i. ha<sup>-1</sup>, W<sub>4</sub>: Iodosulfuron + mesosulfuron-methyl at 14.4 g a.i. ha<sup>-1</sup>, W<sub>5</sub>: Isoproturon + carfentrazone ethyl ester at 1000 g a.i. ha<sup>-1</sup>, W<sub>6</sub>: Pinoxaden at 41.25 g a.i. ha<sup>-1</sup> + Bromoxynil at 225 g a.i. ha<sup>-1</sup> + MCPA at 225 g a.i. ha<sup>-1</sup>. Vertical bars above mean denote  $\pm$ S.E of three replicates.

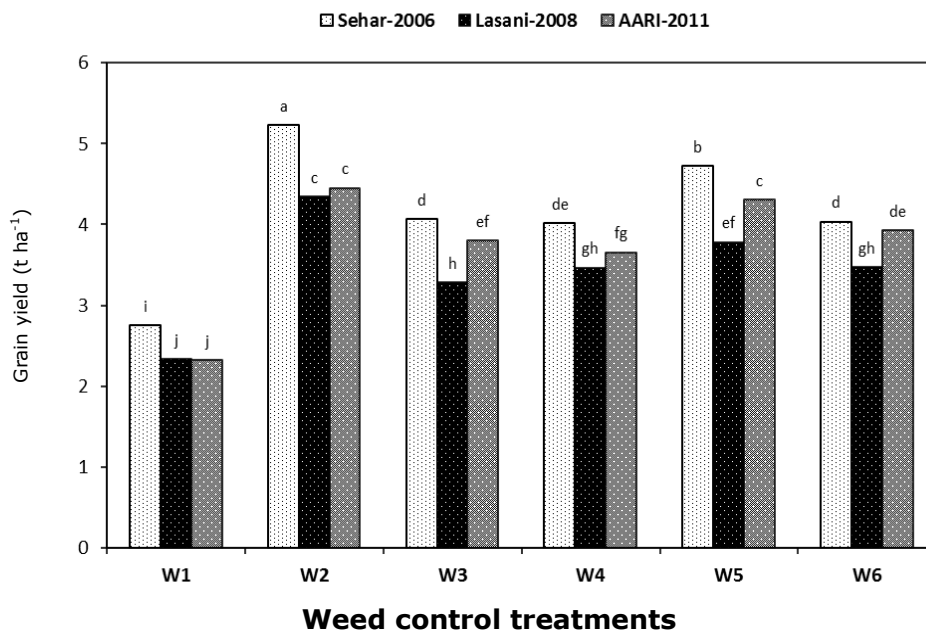


**Figure 9.** Influence of different weed control treatments on leaf area duration. W<sub>1</sub>: Control, W<sub>2</sub>: Weed free, W<sub>3</sub>: Pyaxosulam at 14.4 g a.i. ha<sup>-1</sup>, W<sub>4</sub>: Iodosulfuron + mesosulfuron-methyl at 14.4 g a.i. ha<sup>-1</sup>, W<sub>5</sub>: Isoproturon + carfentrazone ethyl ester at 1000 g a.i. ha<sup>-1</sup>, W<sub>6</sub>: Pinoxaden at 41.25 g a.i. ha<sup>-1</sup> + Bromoxynil at 225 g a.i. ha<sup>-1</sup> + MCPA at 225 g a.i. ha<sup>-1</sup>. Vertical bars e mean denote ±S.E of three replicates.



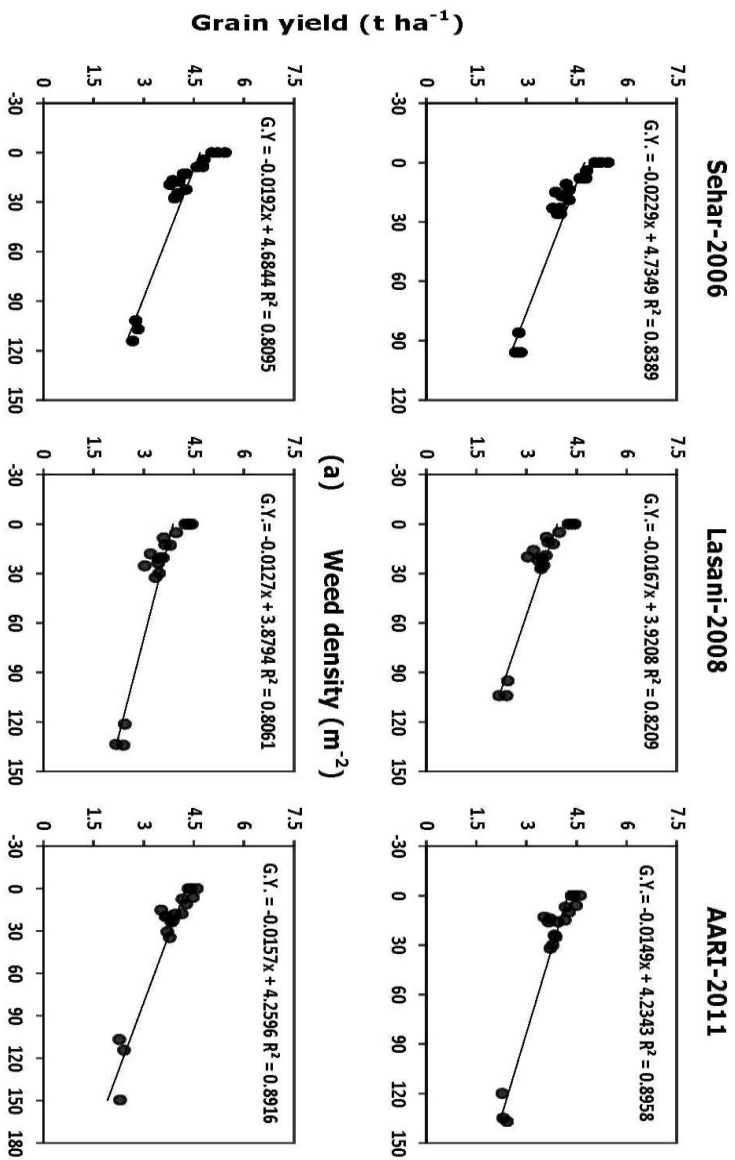


**Figure 10.** Influence of different (a) weed control treatments and (b) wheat cultivars on total dry matter ( $\text{g m}^{-2}$ ) accumulation.  $W_1$ : Control,  $W_2$ : Weed free,  $W_3$ : Pyaxosulam at 14.4 g,  $W_4$ : Iodosulfuron + mesosulfuron-methyl at 14.4 g,  $W_5$ : Isoproturon + carfentrazone ethyl ester at 1000 g,  $W_6$ : Pinoxaden at 41.25 g + Bromoxynil at 225 g + MCPA at 225 g a.i.  $\text{ha}^{-1}$ . Means with different letters differ significantly at 5% probability level by LSD test. Critical value for comparison for weed control treatments and wheat cultivars is (a) 37.346 and (b) 26.407.



**Figure 11.** Influence of different weed control treatments on grain yield ( $\text{t ha}^{-1}$ ) in three wheat cultivars.  $W_1$ : Control,  $W_2$ : Weed free,  $W_3$ : Pyaxosulam at 14.4 g,  $W_4$ : Iodosulfuron + mesosulfuron-methyl at 14.4 g,  $W_5$ : Isoproturon + carfentrazone ethyl ester at 1000 g,  $W_6$ : Pinoxaden at 41.25 g + Bromoxynil at 225 g + MCPA at 225 g a.i.  $\text{ha}^{-1}$ . Means with different letters differ significantly at  $\alpha=0.05$  by LSD test. Critical value for comparison for interaction is 0.231.





**Fig. 12.** Relationship of (a) weed density and (b) weed biomass with grain yield in three wheat cultivars.

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