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Efficacy of herbicides in controlling *Parthenium hysterophorus* L. in spring maize (*Zea mays* L.)

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RESEARCH ARTICLE

Abstract

Parthenium hysterophorus L. is a noxious annual weed rapidly spreading in cropped areas of the irrigated Punjab and other parts of Pakistan. It has become a major threat to grazing lands and crops in Punjab province. The main objective of this study was to explore the efficacy of different herbicides with various concentrations viz. pendimethalin, S-metolachlor + atrazine, bromoxynil + 2-methyl-4-chloorphenoxyacetic acid, and atrazine at their recommended (407, 711, 445 and 469 g a.i./ha, respectively), 50% lower and 50% higher doses against *Parthenium hysterophorus* L. Weeds were allowed to grow in a field for three years (2010-2013) where this spring maize experiment was conducted during the years 2013 and 2014. All herbicide treatments at their recommended and higher doses significantly reduced *Parthenium* dry weight. Minimum density (2.3 and 2.0/m) and dry biomass (39.74 and 43.47 g/m) of parthenium weed was observed with S-metolachlor + atrazine at 711.36 g/ha treatment during 2013 and 2014, respectively. A herbicide efficiency index of 88% was observed with S-metolachlor + atrazine at 711.36 g a.i./ha in 2013 and 2014, respectively. Among the herbicides, atrazine, bromoxynil and metolachlor gave significantly the lowest dry weight of *Parthenium*. Maximum 1000-grain weight (259 and 260.67 g), grain yield (4.86 and 4.87 t/ha), stalk yield (5.60 and 5.42 t/ha) and biological yield (14.80 and 13.80 t/ha) were recorded during both years of experiments when S-metolachlor + atrazine at 711.36 g/ha was applied. These results suggested that over- and underdose of S-metolachlor + atrazine significantly lower the maize growth and yield attributes by allowing more *Parthenium* density at a lower dose, while causing a toxic effect on the maize plants at a higher dose of herbicides. So, the application of S-metolachlor + atrazine (post-emergence) at the recommended rate minimised the weed-crop competition at all the critical crop growth stages, and ultimately yielded the better crop harvest during both years of study.

Keywords: chemical control, doses, *Parthenium*, grain yield, weed density

1. Introduction

Maize (*Zea mays* L.) is the third most important cereal crop, after wheat and rice, in Pakistan. Moreover, it is widely grown in irrigated areas of the country; however, provinces like Punjab and Khyber-Pakhtunkhwa are the major producers. The total area under maize cultivation in Pakistan is about 1,117 thousand hectares, with production totalling 4,527 thousand tonnes. It contributes 2.1% to the value added in agriculture and 0.4% to gross domestic production (Government of Pakistan, 2014). In spite of a favourable environment and high yielding hybrids, its annual production in Pakistan is still low compared to other countries. There are various factors that adversely affect crop productivity, of which weed infestation in crop lands remains the most devastating and is of prime importance. Weeds interfere with crop plants through competition and allelopathic effects and reduce the maize yield from 80 to

66%, which results in direct loss of quantity and quality and has an indirect effect on net monetary returns (Gupta, 2004).

Parthenium hysterophorus L. is the native of the subtropics of North and South America. It is an annual fast-growing weed spreading rapidly in Pakistan. It is very common along the roadsides, around agricultural fields and in wastelands. Moreover, it is becoming a major problematic weed in agricultural fields (Anjum *et al.*, 2005; Oerke, 2005). The allelopathic effect of this weed has been well documented. It has water-soluble phenolics and sesquiterpene lactones which are present in the roots, stems, leaves, inflorescence, pollens and seeds (Evans, 1997; Gnanavel, 2013). To overcome the infestation of *Parthenium*, various approaches have been tried. One of these is a cultural method which is very laborious and time-consuming, causing farmers to look to other alternative methods to control this weed. Chemical weed control seems indispensable and has been proved efficient in controlling weeds (Kahramanoglu and Uygur, 2010). This is quick, more effective, and saves more time and labour than other methods (Juhl, 2004; Khan and Haq, 2004). At the global level, about two-thirds of the pesticides used in agricultural production are herbicides. In Pakistan, herbicide usage accounts for 14% of the total pesticide consumption (Khan, 1998)

Weed growth and phenology, weed emergence pattern, life cycle, development pattern, time of application, dose of herbicides and stage of crop are important in successful chemical weed control (Hoverstad *et al.*, 2004). Moreover, time of herbicide application is very important for effective weed control by herbicides (Vandini *et al.*, 2005). The efficacy of any herbicide depends predominantly on the dose used (Steckel *et al.*, 1997) and in many instances, the same is also decisive for its selectivity. Higher herbicide doses also raise environmental and health issues (Rao, 2000). Indiscriminate use of herbicides for weed control during the past few decades has resulted in serious ecological and environmental problems, such as resistance to chemicals (Heap, 2007). Weed species also tend to vary in their susceptibility to different doses of a specific herbicide. Sometimes, doses are set at their upper limits to achieve weed control under varying compositions, densities, weed growth stages and environmental conditions, and there may be an overestimation of the dose required to get adequate control (Zhang *et al.*, 2000).

Long-term weed-herbicide interactive experiments are rarely done in Pakistan. So, this research provides a base from which to explore the effect of other herbicides on the long-time weed infested fields. In Pakistan, very little emphasis has been placed on finding a suitable chemical control strategy for parthenium weed in maize crop. Therefore, various herbicides which have been widely used in maize need to be tested at different doses against this weed. Bearing in mind the above-mentioned problems, studies were planned to test the efficacy of various registered herbicides at their recommended, lower and higher doses against *Parthenium* control in spring sown maize crop.

2. Materials and methods

Experiment location and crop husbandry

The efficacy of herbicides in controlling *P. hysterophorus* in spring maize (*Z. mays*) was studied by means of field experiments conducted in the Agronomic Research Area of the University College of Agriculture, University of Sargodha, Sargodha, Pakistan, during the spring of 2013 and 2014. The experimental area was located at 32.08°N and 72.67°E and altitude 193 m. The soil of the experimental site was sandy clay loam. The study area had been severely infested by different kinds of weeds for three years. The field contained different types of weeds, e.g. *Parthenium*, nut grass, khabal grass and horse pursalane, but the *Parthenium* infestation represented the most serious infestation. Seedbed preparation was carried out by double ploughing followed by planking. Net plot size allotted to a single treatment was 5×4 m. Maize hybrid seeds were acquired from the local grain market. Maize hybrid HI-corn11 was sown on 19th March, 2013 and 2014 on ridges. A basal fertiliser dose of 150 kg N, 100 kg P_2O_5, and 100 kg K_2O/ha was applied in the form of urea (46% N), diammonium phosphate (18% N; 46% P_2O_5) and sulphate of potash (50% K_2O). The full dose of P and K and half dose of N were applied at sowing. The remaining half of N was top dressed with the third irrigation. Besides soaking irrigation, six irrigations were applied to the maize crop. Shoot fly attack was controlled by the application of an insecticide, i.e. Furadan, to the top of the maize plant after four and six weeks of crop sowing during both years of study. The bird attack on the maize crop during the grain filling stage was controlled by drum beating.

Treatments

Herbicides were taken from three different private multinational pesticide companies: Syngenta Pvt. Ltd (Lahore, Pakistan), Bayer Crop Sciences (Lahore, Pakistan), and Kanzo Ag-Evyol Group (Multan, Pakistan). These herbicides were easily available at the local grain market of Sargodha-Pakistan. Four herbicides treatments viz. pendimethalin, S-metolachlor + atrazine, bromoxynil + 2-methyl-4-chloorphenoxyacetic acid (MCPA), and atrazine at their recommended (407, 711, 445 and 469 g a.i./ha, respectively), 50% lower and 50% higher doses were applied to *Parthenium* in the spring season during the year 2013 and 2014. Pendimethalin was applied as pre-emergence, while S-metolachlor + atrazine, bromoxynil + MCPA, and atrazine were applied as post-emergence. The post-emergence herbicides were sprayed after 25 days of crop sowing (DAS) with a knapsack hand sprayer fitted with a T-jet nozzle (Agro Power Traders, Lahore, Pakistan). The sprayer shield on the nozzle was used to avoid any kind of air drift between herbicide treatments. Control treatment was used for comparison with herbicide treatments and determined the herbicides' efficiency. Main plots were allocated to herbicides while the doses of herbicides were randomised in sub-plots. The spray volume was determined by using the standard calibration method on the non-experimental area. Before the application of each herbicide treatment, the knapsack hand sprayer was properly washed three times with clean water to avoid any kind of contamination of the different types of herbicides with their different concentrations.

Methodology of parameters to be measured

Density of *Parthenium* was measured with the help of a one square metre quadrat sampler at crop harvest during both years of study. Weed samples from each treatment were packed into paper bags. These samples were then dried in the oven at 70±2 °C until the constant dry weight. For the 1000-grain weight of maize, ten cobs were selected randomly from each treatment, and then shelled. The 1000-grain weight was counted manually, and weighed with the help of digital electric weigh scales. All the cobs in each treatment were harvested and shelled using a mechanical sheller, then weighed, and noted in the record book. Then grain yield per treatment was converted into tonne per hectare. Similarly, the biological and stalk yield of maize plants was measured on a per plot basis at the crop harvesting stage, and then converted into t/ha. The herbicide efficiency index of each treatment was calculated using the following formula:

$$HEI = TY - \frac{YC}{YC} \times 100 \; / \; \frac{DMT}{DMC} \times 100$$

Where YT and YC, and DMT and DMC are yields and weed (*Parthenium*) dry biomasses of treated plots and weedy control, respectively.

Statistical analysis

The experimental design was a randomised complete block design under split plot arrangement with three replications. The data, collected on a per treatment basis, were statistically analysed using Fisher's analysis of variance technique, and the difference among the treatment means were compared using LSD at 5% probability (Steel *et al.*, 1997).

3. Results and discussion

Parthenium density and dry biomass

Results revealed that *Parthenium* density and dry weight (at harvest) was significantly affected by herbicides, their doses as well as herbicide × herbicide dose interaction during both years of study (Figure 1). A non-consistent pattern in the *Parthenium* population was recorded between years 2013 and 2014. During 2013, all herbicide treatments except pendimethalin and atrazine at their lower doses caused a significant reduction in *Parthenium*. However, during 2014, a minimum parthenium weed count (3.7, 2.7 and 2.0 m^{-2}) was recorded from pendimethalin, bromoxynil + MCPA and atrazine at their recommended doses.

Regarding *Parthenium* dry biomass, a significant reduction was noted in response to bromoxynil + MCPA (62.2 and 62.2 g/m^2) and atrazine (39.7 and 43.5 g/m^2) at their recommended doses during 2013 and 2014, respectively (Figure 1). A significant reduction in *Parthenium* density and biomass with the post-emergence spray of bromoxynil + MCPA at 560 and 800 g a.i./ha, and atrazine and 560 and 1000 kg/ha compared with weedy check was also noted by Reddy *et al.* (2007) and Khan *et al.* (2014) in maize and non-cropped area, respectively. However, a lower dose of S-metolachlor + atrazine led to maize yield loss due to higher weed-crop competition in all treatments, while the higher than recommended dose of S-metolachlor + atrazine controlled the weeds properly but halted the maize growth, development and ultimately reduced the grain yield (Tamado *et al.*, 2002; Figure 2). Reddy *et al.* (2007) concluded that post-emergence spray of these herbicides resulted in a 33 and 36% decline in the *Parthenium* density, respectively, after 21 days of herbicide application. Javaid (2007) found bromoxynil + MCPA at 1.0, 0.75, 0.5 and 0.25 kg/ha the most effective against 5 and 8 week-old *Parthenium*. The results of this study concluded that the higher doses of herbicides decreased the biological and grain yield of maize during both years of study. Similarly, the same phenomenon was observed in pre-emergence herbicide treatments compared with those of post-emergence treatments (Figure 2). Moreover, this study proved that post-emergence herbicides were safer for spring maize crop compared to pre-emergence herbicides (Javaid, 2007).

Stalk yield (t/ha)

It is apparent from Figure 3 that different weed control treatments had a significant effect on stalk yield of the maize. The interaction between herbicides and doses showed maximum stalk yield (5.60 and 5.42 t/ha during 2013 and 2014, respectively) of maize with atrazine at its recommended dose did not differ significantly from that observed with atrazine at its higher dose during both years of study. Moreover, the recommended dose of bromoxynil + MCPA during 2013 and S-metolachlor + atrazine during 2014 also remained statistically on a par with each other for stalk yield of maize.

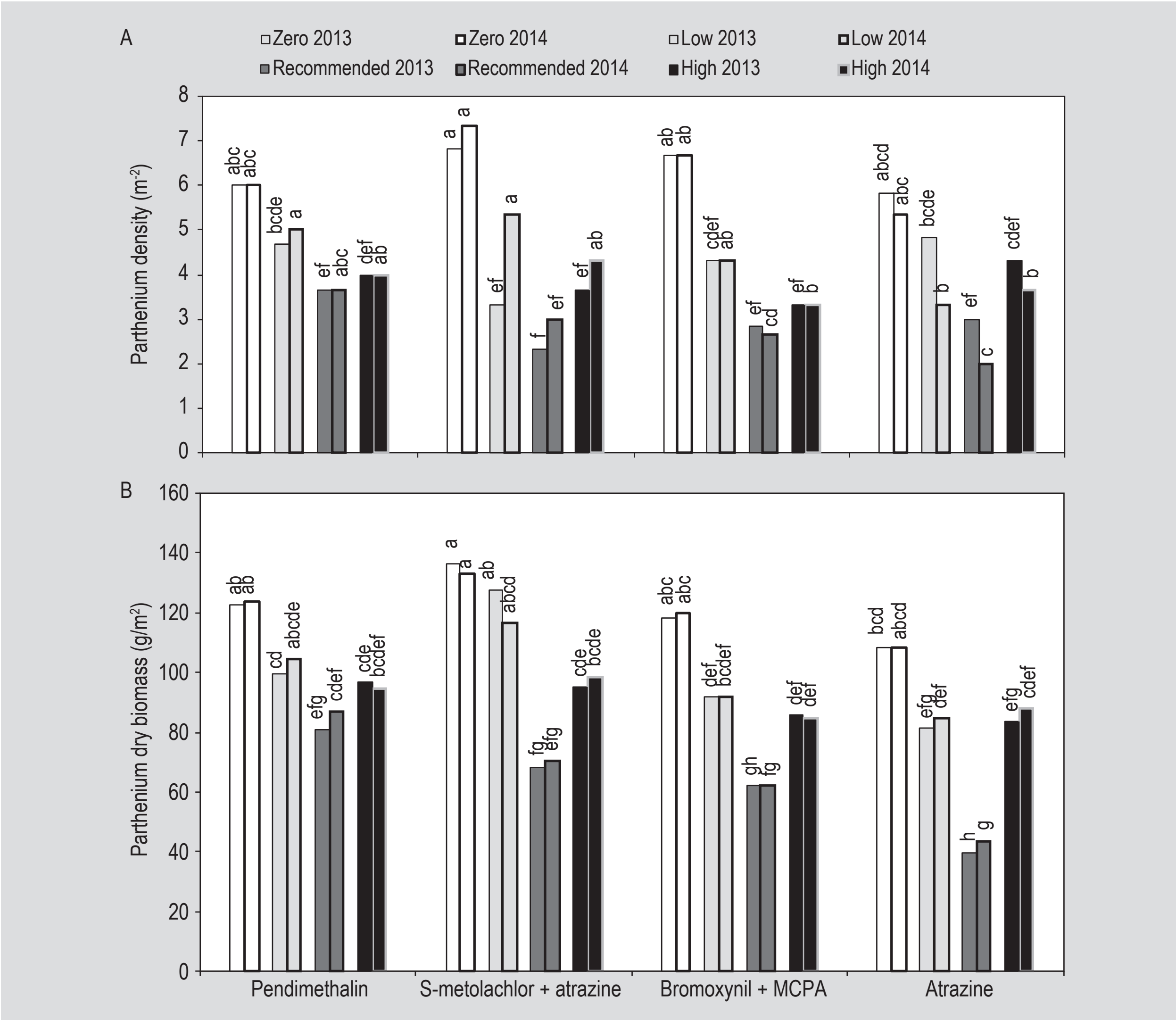

Figure 1. *Parthenium* (A) density and (B) dry biomass in maize as affected by different herbicides at variable application rates density. Treatment means with similar letter(s) for each herbicide treatment are not significantly different at 5% probability level according to the least significance difference test. MCPA = 2-methyl-4-chloorphenoxyacetic acid.

Biological yield (t/ha)

Biological yield is the combination of three components, namely stalk yield, pith and grain yield. It is evident from the results (Figure 3) that herbicides significantly affected biological yield. However, differential behaviour in biological yield was seen between the year 2013 and 2014. During the year 2013, maximum biological yield (14.80 t/ha) was recorded with S-metolachlor + atrazine at its recommended and low doses. However, statistically similar results for biological yield were observed with atrazine at all its doses while, bromoxynil + MCPA at its recommended and low doses. During 2014, the highest biological yield (13.8 and 13.3 t/ha) was recorded with the recommended dose of atrazine and bromoxynil + MCPA, respectively, which was statistically different from all other treatments. These results are in line with those of Fickett *et al.* (2013) and Recker *et al.* (2015) who indicated that delayed application of post-emergence herbicides increased weed-crop competition and lowered corn growth and development. The timely application of post-emergence herbicides substantially increased plant growth and development, and ultimately the stalk and biological yield of maize. In addition, they stated that post-applied herbicides for weed management were safe for the maize plant. Moreover, higher early weed crop competition resulted in delayed maize plant growth and development (Reid *et al.*, 2014) in some treatments during experiments where weed, and especially *Parthenium*, density was above the threshold level during the whole experiment period. That indicated the poor efficiency of herbicides on the weeds. Thus, the poor growth and development of the maize plant was positively correlated with the 1000-grain weight and final grain yield.

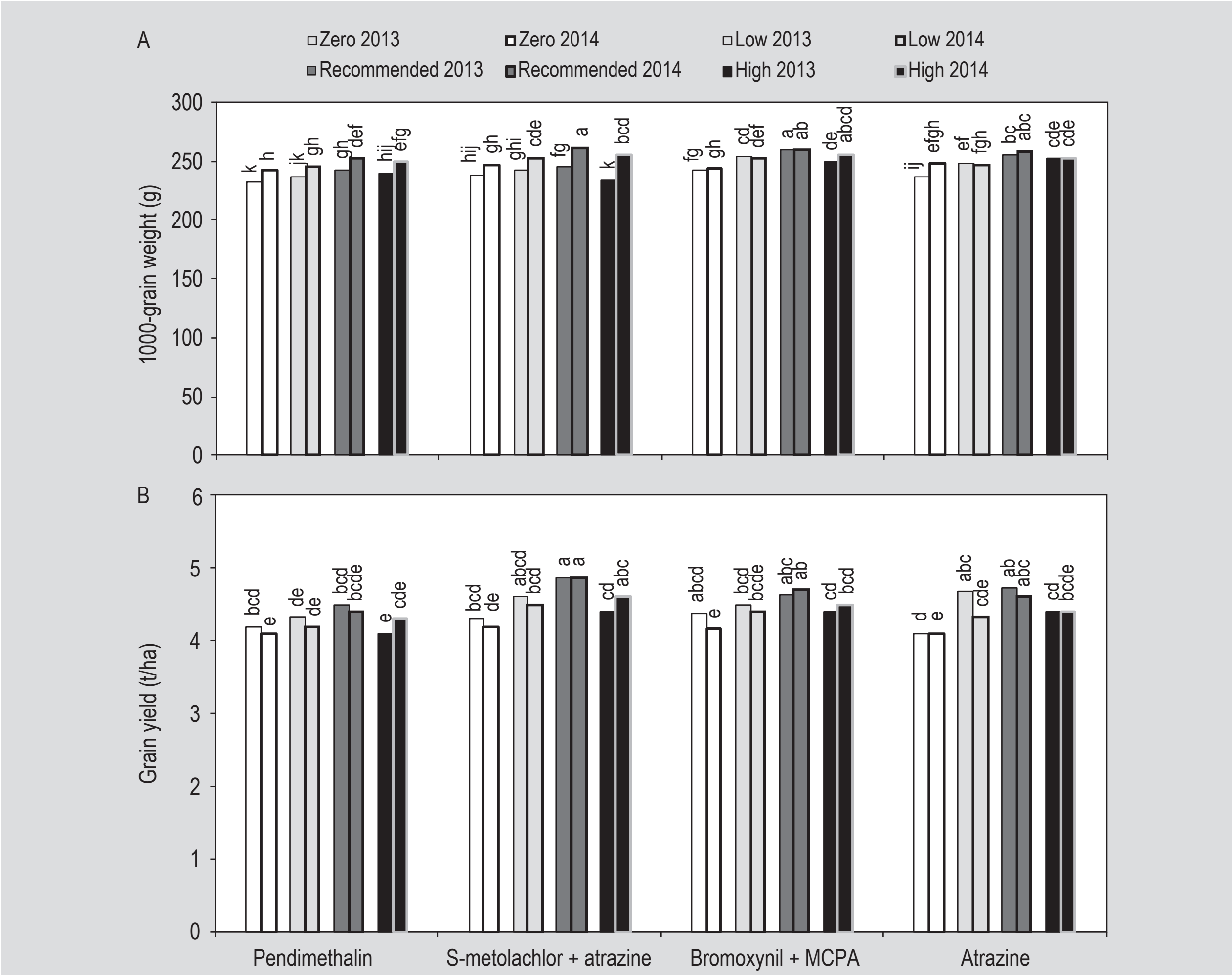

Figure 2. Maize (A) 1000-grain yield and (B) grain yield as affected by variable application rates of different herbicides for controlling *Parthenium*. Treatment means with similar letter(s) for each herbicide treatment are not significantly different at 5% probability level according to the least significance difference test. MCPA = 2-methyl-4-chloorphenoxyacetic acid.

1000-grain weight (g)

Apart from the combined effect of all the other individual yield determining factors, the ultimate final grain yield of a cereal crop depends upon the 1000-grain weight, which reflects seed development under various weed control treatments. Any variation in the 1000-grain weight will affect the grain yield. Statistically maximum 1000-grain weight (259.0 g) was attained with maize plants harvested from plots receiving the recommended dose of bromoxynil + MCPA during 2013 (Figure 2). However, during 2014, in addition to this herbicide treatment, the recommended dose of S-metolachlor + atrazine (260.7 g), higher dose of bromoxynil + MCPA (256 g) and lower dose of atrazine also gave higher values of this parameter. The significant variation for 1000-grain weight in weed control treatment than weedy check was due to vigorous growth and development of maize plants, which resulted in more photosynthate assimilation in grains thus more 1000-grain weight. Similarly, a decrease in the maize gain number might be due to stress caused by early weed-crop competition in the pre-emergence herbicide treatments (Reid *et al.*, 2014). The grain number in maize was positively correlated with the final grain yield but negatively correlated with the weed-crop competition and *Parthenium* density. Khan *et al.* (2014) also concluded that effective control of weeds including *Parthenium* by using herbicides viz. bromoxynil + MCPA, metribuzin and atrazine + S-metolachlor resulted in a significant enhancement of 1000-grain weight in maize.

Grain yield (t/ha)

Grain yield is a function of the accumulation of various yield components, namely; the number of cobs per plants, cob length, number of grains per cob and 1000-grain weight, which showed variations due to prevailing growing conditions and various crop management practices. An overview of the data (Figure 2) revealed that maximum grain yield (4.87 t/ha in both years of study) was attained by using the recommended dose of S-metolachlor + atrazine,

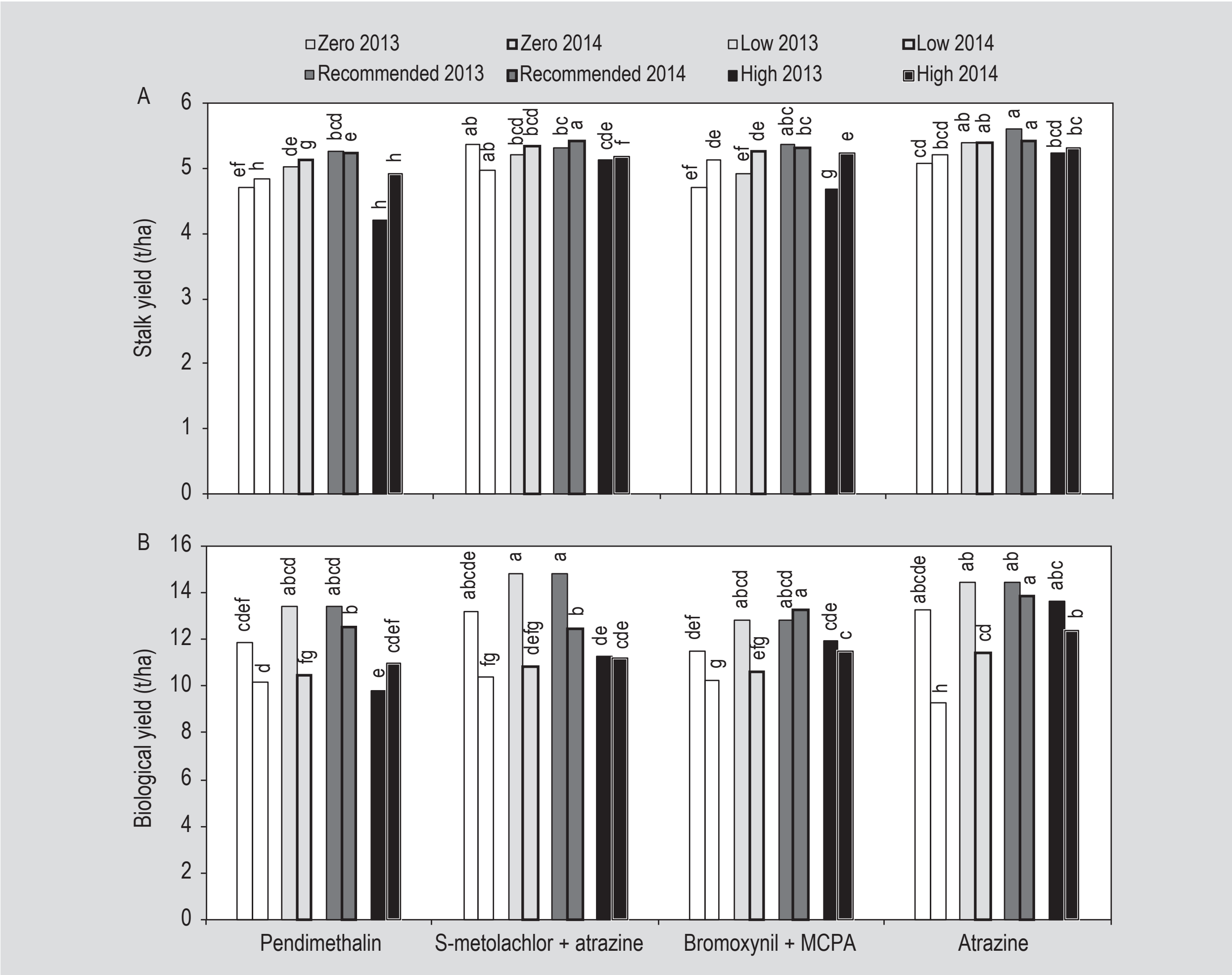

Figure 3. Maize (A) stalk yield and (B) biological yield as affected by variable application rates of different herbicides for controlling *Parthenium*. Treatment means with similar letter(s) for each herbicide treatment are not significantly different at 5% probability level according to the least significance difference test. MCPA = 2-methyl-4-chloorphenoxyacetic acid.

which was statistically similar to that recorded with its lower and higher doses, and recommended doses of bromoxynil + MCPA and atrazine during the year 2013, and almost similar grain yield data pattern was recorded during the year 2014. Overall, the grain yield in the post-emergence herbicide treated plots was significantly higher than the pre-emergence herbicides (Loux *et al.*, 2011) (Figure 2). The results of the experiments were in accordance with those of Nadeem *et al.* (2010), Mahadi (2014), and Safdar *et al.* (2015). They reported an up to 298% increase in maize yield by better *Parthenium* control in response to the application of atrazine and atrazine + metolachlor. Similarly, a significant increase in maize yield as compared to untreated weedy check by the application of atrazine + S-metolachlor, bromoxynil + MCPA, and atrazine herbicides due to a reduction in the density and biomass of mixed weed flora dominated by *Parthenium* was also noted by Khan *et al.* (2014). The results of this study also concluded that the application of tank mix-treatments of herbicides to *Parthenium* was more helpful in increasing corn yield than those treatments using the single herbicide (Johnson *et al.*, 2012). In addition, the injury rate of pre-emergence herbicides on cereal grains was greater than that with post-emergence herbicides (Geier *et al.*, 2009). So, the experiment results supported the use of post-emergence herbicides rather than pre-emergence herbicides in the spring planted maize fields.

The overall efficacy of herbicides in terms of increasing maize yields as a result of decreased parthenium weed biomass has been presented in Figure 4. It can be revealed from data that of the herbicides, S-metolachlor + atrazine showed maximum herbicide efficiency index (88%), followed by pendimethalin (82%), bromoxynil + MCPA (75%) and atrazine (65%).

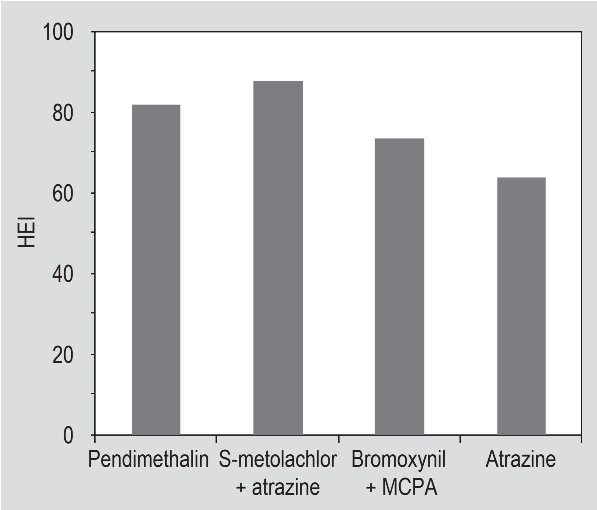

Figure 4. Comparison of herbicide efficiency index (HEI) of different herbicides for controlling *Parthenium* in maize.

4. Conclusions

Different herbicidal treatments controlled parthenium weed to a variable degree at their different doses. The post-emergence herbicide, i.e. S-metolachlor + atrazine at its recommended application rate proved to be the best, as it gave the highest maize grain yield as a consequence of better control of parthenium weed. Our study suggests that this herbicide should be applied after 25 DAS. Moreover, the results of this study recommended the use of tank mix-treatments of herbicides on the maize plants to control the *Parthenium*, and increase the grain yield. This research study helps farmers in the selection and application of herbicides, thus reducing the cost of increasing the efficacy.

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