Weed control and wheat cultivars (*Triticum aestivum* L.) responses to metribuzin application rate and timing in Iran

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Abstract
Field experiments were established at four locations in Iran to evaluate the efficacy of metribuzin in controlling weeds in winter wheat. Metribuzin was applied either post-emergence (POST) or pre-emergence (PRE) at 0, 0.35, 0.52 and 0.70 g a.i. ha^{-1}. At each location three conventionally planted wheat cultivars were tested. In most cases weed control increased with metribuzin rate following a linear or curvilinear trend with an application rate of 0.5 kg ha^{-1} a.i. providing an acceptable level of control. PRE applied metribuzin resulted in better control of weeds at Ahvaz while POST treatments were more effective at Karaj with no differences between PRE and POST treatments at two other locations (Zabol and Gorgan). Wheat yields increased with metribuzin rate at two locations (Ahvaz and Zabol) or showed minor (Karaj) to no changes (Gorgan) across application rates. Wheat yields were higher in PRE treated plots than in POST at Ahvaz, but lower at Karaj and did not vary at Zabol (with one exception) or Gorgan. Wheat cultivars also varied in their responses to metribuzin application rate or timing. Finally, metribuzin could be applied at 0.5 kg ha^{-1} a.i. (regardless of application timing) but not at higher rates at Ahvaz and Karaj, although higher rates at Zabol and Gorgan could provide both an acceptable level of weed control and wheat yield gain as well.

Keywords: Post-emergence, pre-emergence, broadleaved weeds, grass weeds, wheat yield, Iran.

Introduction
Weeds are a major constraint to wheat (*Triticum aestivum* L.) production in Iran, accounting for about 23% of yield losses (Zand 2008). Here, weed control in winter wheat relies almost exclusively on herbicide application (Deihim-Fard and Zand 2006). Applying herbicides with different modes of action can delay the evolution of herbicide resistant weeds, and extend the weed control spectrum. Recently some graminicide and broadleaved weed herbicide options have been evaluated and registered for use in wheat in Iran to satisfy the need for more versatile herbicides (Zand *et al.* 2007, Baghestani *et al.* 2008).

Metribuzin is a triazinone herbicide which has been registered for use in more than 20 different crops (Anon. 1994, Patterson 2004) and has been shown to be tolerated by cereals such as wheat (Runyan *et al.* 1982, Rydrych 1985) or barley (*Hordeum vulgare* L.) (Gawronski *et al.* 1986, Kleemann and Gill 2008). Although, the herbicide has been regarded as the single most effective option for *Bromus* spp. control in wheat (Ratliff and Peeper 1987, Gill and Bowran 1990, Matic and Black 1990), it also controls several other important weeds (Anon. 1994, Hutchinson *et al.* 2004). Metribuzin can be applied PRE, POST or preplant incorporated (PPI) and the time of application can severely influence its effectiveness in controlling weeds and crop tolerance to the herbicide. For example, metribuzin (135 to 203 g a.i. ha^{-1}) incorporated by sowing (IBS) was more effective in controlling *B. rigidus* than the same herbicide dose applied POST (Kleemann and Gill 2008). However, Ratliff and Peeper (1987) found that POST applied ethyl-metribuzin provided better control of *Bromus* spp. than PRE or PPI treatments.

Cultivars of several crops have been shown to differ in their tolerance to metribuzin and injury at recommended rates of application is not uncommon. Differential metribuzin sensitivity has been reported in wheat (Ratliff and Peeper 1987), soybean (*Glycine max* (L.) Merr.) (Barrentine *et al.* 1976, Mangeot *et al.* 1979), barley (Gawronski *et al.* 1986, Kleemann and Gill 2008), potato (*Solanum tuberosum* L.) (Friesen and Wall 1984, Graf and Ogg 1976), tomato (*Lycopersicon esculentum* Mill.) (Gawronski 1983), and sweet potato (*Ipomoea batatas* (L.) Lam.) (Harrison *et al.* 1985). For example, of 15 winter wheat cultivars grown on several soil types, two cultivars showed a high sensitivity to metribuzin with 50% yield reductions at 0.4 kg ha^{-1}, while two others were slightly injured at double that rate (i.e. 0.8 kg ha^{-1} a.i.) (Runyan *et al.* 1982). Similar variation in responses of wheat cultivars to metribuzin was demonstrated in the study of Bridges *et al.* (2000).

The level of weed control and crop injury with this herbicide can be extremely erratic depending on soil characteristics (e.g. soil texture and pH) and conditions such as soil moisture or precipitation at or near the time of application (Runyan *et al.* 1982, Ratliff and Peeper 1987, Matic and Black 1990, Ladlie *et al.* 1976). For example, higher activity and crop phytotoxicity of metribuzin was attributed to lower clay and organic matter content of soil (Ladlie *et al.* 1976, Blackshaw *et al.* 1994). There were also no differences in response of wheat cultivars to metribuzin when precipitation was very light or when the soil was saturated at the time of application (Runyan *et al.* 1982).

Little is known about the efficacy of metribuzin in controlling weeds of wheat and the response of wheat cultivars to the herbicide in Iran. Therefore, the objectives of this study were to determine whether metribuzin could provide acceptable control of weeds in wheat and whether the selected cultivars were sufficiently tolerant to permit selective use of metribuzin for weed control.

Material and methods
Field studies were established in 2005–2006 growing season at four sites in Iran to evaluate the efficacy of metribuzin in controlling weeds in winter wheat. Metribuzin was applied either pre-emergence (PRE) or post-emergence (POST) at 0 (untreated control), 0.35, 0.52 and 0.70 kg ha^{-1} a.i. Three wheat cultivars suited to each location were planted in rows 20 cm apart. The experimental sites, wheat cultivars, soil textures and dominant weed flora for each site are shown in Table 1.

The seedbed was prepared by mouldboard ploughing and tandem disking followed by land levelling. At all locations, plot sizes were 3 m wide by 8 m long and the necessary fertilizers were applied according to the provincial recommendations (Anon. 2002). All herbicide

Table 1. Wheat cultivar, soil type and dominant weeds presented at four test sites.

			Dominant weeds	
Site	Wheat cultivar	Soil texture	Broadleaved	Grasses
Ahvaz	Chamran Dez Sheva	Silt clay loam	*Beta martitima* *Cirsium arvense* *Sinapis arvensis* *Malva nicaeensis*	*Avena ludoviciana* *Lolium rigidum* *Phalaris minor*
Karaj	Pishtaz Shiraz M79	Clay loam	*Sisymbrium irio* *Malcolmia africana*	*Avena fatua* *Hordeum spontaneum* *Bromus* spp.
Gorgan	Zagros Tajan 786	Silt clay loam	*Polygonum aviculare* *Rumex spinosus*	–
Zabol	Kalak Afghani Cross boolani Hamoon	Clay loam	*Chenopodium album* *Polygonum aviculare*	*Bromus tectorum*

treatments were applied using a backpack sprayer delivering 250 L ha^{-1} of spray solution at 240 kPa through a flooding spray nozzle (Goizeper S. Cooperative Company, Guipuzcoa, Spain). The POST metribuzin treatment was applied at the wheat tillering stage (Zadoks 20, Zadoks *et al.* 1974). Weed control was assessed by counting the number of weeds from two 0.5 by 0.5 m quadrats in each plot. Counts were taken 30 days after treatment and data were expressed as a percent of the untreated control. At physiological maturity, the wheat grain was harvested from an area measuring 1.2 m^2 within the two middle rows of each plot.

Statistical analysis

Experimental design at all sites was a randomized complete block with a factorial arrangement of treatments (metribuzin application rate × application timing × wheat cultivars). Each treatment was replicated four times. Analysis of variance (ANOVA) of wheat yield and weed control was performed using PROC GLM procedure of SAS (SAS Institute, 2002). The responses of wheat cultivars and weeds to application rates were further analysed using regression analysis. Before analysis, data were tested for normality and homogeneity of residuals which showed that the data sets did not require a transformation. Data are presented separately for each site as different wheat cultivars were sown at each location. Means were separated using Fisher's protected LSD test (P = 0.05).

Results

Weed control

At Ahvaz, control of both broadleaved and grass weeds increased progressively with increasing metribuzin rate (Figure 1). The regression model showed that a rate of 0.7 kg ha^{-1} a.i. applied PRE gave complete control of broadleaved weeds while POST applications gave 75% control. Similarly, grass weed control was 95% for PRE and 65% for POST applications at 0.7 kg ha^{-1} a.i. At the rates tested, metribuzin applied PRE provided better control of both broadleaved and grass weeds compared to POST applications (Figure 1). Averaged over all application rates, POST applied metribuzin gave 81% control of broadleaved weeds while PRE application gave 57% control (Figure 2). Similarly, grass weeds were controlled more effectively by PRE treatments where control from this treatment was 21% greater than POST application.

At Karaj (Figure 1) there was essentially no dose response to POST applications of

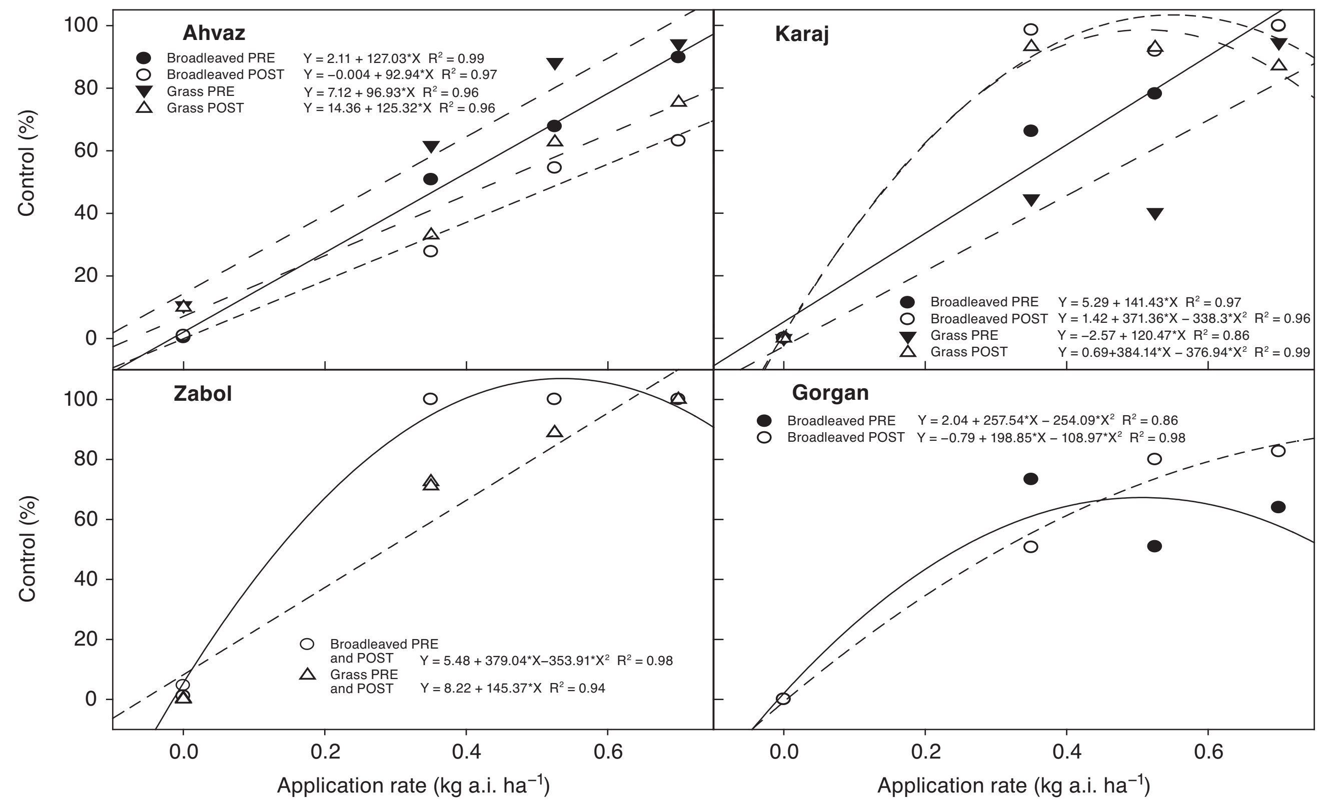

Figure 1. The relationships between weed control and metribuzin rate in PRE and POST application treatments at four test sites.

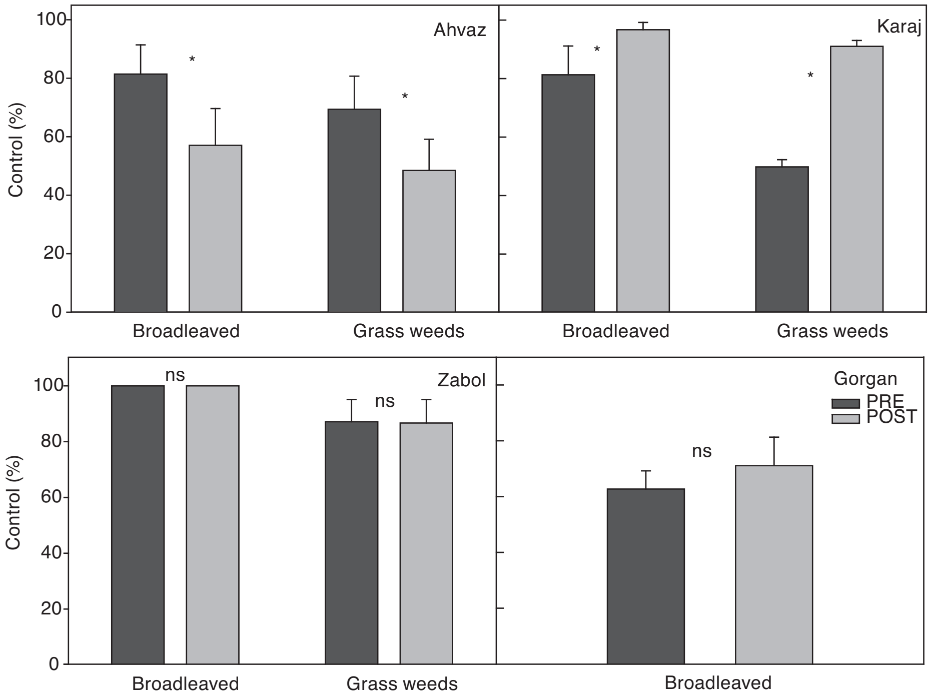

Figure 2. The effect of PRE and POST applied metribuzin on broadleaved and grass weeds control at four test sites. Asterisk symbols indicate significant differences between PRE and POST treatments, ns: not significant. Bars on datapoints are SE.

metribuzin as all but one treatment gave over 90% control. In contrast, for PRE application of metribuzin, broadleaved and grass weed control increased as the rate increased (Figure 1). At the lower rates, POST applied metribuzin provided better control of weeds (both broadleaved and grass weeds) than PRE treatment but this was not evident at the maximum rate. This differed from Ahvaz, where the overall effectiveness of PRE applied metribuzin was significantly greater than POST application, especially in case of grass weeds control (Figure 2). Broadleaved weed control of POST and PRE applied metribuzin were 96% and 81%, respectively, while control of grass weeds with POST and PRE treatment was 91% and 50%, respectively. Both broadleaved and grass weeds responded to POST metribuzin similarly, but grasses were more difficult to control when subjected to PRE treatment (Figure 2).

At Zabol, complete control of broadleaved weeds was obtained from all application rates with no difference between POST and PRE treatments (Figure 1). However, grass weeds showed a dose-response to metribuzin and control increased from 77% for an application rate of 0.35 kg ha^{-1} to 100% at 0.7 kg ha^{-1} a.i. As shown in Figure 2, PRE and POST treatments did not differ significantly in controlling broadleaved or grass weeds.

Very few grass weeds were found at Gorgan (Table 1), thus data on grass weeds were excluded from the analysis. Model predictions show that metribuzin applied at 0.35 kg ha^{-1} a.i. PRE gave 60% broadleaved weed control with no further improvement at higher rates. However, the control level obtained from POST applied metribuzin increased from about 55% (0.35 kg ha^{-1} a.i.) to a maximum of 85% at 0.7 kg ha^{-1} a.i. (Figure 1). The differences between POST and PRE treatments became more apparent as application rate increased. However, when averaged over the application rates, the main effect of application timing was not significant and both PRE and POST applied metribuzin provide an equal control level of 67%.

Wheat grain yield

The response of each wheat cultivar to metribuzin is shown in Figure 3. At Ahvaz no yield improvement was observed when metribuzin was applied at 0.35 kg ha^{-1} a.i. compared to untreated plots. However, applying metribuzin at 0.52 kg ha^{-1} a.i. resulted in distinct yield increases in all cultivars. The degree of increase for Chamran and Shava cultivars was similar (3300 kg ha^{-1}) but was markedly lower in Dez (1900 kg ha^{-1}). Increasing application rate from 0.52 to 0.7 kg ha^{-1} a.i. resulted in minor yield increases for Chamran (3800 kg ha^{-1}) and Dez (2150 kg ha^{-1}) cultivars with some reduction in yield for Shava (2900 kg ha^{-1}). These results are partially in accordance with the weed control levels resulting from the metribuzin application rates. That is, weed control was linearly related to metribuzin rate (Figure 1), but wheat yield response to application rate followed a curvilinear trend and levelled off at higher rates. Thus, it was concluded that application rates above 0.52 kg ha^{-1} a.i. may not cause any noticeable increase in wheat yields and may even adversely affect the yield because of injuries to wheat crop (data not shown). The effect of application timing on wheat yield is shown in Figure 4. At Ahvaz, wheat yields were always higher in plots receiving metribuzin as a PRE treatment than those being subjected to POST application. For example, Chamran yielded 3250 kg ha^{-1} when metribuzin was applied PRE while the yield was reduced to 1360 kg ha^{-1} in POST applied plots. The greater yields achieved from PRE application is in agreement with the higher level of weed control given by this treatment (Figure 2). Dez produced the lowest yields under either PRE (1990 kg ha^{-1}) or POST (906 kg ha^{-1}) treatments (Figure 4). Although, Chamran had the greatest yield in PRE treatment, its yield did not vary from Sheva when metribuzin was applied POST.

At Karaj, the yield for all wheat cultivars was marginally higher at 0.35 kg ha^{-1} a.i. but tended to decrease at higher rates (Figure 3). Shiraz and Pishtaz cultivars responded to metribuzin rates similarly and had lower yields than M79 at any application rate. These results indicated that the common wheat cultivars sown at Karaj may experience yield reductions from high metribuzin rates. All wheat cultivars, except Pishtaz, had significantly greater yields in plots treated with POST metribuzin than PRE applications. There were also some differences among cultivars in grain yield which seemed to be the result of different sensitivity of cultivars to metribuzin as the main effect of wheat cultivar on weed control was not significant. For example, where metribuzin was applied POST, M79 had the greatest yield (3800 kg ha^{-1} a.i.) followed by Shiraz (3560 kg ha^{-1}).

There were no significant differences in rate responses amongst wheat cultivars at Zabol and there was an increasing yield response with increasing metribuzin rate (Figure 3). Although, wheat yields were always greater in POST treated plots than in PRE, the differences were only significant for Hamoon cultivar (Figure 4). Hamoon yielded 1590 and 1070 kg ha^{-1} when metribuzin applied POST or PRE, respectively. Weed control also was not affected by the time of metribuzin application (Figure 2), which may explain why there were only marginal differences between PRE and POST applications. There were no significant differences among cultivars in yield for either POST or PRE applied metribuzin (Figure 4).

Wheat yields at Gorgan remained constant across the range of metribuzin rates

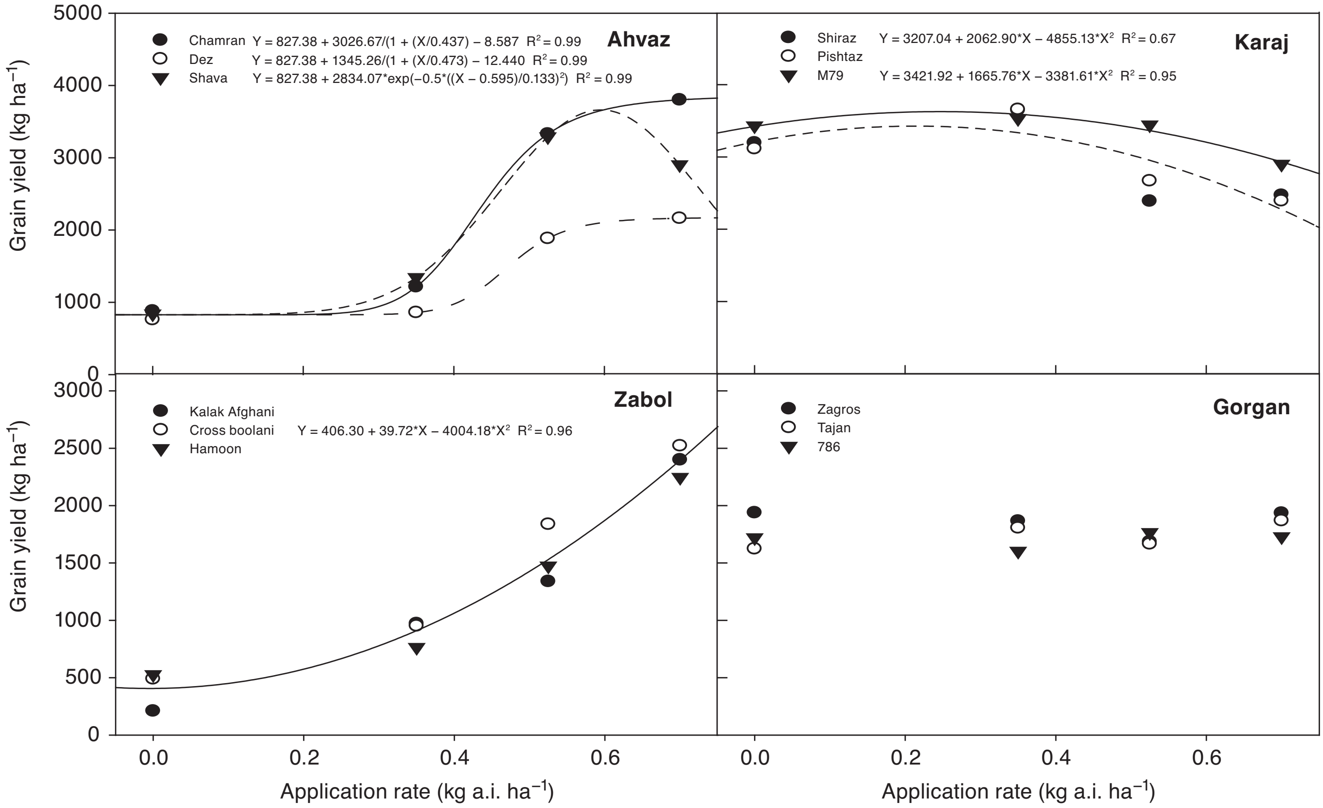

Figure 3. The response of wheat cultivars to metribuzin application rate at four test sites.

tested in this experiment (Figure 3). No differences were also observed among cultivars and there were no significant differences between PRE and POST treatments in grain yield (Figure 4). It seemed that the low populations of weeds (data not shown) at this location had only negligible effects on wheat yield, thus suggesting wheat yield has not been affected by the level of weed control provided by metribuzin.

Discussion

The results of this study showed that the efficacy of metribuzin in controlling weeds is highly variable between locations and depends on the rate and time of application. This variability could also be attributed to the different weed flora presented at each location (Table 1). The results also indicate that different wheat cultivars conventionally sown in different climate conditions may also vary in their responses to metribuzin.

Other studies have also shown variable results from POST and PRE applications of metribuzin. For example, in a study conducted by Ratliff and Peeper (1987), POST applied ethyl-metribuzin provided better control of *Bromus* spp. than PRE or PPI treatments while metribuzin incorporated by sowing (IBS) was more effective than the same rate applied POST. However, Rydrych (1985) found weed control was the same whether metribuzin was applied PRE or POST, which resembles

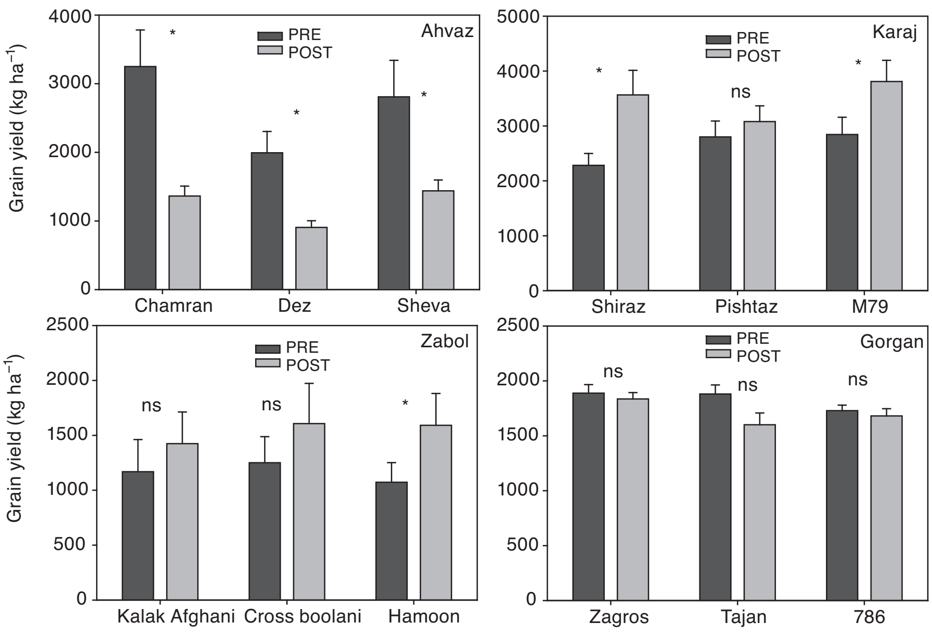

Figure 4. The effect of PRE and POST applied metribuzin on wheat cultivars yields at four test sites. Asterisk symbols indicate significant differences between PRE and POST treatments, ns: not significant. Bars on datapoints are SE.

our results observed in Zabol and Gorgan (Figure 2). This variability among results has been largely attributed to soil or weather conditions. For example, the effective control of weeds was highly dependent to the amount of rainfall received following the application of metribuzin (Runyan *et al*. 1982, Ratliff and Peeper 1987, Matic and Black 1990, Kleemann and Gill 2008) where for a PRE application there should be adequate moisture in the soil to activate metribuzin or move it into the rooting zoon of weeds. Soil texture, pH and organic matter had a marked influence on metribuzin activity and wheat crop tolerance as well (Ladlie *et al.* 1976, Rydrych 1985, Blackshaw *et al.* 1994, Kleemann and Gill 2008). At all locations weed control increased with metribuzin application rate which is in agreement with other reports (Runyan *et al.* 1982, Gill and Bowran 1990, Kleemann and Gill 2008).

The different responses of wheat cultivars to metribuzin (in terms of different grain yield production) might be due to varietal tolerances to this herbicide, different competitive ability of cultivars and/or derived from the different levels of weed suppression given by metribuzin. Wheat cultivars have been shown to differ in their responses to metribuzin (Runyan *et al.* 1982, Ratliff and Peeper 1987) where at least a twofold difference in wheat cultivar responses was demonstrated by Runyan *et al.* (1982). Great variation in competitiveness of Iranian wheat cultivars was detected in the study of Mesgaran *et al.* (2006) that may partially explain the different yield gains observed in this study. The control of weeds resulting from metribuzin application translated into yield increases at Ahvaz and Zabol but not at Karaj or Gorgan. Similarly, control of *Bromus* spp. increased wheat grain yields to more than twice that of the non-treated check at one location but no yield improvement was detected at two other locations (Ratliff and Peeper 1987). There were poor relationships between the rates giving the highest wheat yield and those giving the greatest suppression of the weeds elsewhere (Zand *et al.* 2007, Baghestani *et al.* 2008). The weeds might not be competitive enough to cause yield reductions so that a high level of control would not necessarily improve the crop yield.

Although the very different results observed from four test sites may prevent us from providing a straightforward conclusion, a circumspect recommendation could be the application of metribuzin at 0.5 kg ha^{-1} a.i. (regardless of timing) but not at higher rates at Ahvaz and Karaj, however, higher rates at Zabol and Gorgan could provide both an acceptable level of weed control and wheat yield gain as well.

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