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Effect of Environment on Wild Oat (*Avena fatua*) Control with Imazamethabenz or Fenoxaprop Tank-Mixed with Additives or MCPA

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Abstract. Greenhouse and growth chamber experiments were conducted to determine the effect of soil moisture and temperature on the phytotoxicity in wild oat of imazamethabenz or fenoxaprop tank-mixed with certain additives or MCPA. The surfactants Agral 90 at 0.5% and Enhance at 0.5% increased imazamethabenz phytotoxicity under both moist and drought conditions. These surfactants had no significant effect on fenoxaprop phytotoxicity regardless of the soil moisture regimes. Fenoxaprop activity was increased by ammonium sulfate [$(NH_4)_2SO_4$] at 1% but only under well watered conditions. Wild oat control with imazamethabenz was also slightly enhanced in a well watered regime by the addition of sodium bisulfate ($NaHSO_4$) at 0.13%. At high temperature (30/20°C) and low temperature (10/5°C), the phytotoxicity of imazamethabenz was increased when tank-mixed with Agral 90 at 0.25% or $NaHSO_4$ at 0.13% compared with that when imazamethabenz was applied alone, if soil moisture was adequate. There was no such increase under conditions of drought and high temperature. $(NH_4)_2SO_4$ at 1% did not significantly affect imazamethabenz performance irrespective of temperature/soil moisture conditions. The phytotoxicity to wild oat of imazamethabenz or fenoxaprop was not changed by tank-mixing with MCPA isooctyl ester at 300 g a.i./ha, regardless of soil moisture levels. The reduced fenoxaprop phytotoxicity in wild oat due to moisture stress was not readily alleviated by the inclusion of selected additives or MCPA in the tank mixture.

Key Words. Phytotoxicity—Drought—Temperature—Imazamethabenz—Fenoxaprop—Additives—MCPA

Abbreviation: PPFD, photosynthetic photon flux density.
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Fenoxaprop phytotoxicity in wild oat (*Avena fatua*) is adversely affected by stresses in soil moisture and temperature, and performance of imazamethabenz is relatively insensitive to various environmental stresses (Xie et al. 1994a, 1994b). Additives (Liu et al. 1992, 1995) and MCPA (Liu et al. 1994) have been shown to influence imazamethabenz phytotoxicity in nonstressed environments. In addition, the performance of fenoxaprop in wild oat under nonstressed conditions was found not to be affected by $(NH_4)_2SO_4$ (Harker 1995) and MCPA (Deschamps et al. 1990). The phytotoxicity of several graminicides is known to be enhanced by additives such as surfactants (Beckett et al. 1992, Grayson et al. 1995, Keeney et al. 1988, Streibig and Kudsk 1992), crop oil concentrate (Keeney et al. 1988) and inorganic salts (Chow 1988, Harker 1992). In certain cases, incorporation of additives, notably surfactants and inorganic salts, into the spray resulted in more consistent weed control by postemergence herbicides under drought (Harker and O'Sullivan 1988) and low temperature stresses (Nalewaja and Woznica 1988, Wills and McWhorter 1988). Other studies suggested that the reduced herbicide effectiveness caused by stressful environments could not be overcome by crop oil concentrate (Levene and Owen 1989), surfactant (Nalewaja et al. 1990), or oil adjuvant plus surfactant (Nalewaja and Adamczewski 1988).

There is little information available on the influence of environment on the performance of tank mixtures of imazamethabenz or fenoxaprop, supplemented with additives or MCPA. The objective of the present study was to determine whether the response patterns of those two wild oat herbicides to soil moisture and temperature stresses are changed by the inclusion of surfactants, inorganic salts, or MCPA in the tank mix.

Materials and Methods

General Procedures

The experiments were carried out either in a greenhouse or in a growth chamber of the Agriculture and Agri-Food Canada Regina Research

Station, Regina, Saskatchewan. A natural wild oat (*A. fatua* L.) population collected locally was used. The seeds were pregerminated in Petri dishes for 4 days at room temperature. Two germinating seedlings with radicles just emerged were planted in each plastic pot (10 cm in diameter) filled with loamy sand soil (dark brown Chernozemic) with moderate fertility. A 20:20:20 (N:P:K) water-soluble fertilizer at 210 mg/pot in 40 mL of water was applied at the one-leaf stage. In the greenhouse, the day and night temperatures were 20–29°C and 18–22°C, respectively. The natural light was supplemented with high pressure sodium lamps to provide a 16-h photoperiod with average photosynthetic photon flux density (PPFD) of 390–430 $\mu E/m^2/s$. In the growth chamber, the temperature was set at either 30/20°C or 10/5°C, and PPFD was at 400 $\mu E/m^2/s$ with a 16-h photoperiod. Unless otherwise indicated, the plants were watered daily to maintain adequate soil moisture (>80% field capacity, designated as well watered treatment).

Commercially formulated imazamethabenz-methyl (suspension concentrate, SC; Cyanamid Canada Inc., Markham, ON) and fenoxaprop-ethyl (emulsifiable concentrate, EC; AgrEvo Agriculture Chemicals, Regina, SK), containing 300 and 90 g a.i./liter, respectively, were used in the studies. When wild oat plants reached the three-leaf stage, herbicides were applied to the foliage with an overhead trolley sprayer equipped with a flat-fan nozzle delivering 100 liters/ha at 207 kPa. All of the tank mixtures, as described below, were prepared immediately prior to herbicide spraying, and distilled water was used as the spray carrier. The soil surface was covered with a layer of coarse vermiculite during the spraying to prevent root absorption of herbicides. The vermiculite was removed after the spraying, and the plants were placed into their respective environments.

Unless otherwise stated, the plants were harvested 3 weeks after the herbicide application. Shoot dry weight was determined following oven drying at 70°C for 48 h. Herbicide phytotoxicity to wild oat was assessed using treated shoot dry weight as a percentage of the respective (same environmental regime) unsprayed check. The experiment was arranged as a split plot design, with environments as the main plots and herbicides as the subplots. In each experiment, there were seven replicates with each pot as one replicate. All experiments were repeated once, and the data were pooled since there was no significant difference between the duplicate experiments. If ANOVA (SAS Institute 1985) within each experiment indicated a significant interaction between environment and additive, the treatment means were separated by Fisher's protected LSD at $p = 0.05$ level.

Additive Study in Greenhouse

Four experiments were conducted in the greenhouse. In all four experiments, drought stress was imposed by withholding water for 7 days before herbicide spraying, with the plants showing the sign of wilting during the spraying. Only sufficient water was added to keep the plants alive after spraying for 10 more days (soil moisture was maintained between 23 and 35% of field capacity). The daily watering (>80% field capacity) was then resumed. The herbicide treatments in all four experiments consisted of imazamethabenz at 100 g a.i./ha or fenoxaprop at 100 g a.i./ha. In the first experiment, surfactant Agral 90 (90% nonylphenoxy polyethoxy ethanol; ICI Chipman, Stoney Creek, ON) at 0.5% (v/v) was added into the tank mixture of both herbicides. In the second experiment, surfactant Enhance (64% tallow fatty acid amine ethoxylate and 14% nonylphenoxy polyethoxy ethanol; DowElanco, Scarborough, ON) at 0.5% (v/v) was added into the tank mixture. In the third experiment, ammonium sulfate [$(NH_4)_2SO_4$; BASF Canada, Calgary, AB] at 1% (w/v) was added into the tank mixture. In the fourth experiment, sodium bisulfate ($NaHSO_4$; Alec Ltd., Calgary, AB) at 0.13% (w/v) was added into the imazamethabenz tank mixture.

Additive Study in Growth Chamber

Two experiments were conducted in the growth chamber with imazamethabenz applied at 150 g a.i./ha. The additives used included: Agral 90 at 0.25% (v/v), $(NH_4)_2SO_4$ at 1% (w/v), and $NaHSO_4$ at 0.13% (w/v). In the first experiment, the temperature was set at 30/20°C; and drought stress was imposed by withholding water for 7 days before spraying, with an additional 10 days of drought stress after spraying. A well watered control was maintained at the same temperature regime. In the second experiment, the temperature was set at 10/5°C, and all plants were grown under well watered conditions. The plants in the second experiment were harvested 4 weeks after the herbicide application.

Greenhouse Study on MCPA

This experiment was conducted in the greenhouse. The treatments consisted of imazamethabenz at 200 g a.i./ha alone or plus a commercially formulated broadleaf herbicide, MCPA isooctyl ester (containing 500 g a.i./liter; DowElanco Canada) at 300 g a.i./ha, or fenoxaprop at 140 g a.i./ha alone or plus MCPA ester at 300 g a.i./ha. Drought was imposed by withholding water for 8 days before herbicide spraying with 10 more days of drought stress after spraying.

Results and Discussion

Effect of Additives on Imazamethabenz Phytotoxicity

Under greenhouse conditions, the phytotoxicity of imazamethabenz in wild oat was increased by the addition to the spray of either surfactant Agral 90 at 0.5% or surfactant Enhance at 0.5% (Table 1). When wild oat plants were subjected to drought stress, imazamethabenz plus Agral 90 or plus Enhance was still more effective than the herbicide applied alone, although slightly less so than under well watered conditions. Regardless of soil moisture regimes, wild oat foliage absorbed less than 40% of applied imazamethabenz (SC formulation alone) as measured 4 days after application (Xie et al. 1996). The positive effect of Agral 90 on imazamethabenz performance had been reported under nonstressed conditions and was attributed to surfactant-increased herbicide retention and absorption (Smith and Chow 1990). Thus, greater imazamethabenz absorption by droughted wild oat plants might also result from the addition of Agral 90 or Enhance, leading to improved wild oat control relative to imazamethabenz alone.

Under well-watered conditions in the greenhouse, the phytotoxicity to wild oat of imazamethabenz tended to be increased when $(NH_4)_2SO_4$ at 1% or $NaHSO_4$ at 0.13% was added to the spray solution (Table 1). However, this enhancement was much less than that induced by the surfactants. These effects of $(NH_4)_2SO_4$ and $NaHSO_4$ on imazamethabenz phytotoxicity disappeared when the plants were subjected to moisture stress. With nonstressed wild oat plants, other studies showed that $NaHSO_4$ resulted in only a moderate enhancement in

Table 1. Effect of additives on the phytotoxicity of imazamethabenz at 100 g/ha or fenoxaprop at 100 g/ha in droughted wild oat plants. The experiment was conducted in the greenhouse. The drought was imposed by withholding water for 7 days before spraying with an additional 10 days of stress after spraying.

	Imazamethabenz		Fenoxaprop	
Additive	Well watered	Drought	Well watered	Drought
	shoot dry weight (% of respective control)			
Agral 90 at 0.5%				
−	42	45	40	71
+	12	21	49	74
LSD (0.05)	6		15	
Enhance at 0.5%				
−	52	49	38	70
+	13	19	30	65
LSD (0.05)	12		14	
$(NH_4)_2SO_4$ at 1%				
−	48	45	53	68
+	36	49	34	68
LSD (0.05)	NS		15	
$NaHSO_4$ at 0.13%				
−	37	40	—[a]	—
+	31	40	—	—
LSD (0.05)	NS			

[a] $NaHSO_4$ was not tank-mixed with fenoxaprop.

imazamethabenz activity, which appeared to be related to herbicide solubility and absorption (Liu et al. 1992, 1995). The response of low rates of imazamethabenz to $(NH_4)_2SO_4$ was also marginal (Liu et al. 1992). It is unclear why drought stresses could counteract the effect of $(NH_4)_2SO_4$ or $NaHSO_4$ on imazamethabenz phytotoxicity even though drought had no substantial influence on imazamethabenz retention, absorption, and translocation (Xie et al. 1995, 1996).

In the growth chambers set at high temperature (30/20°C), imazamethabenz phytotoxicity was enhanced by the addition of Agral 90 at 0.25% or $NaHSO_4$ at 0.13%, as long as wild oat plants were watered adequately (Table 2). But such enhancement could not be found under the combined stress of high temperature and long term drought. The addition of Agral 90 at 0.25% under low temperature (10/5°C) increased imazamethabenz phytotoxicity relative to that of imazamethabenz alone. $(NH_4)_2SO_4$ at 1% had no significant impact on imazamethabenz performance in growth chamber-grown wild oat irrespective of temperature and soil moisture conditions (Table 2).

Table 2. Effect of additives on the phytotoxicity imazamethabenz at 150 g/ha in wild oat plants grown under different temperature conditions. The experiment was conducted in two growth chambers set at either 30/20°C or 10/5°C. The drought was imposed by withholding water for 7 days before spraying with an additional 10 days of stress after spraying.

		30/20°C		10/5°C
Additive	Rate (%)	Well watered	Drought	Well watered
		shoot dry weight (% of respective control)		
None		61	52	65
Agral 90	0.25	22	51	38
$(NH_4)_2SO_4$	1	54	51	52
$NaHSO_4$	0.13	35	62	47
LSD (0.05)		16		14

Effect of Additives on Fenoxaprop Phytotoxicity

Drought stress significantly reduced the phytotoxicity of fenoxaprop in wild oat (Table 1), which was consistent with the previous results (Xie et al. 1994b). Within the same soil moisture regime, surfactants Agral 90 at 0.5% or Enhance at 0.5% had no significant impact on fenoxaprop phytotoxicity (Table 1). Crabgrass [*Digitaria sanguinalis* (L.) Scop. and *D. ischaemum* [(Schreb. ex Schweig.) Schreb. ex Muhl.] control with fenoxaprop was also not increased by surfactants (Neal et al. 1990). Agral 90 surfactant did not change the level of wild oat control with barban (4-chloro-2-butynyl 3-chlorophenylcarbamate) (Chow 1988) or with sethoxydim {2-[1-(ethoxyimino)butyl]-5-[2-(ethylthio)propyl]-3-hydroxy-2-cyclohexen-1-one} (Harker 1992). With EC-formulated fenoxaprop alone, it was shown that wild oat foliage under both well watered and drought conditions could absorb approximately 90% of applied herbicide 4 days after application (Xie et al. 1996), indicating that the absorption of fenoxaprop by wild oat plants was not the process limiting fenoxaprop phytotoxicity. Since the influence of surfactants, when used as spray additives, on

Table 3. Effect of MCPA at 300 g/ha on the phytotoxicity of imazamethabenz at 200 g/ha or fenoxaprop at 140 g/ha in droughted wild oat plants. The experiment was conducted in the greenhouse. The drought was imposed by withholding water for 8 days before spraying with an additional 10 days of stress after spraying.

	Imazamethabenz		Fenoxaprop	
MCPA	Well watered	Drought	Well watered	Drought
	shoot dry weight (% of respective control)			
−	25	43	29	73
+	30	44	31	75
LSD (0.05)	12		13	

herbicide performance is associated primarily with their impact on herbicide retention and penetration into plants (Kirkwood 1993, Stock and Holloway 1993, Wills and McWhorter 1988), the present study (Table 1) suggested that the adverse drought effect on the phytotoxicity of commercially formulated fenoxaprop could not be alleviated by the use of surfactants, and the adverse effect of drought was not mediated by limiting the herbicide absorption.

Under well watered conditions, the activity of fenoxaprop in wild oat was increased significantly by the addition of $(NH_4)_2SO_4$ at 1% (Table 1); but under drought stress, fenoxaprop was less effective, and the positive impact of $(NH_4)_2SO_4$ disappeared. With nonstressed wild oats plants, the phytotoxicity of barban (Chow 1988), sethoxydim (Harker 1992, 1995) and clethodim {(*E*,*E*)-(±)-2-[1-[[(3-chloro-2-propenyl)oxy]imino]propyl]-5-[2-(ethylthio)propyl]-3-hydroxy-2-cyclohexen-1-one} (Harker 1995) was enhanced by the addition of $(NH_4)_2SO_4$. Drought stress reduced thifensulfuron {3-[[[[(4-methoxy-6-methyl-1,3,5-triazin-2-yl)amino]-carbonyl]amino]sulfonyl]-2-thiophenecarboxylic acid} phytotoxicity regardless of spray additives (Nalewaja and Adamczewski 1988). Nevertheless, the present study (Table 1) indicated that it was unlikely that the reduction in fenoxaprop activity in wild oat caused by drought could be alleviated by tank-mixing with $(NH_4)_2SO_4$.

Effect of MCPA on Imazamethabenz or Fenoxaprop Phytotoxicity

Within the same soil moisture regime, the addition to spray solution of MCPA ester at 300 g a.i./ha had no significant influence on the phytotoxicity of imazamethabenz in wild oat (Table 3). This suggested that MCPA ester could be tank-mixed with imazamethabenz without reducing wild oat control regardless of soil moisture conditions, an extension of our previous study, which found this to be true of well watered wild oat plants (Liu et al. 1994).

Fenoxaprop phytotoxicity was reduced when applied on wild oat under drought conditions, a pattern unchanged by the addition of MCPA ester at 300 g a.i./ha (Table 3). Although the activity of some other graminicides in grassy weeds could be antagonized by MCPA (Barnwell and Cobb 1994, O'Sullivan and Kirkland 1983), Deschamps et al. (1990) demonstrated that fenoxaprop could be applied as a tank mixture with MCPA ester to control wild oat effectively while protecting wheat from herbicide injury. The present study (Table 3) suggests that MCPA does not alter the response pattern of fenoxaprop activity to drought stress and that unless the stress is relieved, MCPA and fenoxaprop mixture should not be applied.

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