Crop Response to Fallow Applications of Atrazine and Clomazone[1]

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Abstract. The response of oat, foxtail millet, proso millet, and sunflower to atrazine and clomazone applied the previous fall was investigated two years in field studies near Akron, CO and Sidney, NE. Foxtail millet biomass, and proso millet and sunflower grain yields were not reduced when these crops were seeded into soil that had been treated the previous fall with atrazine and/or clomazone at rates of 0.6 or 1.1 kg ai/ha. Forage yield of oat was reduced 11 to 18% by some treatments, but this effect was not consistent over years or sites. Treatments containing 1.1 kg/ha of atrazine provided 1 to 5 wk of residual weed control in foxtail millet, proso millet, and sunflower. The study indicated that producers have flexibility in crop selection when using atrazine and clomazone in reduced- and no-till production systems. **Nomenclature:** Atrazine, 6-chloro-*N*-ethyl-*N'*-(1-methylethyl)-1,3,5-triazine-2,4-diamine; clomazone, 2-[(2-chlorophenyl)methyl]-4,4-dimethyl-3-isoxazolidinone; foxtail millet, *Setaria italica* (L.) Beauv.; oat, *Avena sativa* L.; proso millet, *Panicum miliaceum* L.; sunflower, *Helianthus annuus* L.

Additional index words: Follow crop, no-till fallow, reduced-till fallow, crop rotation, cropping intensity.

INTRODUCTION

The predominant crop rotation in the western portion of the Central Great Plains is winter wheat (*Triticum aestivum* L.)-fallow. Fallowing soil is a recognized practice in areas receiving 400 mm or less annual precipitation. Fallowing helps to ensure establishment of winter wheat and stabilizes economic production (17). Replacing tillage with herbicides for weed control in a reduced- or no-till fallow production system improves soil water storage (7, 9), allowing producers to explore more intensive crop rotations involving two or three crops in a three- or four-year time period, respectively (11, 15).

Atrazine and clomazone may be applied after winter wheat harvest for weed control during the non-crop periods in chemical fallow (16, 20). Maintaining wheat residues on the soil surface with chemical fallow has been shown to increase grain yields of summer crops such as safflower (*Carthamus tinctorius* L.), corn (*Zea mays* L.), and proso millet in the Central Great Plains (2). However, injury to corn, spring wheat, and oat in the year following application of clomazone has been observed (10). Atrazine injury to barley (*Hordeum vulgare* L.), spring wheat, and oat the year following application of atrazine also has been reported (3).

Winter annual grass weeds, such as downy brome (*Bromus tectorum* L.) and jointed goatgrass (*Aegilops cylindrica* L.), have become troublesome in the winter wheat-fallow production regions of the Central Great Plains and the Pacific Northwest. The inclusion of a summer crop in the rotation with winter wheat is a recognized practice to control the winter annual grass weeds in winter wheat (11). The summer crop lengthens the time between winter wheat crops, allowing germination and natural seed decay to reduce weed seed populations in the soil before seeding the next winter wheat crop.

Triazine-resistant biotypes of downy brome have been reported (14), and atrazine has not controlled jointed goatgrass consistently (5, 6). Clomazone controls both downy brome and jointed goatgrass when applied in the fall before germination (16). The cost of clomazone has limited the use of this herbicide in many dryland winter wheat production areas, therefore producers may tank mix atrazine with a reduced rate of clomazone to reduce treatment costs and improve the consistency of control provided by clomazone alone. Tank mixing herbicides with different modes of action is also a recognized strategy to delay development of resistant biotypes to either herbicide (13).

The objectives of this study were to determine the response of oat, foxtail millet, proso millet, and sunflower to atrazine and clomazone alone or in combination applied the previous fall, and the length of residual weed control in the summer crop canopy from fall-applied herbicide treatments.

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Table 1. Agronomic operations for site establishment at Akron, CO and Sidney, NE.

Crop[a]	Akron, CO Seeding date	Akron, CO Seeding rate	Akron, CO N rate[b]	Sidney, NE Seeding date	Sidney, NE Seeding rate	Sidney, NE N rate[b]
		kg/ha	kg/ha		kg/ha	kg/ha
1991						
Oat	April 5	78	67	April 4	67	67
Foxtail millet	June 12	12	34	June 13	15	34
Proso millet	June 12	12	34	June 13	15	34
Sunflower	June 13	45 500[c]	67	June 13	38 300[c]	67
1992						
Oat	March 27	78	67	March 31	67	67
Foxtail millet	June 11	6	34	June 8	15	34
Proso millet	June 11	12	34	June 8	15	34
Sunflower	June 12	45 500[c]	67	June 10	38 300[c]	67

[a]Varieties: Akron—'Russell' oat, 'German Red' foxtail millet, 'Sunup' proso millet, and Triumph 'Hybrid 566' sunflower; Sidney—'Ogle' oat, 'White Wonder' foxtail millet, 'Sunup' proso millet, and Jacques 'Hybrid 827' sunflower.

[b]Nitrogen applied as ammonium nitrate.

[c]Sunflower seeding rate in plants per hectare.

MATERIALS AND METHODS

Field studies were located near Akron, CO and Sidney, NE in 1990–1991 and 1991–1992. Studies both years near Akron, CO were conducted on a Platner loam (Aridic Paleustoll) with 1.3% organic matter, 18% clay, and pH 6.7. Studies both years near Sidney, NE were on an Alliance silt loam (Aridic Argiustoll) with 2.8% organic matter, 24% clay, and pH 6.7 in 1990–1991 and 3.5% organic matter, 15% clay, and pH 6.5 in 1991–1992.

Atrazine and clomazone were applied in the last half of August at rates of 0, 0.6, and 1.1 kg/ha alone and in all possible combinations, resulting in nine herbicide treatments. Herbicides were applied with a CO_2-pressurized, backpack sprayer delivering 102 L/ha at 150 kPa at Akron, CO and 102 L/ha at 138 kPa at Sidney, NE. Plots at Akron, CO were 5 by 5 m and at Sidney, NE were 3 by 5 m. A randomized complete block design with four replications was used for each crop.

Seeding dates and rates, and nitrogen application rates for the four summer crops at both locations are presented in Table 1. Herbicide injury to crops was assessed 3 and 6 wk after planting by visual evaluations and biomass measurements. Visual evaluations were on a scale of 0 to 100, with 0 being no injury and 100 being complete mortality. Biomass was collected from a 0.5-m^2 area within each plot and oven-dried.

Weed control in the crop was assessed weekly until flowering. Once greater than 15% of the area within a plot was infested, residual weed control was declared inadequate and the plot was kept weed free by hoeing until harvest. The predominant weed species at Akron, CO and Sidney, NE were volunteer winter wheat, Russian thistle (*Salsola iberica* Sennen & Pau #[3] SASKR), kochia [*Kochia scoparia* (L.) Schrad. # KCHSC), slimleaf lambsquarters [*Chenopodium leptophyllum* (Mog.) Nutt. ex S. Wats. # CHELE), redroot pigweed (*Amaranthus retroflexus* L. # AMARE), and witchgrass (*Panicum capillare* L. # PANCA).

Forage yields were determined for oat and foxtail millet at the early milk and heading stage, respectively. Grain yields for proso millet and sunflower were determined at maturity. Forage and grain yields were determined by harvesting 10 and 4.3 m of the center two rows at Akron and Sidney, respectively. Sunflower data were not collected at Akron in 1991 because of poor sunflower stand.

In late spring of 1992, soil samples were collected at both Akron and Sidney from plots treated previously with 1.1 kg/ha atrazine and seeded to oat. Six soil samples were taken per plot at depths of 0 to 2.5, 2.5 to 7.5, and 7.5 to 15 cm and composited by depth. Soil samples were air-dried and frozen 6 mo prior to atrazine analysis. Water (3 ml) was added to each soil sample (40 g) and atrazine was extracted with 100 ml methanol by shaking for 1 h on a rotary shaker. Extract and soil were separated by suction filtration. Methanol was removed by vacuum rotary evaporation and 2.5 to

[3]Letters following this symbol are a WSSA-approved computer code from Composite List of Weeds, Revised 1989. Available from WSSA, 309 W. Clark St., Champaign, IL 61820.

7.0 ml of xylene was added prior to measurement with a Hewlett-Packard 5840 gas chromatograph[4] equipped with a nitrogen-phosphorus specific thermionic detector and a limit of quantitative detection for atrazine at 0.001 mg/kg.

Data for each crop were pooled for statistical analysis unless an interaction between sites and/or years was observed, in which case data were analyzed individually by site and/or year. Means from grain and forage yield were compared using single degree of freedom contrasts at $\alpha = 0.05$. No interaction between herbicides was detected, so yield data from all treatments at a single herbicide use rate were pooled for analysis. Means from residual weed control data were compared with Dunnett's one-tailed T test ($\alpha = 0.05$) for comparison of all treatments against the control treatment. Some interaction between herbicides was detected with the residual weed control data, so individual treatment means are presented. Means from the atrazine soil residual data were compared with Fisher's protected LSD at $\alpha = 0.05$.

RESULTS AND DISCUSSION

Foxtail millet biomass, and proso millet and sunflower grain yields were not reduced when these crops were seeded into soil that had been treated the previous fall with atrazine and/or clomazone. Yields averaged across herbicide treatments, sites, and years were 4280, 2300, and 1960 kg/ha for foxtail millet, proso millet, and sunflower, respectively. Visible crop injury or early-season biomass reduction were not observed with any crop (data not shown). It appears that foxtail millet, proso millet, or sunflower may be used in a no-till or reduced tillage 3-yr crop production system where atrazine and/or clomazone are applied in the fall following winter wheat harvest for fallow weed control.

Oat responded more erratically to increasing rates of atrazine and clomazone than did the other three crops. At Akron, the higher rate of atrazine reduced oat yields in 1991, whereas in 1992, clomazone at both rates reduced oat yields (Table 2). At Sidney, oat forage yield increased with atrazine and clomazone application in 1991. Volunteer winter wheat was a troublesome weed at Sidney in the fall of 1990 and early spring of 1991. Plots treated with 1.1 kg/ha of atrazine and/or clomazone controlled volunteer wheat 100% in the fall and

[4]Hewlett-Packard, Avondale, PA 19311.

Table 2. Biomass of oat as affected by atrazine and clomazone treatments at Akron, CO and Sidney, NE in 1991 and 1992.

Herbicide rate	Akron 1991	Akron 1992	Sidney 1991	Sidney 1992
	kg/ha			
Atrazine				
0	5700	4130	3410	3100
0.6	6080	4050	4950	3090
1.1	4680	3980	4860	3190
Clomazone				
0	5640	4370	4080	3190
0.6	5640	3900	4690	3060
1.1	5380	3900	4450	3130
	Significance of contrast			
No atrazine (A) vs A	NS[a]	NS	**	NS
Low A vs high A	**	NS	NS	NS
No clomazone (C) vs C	NS	**	*	NS
Low C vs high C	NS	NS	NS	NS

[a]NS = not significant at 0.05; * and ** indicates statistical significance at levels of 0.05 and 0.01, respectively.

subsequent spring. Volunteer wheat present prior to seeding oat was killed with glyphosate [*N*-(phosphonomethyl)glycine], but oat yields may have been adversely affected in plots where volunteer winter wheat was not controlled early. Oat yields at Sidney in 1992 were not affected by herbicide treatments. Oat injury may reflect its earlier planting date (Table 1), as well as its higher susceptibility to these herbicides (3, 10).

Stratification of residual atrazine in the soil in 1992 may explain the lack of oat response to that herbicide in that year. Soil from three depths was analyzed for atrazine at Akron and Sidney in 1992. Atrazine concentration in the top 2.5 cm of soil was 0.119 mg/kg, more than twice greater than in the next 5 cm of soil (0.054 mg/kg) and tenfold the concentration found in the 7.5 to 15 cm soil depth (0.011 mg/kg). Stratification of atrazine may have resulted from either a lack of downward movement by leaching or an enhanced upward movement with evaporating water, both a possible result of the dry spring of 1992.

Hoffman and Lavy (12) reported an approximate 35% reduction in plant dry weight, when averaged over four seeding rates, for oat grown in the greenhouse in a silt loam soil with pH 7.0, 3.0% organic matter content, and 20% clay content and treated with atrazine at 0.1 mg/kg. Oat dry weight reduction was only about 7% for oat seeded in a silty clay loam with pH 6.2, 3.8% organic matter content, 36% clay content and treated with 0.1 mg/kg atrazine. Oat at Akron and Sidney were seeded at a depth greater than 2.5 cm with a hoe drill,

Table 3. Weed control[a] in proso millet and sunflower from fall treatments of atrazine and clomazone alone or in combination at Akron, CO and Sidney, NE in 1991 and 1992[b].

Herbicide combinations		Proso millet			Sunflower	
Clomazone	Atrazine	Akron 1991	Akron 1992	Sidney '91+'92	Akron 1992	Sidney '91+'92
kg/ha		weeks after seeding				
Control		0	0	0	0	0
0.0	0.6	0	0	1	0	2*
0.0	1.1	1*	0	2*	0	2*
0.6	0.0	0	0	0	0	1
0.6	0.6	0	0	0	0	1
0.6	1.1	1*	4*	2*	4*	2*
1.1	0.0	0	1	0	1	1
1.1	0.6	0	3*	1	4*	0
1.1	1.1	1*	5*	2*	5*	2*

[a]Predominant weed species were volunteer winter wheat, Russian thistle, kochia, slimleaf lambsquarters, redroot pigweed, and witchgrass.

[b]Means within columns followed by an asterisk (*) indicates significant difference from the nontreated control at the 5% level as indicated by Dunnett's one-tailed T test for comparison of all treatments against a control.

which displaces surface soil from the row to form a ridge between rows. A dry spring in 1992 (Figure 1) may have allowed the oat to establish roots below the atrazine-treated soil and thus grow large enough to avoid injury from any subsequent atrazine exposure. Our results, though not consistent, suggest that oat planted in the spring following fall applications of atrazine and/or clomazone may be injured by these herbicides.

Fall applications of atrazine and/or clomazone provided short residual weed control in the summer crops (Table 3). Weed control in foxtail millet was similar to that in proso millet; therefore, only weed control in proso millet is shown. Treatments containing atrazine at 1.1 kg/ha consistently provided 2 wk of greater than 85% weed control in proso millet, foxtail millet, and sunflower at Sidney in 1991 and 1992. The same treatments provided 1 wk of weed control in proso millet and foxtail millet at Akron in 1991. As much as 4 to 5 wk of weed control was provided in proso millet, foxtail millet, and sunflower at Akron in 1992 by treatments containing 1.1 kg/ha of atrazine and either 0.6 or 1.1 kg/ha clomazone, respectively.

Few weeds infested oat (data not shown) except in the untreated check at Akron in 1991. The well-established stand of oat was competitive with summer annual weeds.

When atrazine was used initially for chemical fallow in a winter wheat-fallow rotation in the Central Great Plains, producers occasionally experienced severe crop injury 14 mo after application. Research indicated yield loss due to atrazine was correlated with soil pH exceed-

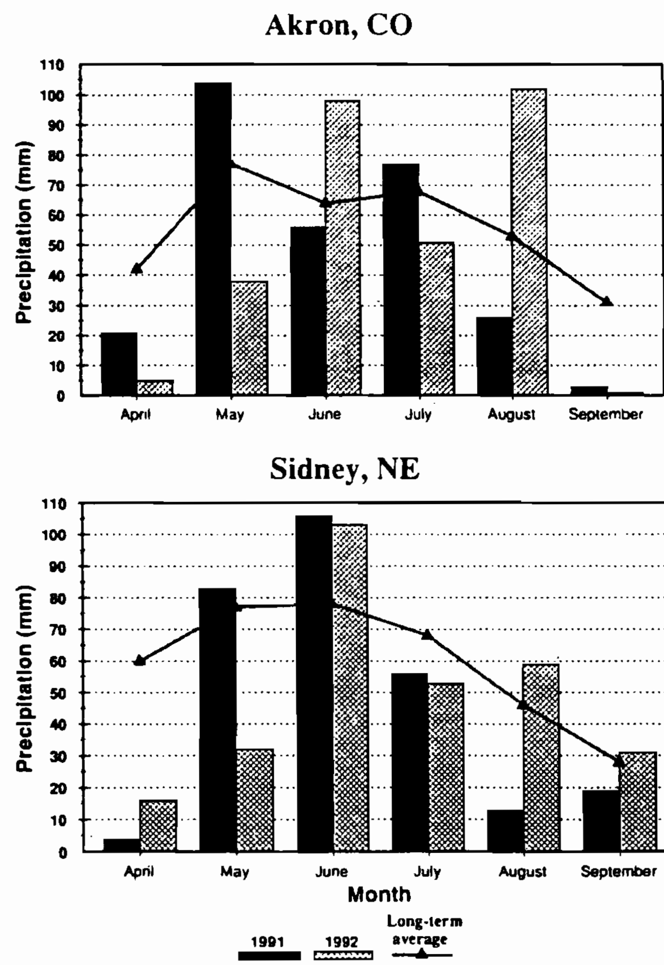

Figure 1. Growing season precipitation at Akron, CO and Sidney, NE in 1991 and 1992 vs the long-term average for each site. Precipitation during fallow (August-March) at Akron was 112 and 110% of normal (142 mm) for 1990–1991 and 1991–1992, respectively, and at Sidney was 116 and 97% of normal (158 mm) for 1990–1991 and 1991–1992, respectively.

ing 7.5 (18). Yield loss was reduced in soil with clay contents greater than 20%. In this study, only minor oat injury was observed 8 to 9 mo after atrazine application on soils with pH 6.5 to 6.7, a pH level conducive to atrazine degradation (18).

Producers should be aware of the characteristics of the soil before using the technology described here. The concept "farming soils, not fields" developed for fertilizer applications (4) would also apply for planning cropping options after herbicide treatments in reduced- and no-till production systems. Knowledge of soil characteristics, particularly pH, will enable producers to avoid potential atrazine carryover, and increase their frequency of cropping.

Clomazone soil activity is influenced by soil organic matter, clay content, and cation exchange capacity (19). Clomazone activity is highest in sandy soils with low organic matter content and low cation exchange capacities. Unlike atrazine, no correlation between soil pH and activity has been shown for clomazone (19). The half-life of clomazone was 33 and 37 d for a Montana loam and silty clay loam soil, respectively (8).

The effectiveness of atrazine and clomazone in controlling weeds during fallow enables producers to crop more intensively in this region. Our study, in conjunction with previous research (1, 2) demonstrates that producers have cropping flexibility within reduced- and no-till production systems with atrazine and clomazone. This flexibility in crop selection enables the producer to base rotations on expected economic return and maximum water use efficiency by the crop, while still controlling weeds during fallow and maintaining adequate crop residue levels on the soil surface for soil erosion control.

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