Tolerance of Safflower (*Carthamus tinctorius*), Corn (*Zea mays*), and Proso Millet (*Panicum miliaceum*) to Clomazone[1]

RANDY L. ANDERSON[2]

Abstract. Clomazone is used in the Central Great Plains for weed control during fallow in a winter wheat-fallow rotation. Improved precipitation storage during non-crop periods has stimulated new crop rotations such as winter wheat-corn or proso millet-fallow. The objective of this study was to determine if clomazone applied in the fall after winter wheat harvest would injure succeeding spring-planted crops. Greenhouse studies indicated crop tolerance to clomazone was in the order of safflower > corn > proso millet > barley > winter wheat. Clomazone did not affect grain yields of safflower, corn, or proso millet grown at two field sites with different soil textures (silt loam and sandy loam), nor germination of seed from treated plants of these crops. A no-till production system with clomazone increased grain yields for all crops compared to the conventional system where tillage replaced clomazone for fallow weed control. **Nomenclature:** Clomazone, 2-[(2-chlorophenyl)methyl]-4,4-dimethyl-3-isoxazolidinone; barley, *Hordeum vulgare* L. 'Steptoe'; corn, *Zea mays* L. 'Pioneer 3732'; proso millet, *Panicum miliaceum* L. 'Cope'; safflower, *Carthamus tinctorius* L. 'S-208'; winter wheat, *Triticum aestivum* L. 'Vona'.
Additional index words: Tillage system, atrazine, paraquat, pendimethalin, *Amaranthus retroflexus, Kochia scoparia, Salsola iberica, Setaria viridus*, AMARE, KCHSC, SASKR, SETVI.

INTRODUCTION

The prevalent crop rotation for the western part of the Central Great Plains is winter wheat-fallow. The purpose for fallowing is to minimize drought effects on winter wheat production by supplying soil water stored from precipitation during the non-crop interval for crop use (8, 12). Weed control programs for fallow have evolved by periodically introducing improved equipment and replacing some tillage operations with herbicides. These new fallow methods have increased the precipitation-storage-efficiency significantly (8). This increase in storage efficiency has stimulated a shift to crop rotations that grow two crops in 3 yr, with safflower, corn, or proso millet being planted after winter wheat (3, 4, 12).

The wheat-fallow cropping rotation encourages difficult-to-control weeds such as downy brome (*Bromus tectorum* L.) and jointed goatgrass (*Aegilops cylindrica* Host) to infest winter wheat as they have similar growth habits (12). This two-crops-in-three-years rotation is advantageous for producers in controlling these two species. The summer crop lengthens the time between winter wheat crops. This allows germination and natural seed decay to reduce weed seed populations in the soil before the next winter wheat crop is planted. However, the producers must ensure that downy brome or jointed goatgrass seedlings do not produce seeds during the fallow period.

Atrazine [6-chloro-*N*-ethyl-*N'*-(1-methylethyl)-1,3-5-triazine-2,4-diamine] is applied after winter wheat harvest for weed control during non-crop periods in chemical fallow (9, 19, 20), but its bioactivity on downy brome and jointed goatgrass has not always been effective. Triazine-resistant biotypes of downy brome have been reported (14, 16), and atrazine has not performed consistently on jointed goatgrass (5, 6). Clomazone controls both downy brome and jointed goatgrass when applied in the fall before germination (17) and it is labeled for weed control during fallow.

Using clomazone would eliminate triazine-resistant downy brome biotypes, and also allow producers to rotate herbicides in their weed management programs during fallow. This rotation of herbicides would delay development of resistant biotypes to either herbicide (14). However, injury to corn, wheat, and oats (*Avena sativa* L.) the year following applications of clomazone has been observed (10, 15).

The objectives of this study were to determine: 1) susceptibility of barley, safflower, corn, proso millet, and winter wheat to clomazone; 2) response of the more tolerant spring-planted crops to clomazone applied the previous fall; and 3) weed control enhancement of conventionally used herbicides within the spring-

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[2]Res. Agron., Agric. Res. Serv., U. S. Dep. Agric., Akron, CO 80720.

Table 1. Weed control operations during fallow and crop seasons.

Fallow treatment	Fall operations 1		Fall operations 2		Crop	Spring operations 1		Spring operations 2		Economic cost[a]
										$ ha^{-1}
1986–1987										
Clomazone	CH:[b]	July 22	RH*:	Oct. 29	Safflower	RH*:	April 15			58
					Corn	RH*:	May 19			53
					Proso millet	RH*:	May 29			52
Conventional	SP:	July 22	SP:	Oct. 27	Safflower	DK:	April 15	RH:	April 15	52
					Corn	DK:	April 15	RH*:	May 19	51
					Proso millet	DK:	April 15	RH*:	May 29	50
1987–1988										
Clomazone	RH*:	Aug. 31			Safflower	RH*:	April 19			44
					Corn	RH*:	May 16			39
					Proso millet	RH*:	May 16			38
Conventional	SP:	July 23	SP:	Sept. 18	Safflower	DK:	April 18	RH:	April 19	52
					Corn	DK:	April 18	RH*:	May 16	51
					Proso millet	DK:	April 18	RH*:	May 16	50

[a]Projected costs: Clomazone: $15.70/kg; atrazine: $2.25/kg; pendimethalin: $6.75/kg; paraquat: $14.00/kg; disk: 17.35/ha; sweep plow: $11.10/ha; and spraying operation: $9.90/ha. The calculated economic cost includes clomazone at the 0.5 rate only and the conventional use rate for within-crop herbicides.

[b]CH: contact herbicide (paraquat); RH: residual herbicide; RH*: residual herbicide + paraquat; SP: sweep plow; DK: disk.

planted crops by clomazone applied after winter wheat harvest.

MATERIALS AND METHODS

Crop susceptibility study. A preliminary study examining crop susceptibility to clomazone was conducted in the greenhouse between Oct., 1985 and Feb., 1986. A Valent sand (mixed, mesic Ustic Torripsamment) was treated with clomazone and mixed in a soil blender to establish a concentration gradient of 0, 40, 80, 120, 160, and 200 ng g^{-1}. Six seeds of 'Vona' winter wheat, 'Steptoe' barley, 'S-208' safflower, 'Pioneer 3732' corn, and 'Cope' proso millet were planted into 300 g of treated soil contained in 9-cm diam. by 9-cm deep plastic pots without drainage holes. The soil water level was maintained at 80% field capacity by daily weighing and watering. Plant fresh weight, dry weight, and percent chlorosis of four random plants were measured 21 d after planting. The percent chlorosis was determined by dividing the length of the leaf which was chlorotic by the total length of the leaf, as clomazone chlorosis appears in distinct bands. The technique for determining the percent chlorosis was similar to Gallandt et al. (7). The experimental design was a randomized complete block with five replications and the study was conducted twice.

Field studies. The effect of clomazone on production of the three most tolerant crops (safflower, corn, and proso millet) determined from the crop susceptibility study were evaluated at two field sites at Akron, CO. The average precipitation for this location is 416 mm, with 80% of this moisture occurring between April and September each year. The soil at one site was a Rago silt loam (fine, montmorillonitic, mesic Pachic Argiustoll) with 1.3% organic matter and a pH of 7.0. The second site was on a Paoli fine sandy loam (coarse-loamy, mixed, mesic Pachic Haplustoll) with 0.9% organic matter and a pH of 7.1. Before this study, both sites had been in a winter wheat-fallow rotation for several years. The study was initiated in July, 1986 and concluded in Oct., 1988.

A randomized complete block design with four replications was used for each crop. Six herbicide treatments within a no-till production system were evaluated. Clomazone was applied at 0.5, 0.8, and 1.1 kg ai ha^{-1} after winter wheat harvest in 1986 and 1987 (dates of weed control operations during this study are listed in Table 1).

Two within-crop preemergence herbicide levels were combined with each clomazone rate. The herbicide levels were the conventional rate used for each crop by the local producers {safflower: 1.1 kg ha^{-1} of pendimethalin[3] [*N*-(1-ethylpropyl)-3,4-dimethyl-2,6-dinitrobenzenamine]; corn: 1.1 kg ha^{-1} of atrazine; and

[3]Pendimethalin is not currently registered for use in safflower, but was included in this study for research purposes in developing no-till production systems.

Table 2. Clomazone effect on grain yield of safflower, corn, and proso millet, and biomass production of corn and proso millet[a].

		Grain yield						Biomass production			
		Silt loam			Sandy loam			Silt loam		Sandy loam	
Treatment	Rate	Safflower	Corn	Proso millet	Safflower	Corn	Proso millet	Corn	Proso millet	Corn	Proso millet
	kg ha^{-1}	kg ha^{-1}						Mg ha^{-1}			
Clomazone	0.5	1140	3950	2950	620	1340	860	22.3	7.4	13.0	4.3
Clomazone	0.8	1140	3860	3230	690	1270	930	22.2	8.1	12.5	4.3
Clomazone	1,1	1210	4090	3150	640	1300	980	22.9	8.0	13.0	4.4
Conventional system		1040	2800	2600	570	950	760	17.7	7.0	9.8	3.8
LSD (0.05)		90	400	140	60	220	70	1.7	0.7	0.7	0.2

[a]Data means are averaged over years and within-crop herbicide levels.

proso millet: 0.6 kg ha^{-1} of atrazine}, and one-half of the conventional rate. The conventional system of production in this region for each crop {sweep plowing for fallow weed control, disking for seedbed preparation, and the same herbicides for within-crop weed control at the conventional rate listed above} was included as a seventh treatment. Plot size was 4 m by 4 m.

If weeds were present when residual herbicides were applied, paraquat (1,1′-dimethyl-4,4′-bipyridinium ion) at 0.3 kg ha^{-1} was applied in a tank-mix application (indicated by an * in Table 1). The clomazone treatments maintained weed-free conditions until early May of each year, which necessitated adding paraquat to the within-crop herbicide treatments for corn and proso millet.

'S-208' safflower was planted at 50 kg ha^{-1} on Apr. 15, 1987 and Apr. 18, 1988. 'Pioneer 3732' corn was planted at 28 900 plants/ha on May 19, 1987 and May 16, 1988. 'Cope' proso millet was planted at 11 kg ha^{-1} on June 3, 1987 and June 3, 1988. Each crop was treated as a separate experiment and the crops were planted adjacent to each other. Nitrogen as ammonium nitrate was broadcast applied on Apr. 8 of both years, with 56, 56, and 34 kg N ha^{-1} applied for safflower, corn, and proso millet, respectively.

The percent chlorosis was estimated visually 14 and 28 d after planting for each crop. Weed control evaluations were made 42 and 63 d after planting for safflower, and 42 d after planting for corn and proso millet. Visual estimates of broad spectrum weed control and plant counts per plot area were recorded.

Safflower from 6 m^2 was harvested on Sept. 20, 1987 and Sept. 23, 1988. Corn aboveground biomass from 4.5 m^2 was harvested on Aug. 4, 1987 and Aug. 5, 1988; and grain yields from 6 m^2 were collected on Sept. 22, 1988. Grain yields were not collected for the corn in 1987 as the silt loam site was destroyed by hail on Aug. 6, 1987 and water stress conditions at the sandy loam site resulted in lack of kernel pollination and development. Grain yields and above-ground biomass for proso millet were harvested from a 6 m^2 area for the sandy loam site on Aug. 29, 1987, and for both sites in 1988 on Aug. 30. The 1987 silt loam site was destroyed by hail; thus no yield data were collected.

Kernel weight was determined for the grain of each crop, and 100 kernels from each plot were tested for germination 120 d after harvest at 15 C for safflower and 20 C for corn and proso millet. The duration of the germination test was 14 d.

All data were subjected to analyses of variance, and differences between treatment means were determined at the 0.05 level of probability.

RESULTS AND DISCUSSION

Crop susceptibility study. Of the plant injury parameters investigated, percent chlorosis was the most sensitive in detecting clomazone in soil; thus only the percent chlorosis data are presented. The crops varied widely in susceptibility to clomazone (Figure 1). Crop tolerance to clomazone was safflower > corn > proso millet > barley > winter wheat. Clomazone did not affect safflower at any concentration, so safflower data are not shown in Figure 1. Safflower, corn, and proso millet were at least 10 times more tolerant to clomazone than barley or wheat, as shown by the percent chlorosis at the 120 ng g^{-1} concentration.

Field studies. Data for the crop response to clomazone shown in Table 2 are expressed as the means averaged over years (except for crops which were not harvested due to hail or water stress) and within-crop herbicide levels, as no interactions between these factors oc-

Table 3. Percent visual weed control and plant counts of Russian thistle and redroot pigweed for clomazone-pendimethalin[a] combinations in safflower. Data was collected 63 d after planting and treatment means were averaged over years.

		% Weed control				Plant counts							
						Russian thistle				Redroot pigweed			
		Silt loam		Sandy loam		Silt loam		Sandy loam		Silt loam		Sandy loam	
		Pendimethalin (kg ha^{-1})				Pendimethalin (kg ha^{-1})				Pendimethalin (kg ha^{-1})			
Treatment	Rate	0.6	1.1	0.6	1.1	0.6	1.1	0.6	1.1	0.6	1.1	0.6	1.1
	kg ha^{-1}	%				plants m^{-2}							
Clomazone	0.5	81	84	88	88	0.2	0.0	0.9	0.3	0.5	0.5	0.7	1.5
Clomazone	0.8	92	95	89	93	0.1	0.1	0.5	0.7	0.0	0.0	0.7	0.6
Clomazone	1.1	94	91	87	89	0.2	0.1	0.7	0.8	0.3	0.5	0.9	0.6
Conventional system		91		65		0.2		0.4		0.5		6.9	
LSD (0.05)		8		8		NS		NS		NS		2.7	

[a]Pendimethalin is not currently registered for use in safflower.

curred. Safflower did not exhibit chlorosis at either site in either year (data not shown), and grain yield was not affected by increasing clomazone rates (Table 2). These results agree with previous research indicating safflower tolerance to clomazone (18). Safflower tolerated hail, as leaves were not severely damaged by hail at the silt loam site in 1987, and grain yields exceeded 800 kg ha^{-1}, while corn and proso millet were completely destroyed by this hail storm.

Slight chlorosis (5%) occurred with corn at all clomazone rates at both sites in 1987, but this symptom was not observed in 1988. This chlorosis in 1987 may have resulted from the late application of clomazone in 1986 (Oct. 31). Clomazone was applied 60 days earlier in 1987 (Aug. 31), and would have degraded more before corn planting in 1988. However, corn biomass production by early August was not affected by clomazone in either year, and grain yield was not affected by clomazone at either site in 1988 (Table 2). Clomazone did not reduce biomass or grain yield of proso millet at either site (Table 2), nor cause chlorosis. For all crops, the production system with clomazone yielded more than the conventional system where tillage controlled weeds during fallow.

Herbicides can affect seed of treated parent plants. Germination of seed from plants of mouse-ear cress [*Arabidopsis thaliana* (L.) Heynh.] treated with atrazine was reduced and surviving seedlings were less vigorous (11). Metribuzin [4-amino-6-(1,1-dimethylethyl)-3-(methylthio)-1,2,4-triazin-5(4*H*)-one] reduced 1000-kernel weight and seedling vigor of seed from treated winter wheat plants, but this response was cultivar-related (2). In this study, however, clomazone did not affect germination nor 1000-kernel weight of seed from any treated crop (data not shown).

Weed control in corn and proso millet was >95% for all herbicide combinations and the conventional system, and season-long control was maintained by all treatments (data not shown). The only species infesting the plot area of either crop was kochia (*Kochia scoparia* (L.) Schrad. #[4] KCHSC). Combining clomazone applied in the fall with atrazine applied preemergence for both crops in a no-till system would allow producers to reduce herbicide rate, as reduced rates were as effective as normal use rates.

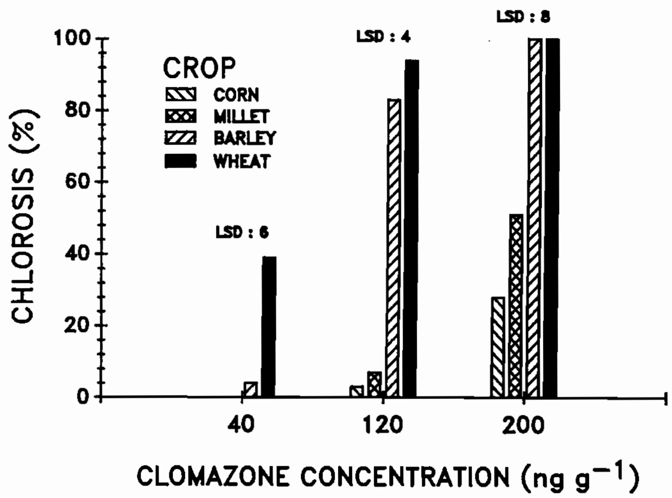

Figure 1. Chlorosis by clomazone at three concentrations to four crops in the greenhouse.

[4]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.

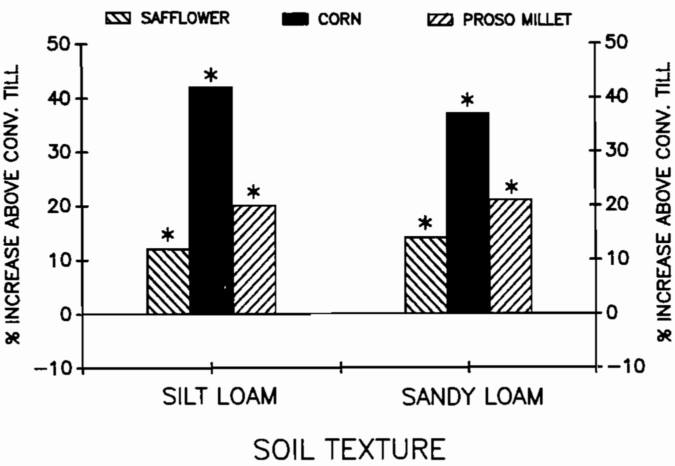

Figure 2. Response of safflower, corn, and proso millet grain yield to a no-till production system at two sites. The * indicates significant difference exists as determined by a single degree of freedom comparison between the three clomazone treatments and the conventional system within each crop.

Weed control evaluations for herbicide combinations in safflower are shown in Table 3. The treatment means are averaged over years, as there was not a significant year-by-treatment interaction. Clomazone at higher rates increased weed control by pendimethalin in safflower at the silt loam site, but not at the sandy loam site. Pendimethalin at 1.1 kg ha^{-1} in the conventional system controlled only 65% of the weeds at the sandy loam site 63 d after planting, 20% less than the clomazone plus pendimethalin combinations. All safflower plots were relatively weed free 42 d after planting (data not shown), indicating that herbicide bioactivity persisted for at least six weeks after application.

The predominant species infesting safflower at both sites were Russian thistle (*Salsola iberica* Sennen & Pau # SASKR) and redroot pigweed (*Amaranthus retroflexus* L. # AMARE). Reduced weed control with pendimethalin applied alone in the conventional system at the sandy loam site resulted from infestations of redroot pigweed (Table 3) and green foxtail (*Setaria viridis* (L.) Beauv. # SETVI) (data not shown). Clomazone controlled these species in the combination treatments.

Late season weeds, such as kochia and Russian thistle, established in safflower in all treatments at both sites, and hindered harvest operations. Safflower's lower leaves senesce rapidly after flowering in July, which allows increased light penetration and weed seed germination following late season precipitation (3). Previous research at Akron, CO, has shown that dinitroaniline herbicides incorporated into the soil will maintain weed-free safflower for the entire growing season (1). This study shows that clomazone plus pendimethalin will achieve >80% early season weed control in safflower grown without tillage, but that efficient safflower harvest operations may require a late season broadleaf herbicide to control kochia and Russian thistle.

Maintaining wheat residue on the soil surface in the Central Great Plains increases grain yield of spring-planted crops such as proso millet (4). Results from this study also demonstrate this positive response of safflower, corn, and proso millet to no-till cultural practices (Figure 2). Grain yields were increased 10 to 15% for safflower, 18 to 22% for proso millet, and 35 to 40% for corn at the two sites when residue was maintained on the soil surface. This yield response can be attributed to increased soil water storage during the non-crop period (8, 20), and more efficient water use during the crop season (4, 8).

Using clomazone will enable producers to achieve higher success in controlling downy brome and jointed goatgrass during fallow periods with a no-till production system, and also increase grain yields by maintaining wheat residue on the soil surface. Clomazone does not have a detrimental effect on safflower, corn, or proso millet production; however, producers should be aware that with corn, tolerance to clomazone is hybrid-related (13).

The economic cost of including clomazone in the no-till system is not prohibitive, especially with corn and proso millet (Table 1). In the 1987–1988 fallow-crop sequence, weed control costs for the clomazone no-till system were less than the conventional system. In 1986–1987, however, the late clomazone application necessitated an earlier contact herbicide operation and cost for the no-till system was 4% greater than the conventional system with corn and proso millet and 11% greater with safflower. Increased grain yield from the no-till system will compensate the producers for possible increased weed control costs. However, season-long weed control in no-till safflower is not easily achieved with presently available herbicides, and may inhibit the adoption of no-till production systems for this crop.

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