Photo by Susan R Winslow

THE EFFECT OF

FIVE PRE-EMERGENCE HERBICIDES

ON EMERGENCE AND ESTABLISHMENT OF

ABSTRACT

Careful selection of pre-emergence herbicide for control of weeds may improve establishment of native wildflowers grown for seed production. In a 28-d greenhouse herbicide injury experiment, 4 emerging wildflower species were established on soil treated with one of 6 pre-emergence herbicide treatments. No wildflower seedlings survived the atrazine treatment and few survived the sulfentrazone treatment. Of the 5 herbicides tested, DCPA applied at 1100 g active ingredient (ai) per ha (8 lb ai/ac) and trifluralin applied at 184 g ai/ha (2 pt ai/ac) caused the least reduction in wildflower seedling density, height, and shoot dry mass of all species. The densities, however, of *Dalea candida* Michx. ex Willd. (Fabaceae), *Gaillardia aristata* Pursh (Asteraceae), and *Ratibida columnifera* (Nutt.) Woot. & Standl. (Asteraceae) were each reduced in 1 of the 2 experimental runs, whereas the height of *D. candida* and *G. aristata* and the shoot dry mass of *R. columnifera* seedlings were reduced by trifluralin. *Liatris punctata* Hook. (Asteraceae) densities were reduced only by atrazine and sulfentrazone.

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KEY WORDS
wildflower seed crop, herbicidal weed control, herbicide injury, *Dalea, Gaillardia, Liatris, Ratibida*

NOMENCLATURE
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FOUR NATIVE WILDFLOWERS

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Recognizing the role of diversity in plant community and ecosystem function, prairie restorationists and people applying conservation plantings are requesting more wildflower species in seed mixes. Many of these species are difficult to propagate for seed production plantings. Weed competition during establishment is an important factor contributing to the failure of native wildflower plantings. Developing pre-emergence herbicide management specific to wildflower species may help reduce weed competition in the critical early establishment period.

Herbicide management of weeds during establishment of wildflower plantings is one of the most active areas of recent research (Aldrich 2002); however, there is little information available about herbicide management for wildflower seed production. Some pre-emergence herbicides have been tested for wildflower planting. In a study conducted in Nebraska and Oregon, about 35% of the 50 wildflower species planted were adversely affected by EPTC at 2.3 kg/ha (2.1 lb/ac) mixed with 0.6 kg/ha (0.5 lb/ac) trifluralin applied and incorporated into the soil before broadcast seeding (Erusha and others 1991). Johnson (1995) lists napropamide, EPTC, alachlor, pendimethalin, metolachlor, and trifluralin as herbicides for weed management when planting wildflowers along roadsides. Dickens (1992) listed the herbicides benefin, metcholachlor, EPTC, pronamide, alchlor, and trifuralin as pre-emergence herbicides for other wildflower plantings.

A controlled-environment herbicide injury study is a first step in developing herbicide management for wildflower seed production plantings because in a controlled environment, death or damage to emerging seedlings is more likely to be caused by herbicide injury than by weed competition or environmental conditions. Our overall objective was to gain a better understanding of the effects of pre-emergence herbicides on establishing native wildflower species grown for seed production. Our specific objective was to measure the emergence and early growth of 4 North American wildflower species on soil treated by one of 5 pre-emergence broadleaf herbicides and to compare that with a non-treated control in a controlled-environment greenhouse study.

MATERIALS AND METHODS

Our experimental design was a randomized split-plot with 4 replications, and it was conducted twice. The 5 herbicides and a non-treated control (Table 1) were the whole-plot treatments, and the 4 wildflower species (Table 2) were the subplot treatments. The herbicides were selected and applied at their known efficacy rate for weeds known to exist at the USDA NRCS Bridger Plant Material Center and according to the recommendations of chemical companies and the Montana State University Extension Weed Specialist. The wildflower species chosen are important in revegetation and restoration. Seed viabilities (Table 2) were tested using tetrazolium staining (Moore 1985) prior to seeding to increase the likelihood of a target seeding density of 25 viable seeds per treatment row.

Procedures

Steel trays 80 cm long, 30 cm wide, and 5 cm deep (31 in x 12 in x 2 in) were filled to a depth of 4 cm (1.6 in) with a pasteurized mixture of 50% Farland silt loam (fine-silty mixed Typic Argiboroll) and 50% sand (v:v), and the soil was watered to capacity. Each tray was assigned at random to one of 4 replications and one of 6 herbicide treatments. All 4 wildflower species were seeded in rows by species widthwise in each tray at a rate of 25 pure live seeds (PLS) per row. The placement of each species row within the tray was randomized for each tray. After seeding, trays were loosely covered with plastic wrap and placed in a dark room at 4 °C (39 °F) for a 10-d stratification period.

After stratification, herbicide treatments were applied on 22 March 2005 for run 1 and 6 June 2005 for run 2 using a spray table fitted with a TeeJet® Flat Fan 8002E nozzle (TeeJet Technologies, Wheaton, Illinois). Prior to application, the spray table was calibrated based on a 35 l/ha (3.7 gal/ac) volume applied at 5 kmph (3 mph) with 2.8 kg/cm (40-psi) pressure. The nozzle height was 30 cm (12 in) above the soil surface. Six hours after herbicides were applied, each tray was misted using a fog nozzle with enough water to incorporate the herbicide into the soil. Each tray of each run received approximately the same amount of mist spray.

After herbicide application, the trays were placed at random on a bench in a greenhouse with supplemental lighting to provide 12 h photoperiod and 25 °C (77 °F) daytime temperature and 16 °C (61 °F) nighttime temperature. To account for environmental variation along the greenhouse bench, all trays were re-randomized weekly. Soils in the trays were kept moist by fog watering 3 times per wk.

Sampling

The 2 experimental runs were sampled beginning 7 d after herbicide application (Days After Treatment [DAT]) and at 7-d intervals for 28 d (4 sample times). At each sampling date, living seedlings per row were counted; and at the final sampling time (28 DAT), all living seedlings were measured for height from the soil surface, severed at the soil surface, and oven-dried at 45 °C (113 °F) for 96 h to determine dry mass.

Data Analysis

The data were analyzed by species. The numbers of plants per row (density data) were analyzed using a repeated measures, randomized-block analysis of variance model with run, herbicide treatments, and their interaction as main plots, and

TABLE 1

The trade names, chemical names, modes of action, and application rates (grams active ingredient per hectare) of the 5 herbicides used as the whole-plot treatments in the controlled-environment greenhouse study.

Trade name	Chemical name	Mechanism of action	Application rate g ai/ha (oz ai/ac)
Dacthal WP	DCPA	Mitosis inhibitor	1100 (15.7)
Spartan	Sulfentrazone	Photosynthesis inhibitor	32 (0.5)
Aatrex	Atrazine	Photosynthesis inhibitor	367 (5.2)
Surflan	Oryzalin	Microtubule assembly inhibitor	370 (5.3)
Treflan	Trifluralin	Microtubule assembly inhibitor	184 (2.6)

TABLE 2

The 4 wildflower species, their seed length, weight, and viability as determined by tetrazolium testing, seeded within each herbicide treatment in the controlled-environment greenhouse study.

Scientific name	Common name	Seed length (mm)	Seed weight (mg)	Viability (%)
Dalea candida Michx. ex Willd. (Fabaceae)	white prairieclover	1.5 to 2.5	613	78
Gaillardia aristata Pursh (Asteraceae)	blanketflower	2 to 4	411	55
Liatris punctata Hook. (Asteraceae)	dotted gayfeather	6 to 8	139	87
Ratibida columnifera (Nutt.) Woot. & Standl. (Asteraceae)	prairie coneflower	1.5 to 3	1625	96

sampling time and all interactions with run and herbicide treatments as the sub-subplots (Proc GLM, SAS Institute 1990). Seedling height and per-plant seedling dry mass at the final harvest time of surviving seedlings were analyzed using a randomized block analysis of variance model. Square root transformations were used to improve normality and homoscedasticity for per plant seedling dry mass and seedling height. Non-transformed means are presented when significant. The tests for run × herbicide for density of *Dalea candida, Gaillardia aristata,* and *Ratibida columnifera* were significant ($P < 0.05$), and therefore run was left in the model to compare differences between runs. All other run × herbicide and run × herbicide × time interactions were not significant ($P > 0.05$) and therefore the data for runs were combined. When *P*-values from *F*-tests were 0.05 or less, means were compared using Fisher's protected least significant differences test at the 0.05 level of confidence (Peterson 1985).

RESULTS

Dalea candida

The time × herbicide interaction ($P < 0.0001$) on *D. candida* densities depended on run ($P = 0.0194$). Differences between runs were detected at each sampling time and in change in density over time (Table 3). The relevant differences between runs were detected in the DCPA and trifluralin treatments, which resulted in lower densities in run 2 than run 1. Densities were not different between runs in the no herbicide control. The 28 DAT results for run 1 show DCPA and trifluralin did not reduce the density of *D. candida* whereas in run 2 herbicides reduced *D. candida* densities as compared with the control. Atrazine, oryzaline, and sulfentrazone caused the greatest decline in density of all treatments in both runs.

The herbicide treatment effects on surviving seedling height ($P = 0.8029$) and shoot dry mass ($P = 0.8269$) were not different between runs. Seedling survival at harvest was only sufficient in the control, DCPA, and trifluralin treatments for analysis of herbicide effects on height and shoot dry mass. There were no differences among these treatments in harvest shoot dry weight ($P = 0.7001$). The heights of seedlings at harvest in the trifluralin treatment were less than those in the control and the DCPA treatments ($P = 0.0447$; Table 4).

Gaillardia aristata

The time × herbicide interaction ($P < 0.0001$) on *G. aristata* densities depended on run ($P = 0.0157$). Densities were lower in run 2 than run 1 in the non-treated control and all herbicide treatments except atrazine (Table 3). The difference between runs in the control suggests factors other than herbicides may have contributed to low densities in run 2. When comparing seedling density at 28 DAT with the control, atrazine, oryzalin, and sulfentrazone caused the greatest decline in both runs; DCPA was no different in both runs; and trifluralin was greater in run 1 and the same in run 2.

The herbicide treatment effects on surviving seedling height and dry mass were not different between runs ($P = 0.0998$). Oryzalin, DCPA, trifluralin, and the control had sufficient seedling survival to include in the analysis. Seedling shoot dry weight was not different among these treatments at 28 DAT ($P = 0.4556$). The mean heights of seedlings treated with these 3 herbicides were shorter than those in the control ($P = 0.0479$; Table 4).

Liatris punctata

Although the time × herbicide interaction for *L. punctata* density was significant ($P < 0.0001$), we detected no differences between runs ($P = 0.3905$). Density was reduced by atrazine at 14 DAT as compared with the control, and atrazine subsequently killed all seedlings (Table 3). Sulfentrazone reduced density as compared with the other 3 herbicides and the control at 28 DAT. The densities in the oryzalin and DCPA treatments were the same as the control, and densities in the trifluralin treatment were greater than the control at 28 DAT. There were no differences among treatments in height ($P = 0.1323$) or shoot dry mass ($P = 0.1269$) of surviving *L. punctata* seedlings.

Ratibida columnifera

The time × herbicide interaction ($P < 0.0001$) on *R. columnifera* density depended on run ($P = 0.0198$). Differences between runs were not consistent over the 28 d of the experiments. Densities in the non-treated control, trifluralin, and atrazine were initially greater in run 2 than run 1 but by 28 DAT density was lower in the DCPA treatment in run 2 as compared with run 1 only (Table 3). At 28 DAT, DCPA reduced the density of *R. columnifera* by 9 seedlings compared with the non-treated control. No seedlings survived in the atrazine and sulfentrazone treatments at 28 DAT. Densities in the oryzalin treatment were less than the control in both runs, and densities in the trifluralin treatment were lower than the control in run 1 and no different than the control in run 2 at 28 DAT.

Herbicides did not significantly reduce the height of surviving seedlings at harvest ($P = 0.0615$); however, the average height of seedlings in the trifluralin treatment was 16.5 mm compared with 32.8 mm in the control. Trifluralin reduced the average weight of seedling shoots by about 33% as compared with the control at 28 DAT ($P = 0.0455$; Table 4).

DISCUSSION AND CONCLUSIONS

Our results indicate there is considerable risk to seedling wildflowers planted for seed production when using pre-emergence herbicides to manage weeds during establishment. No seedlings of any species survived the atrazine treatment, and few seedlings survived the sulfentrazone and oryzalin treatments, indicating these chemicals should not be used for pre-emergence weed control for the wildflowers tested. DCPA and trifluralin caused the least seedling mortality and may therefore help wildflower establishment where weeds controlled by these chemicals are problematic. However, the densities of *D. candida*, *G. aristata*, and *R. columnifera* were reduced in one of the 2 experimental runs. This suggests these species may be sensitive to the herbicide under some environmental conditions, timing of application, or slight variation in rate. In addition, trifluralin reduced height growth of *D. candida* and *G. aristata* and reduced harvest shoot weight of *R. columnifera*, indicating injury from the chemical. Injured wildflowers may be at a competitive disadvantage with weeds that survive the herbicide treatment or may be vulnerable to further injury from environmental stress (Erusha and others 1991).

Wildflower species responded differently to pre-emergence herbicides. We found *L. punctata* had some tolerance to the sulfentrazone and oryzalin treatments whereas the other species did not, and *D. candida* showed some susceptibility to trifluralin whereas the other species did not. With several Asteraceae species, Derr (1994) found Shasta daisy (*Leucanthemum x superbum* (Bergmans ex. J.W. Ingram) Berg. ex Kent. [*maximum* x *lacustre*]), black-eyed Susan (*Rudbeckia hirta* L. var. *pulcherrima* Farw.), and blanketflower (*Gaillardia aristata*) had greater injury, fewer survivors, and less shoot fresh weight than did purple coneflower (*Echinacea purpurea* (L.) Moench) when treated with 4.5 or 9.0 kg ai/ha (4.0 or 8.0 lb ai/ac) oryzalin, or isoxaben plus trifluralin (1.1 + 4.5 or 2.2 + 9.0 kg ai/ha [1.0 + 4.0 or 2.0 + 8.0 lb ai/ac]). Erusha and others (1991) found *Gaillardia pulchella* Foug. (Asteraceae), *Ratibida columnifera* (Asteraceae), and both red and white yarrow (*Achillea millefolium* L. [Asteraceae]) tolerant to EPTC plus trifluralin (2.3 + 0.6 kg ai/ha [2.1 + 0.5 lb ai/ac]) applied pre-emergence, whereas *Phacelia campanularia* Gray (Hydrophyllaceae) and *Penstemon strictus* Benth. (Scrophulariaceae) were susceptible.

We recognize the limitations of our controlled-environment study. Our objective was to measure herbicide injury during establishment, however, injury may be expressed after wildflowers have established. For example, Erusha and others (1991) observed lodging of *Coreopsis tinctoria* Nutt. (Asteraceae) and *Cosmos bipinnatus* Cav. (Asteraceae) in herbicide-treated plots, but not the control, following heavy rains after establishment. Also, plant tolerance to herbicides may be affected by environmental stress. Field experiments of longer duration are needed to determine the effects of pre-emergence herbicides on wildflower species under competition with weeds and under environmental stress.

TABLE 3

The density of wildflower seedlings on herbicide-treated soil 7, 14, 21, and 28 days after treatment (DAT) with pre-emergent herbicides. See Table 1 for herbicide rates.

DAT	*Herbicide*	*Dalea candida run 1*	*Dalea candida run 2*	*Gaillardia aristata run 1*	*Gaillardia aristata run 2*	*Ratibida columnifera run 1*	*Ratibida columnifera run 2*	*Liatris punctata runs 1 and 2*
7	atrazine	11.5	15.0	11.5	11.0	8.8	16.3	11.8
7	oryzalin	12.0	6.3	8.5	3.0	9.5	5.3	15.4
7	DCPA	17.5	11.3	11.8	8.3	14.5	13.3	12.3
7	sulfentrazone	5.0	3.5	3.3	0.5	3.3	1.8	12.1
7	trifluralin	11.8	14.5	14.0	8.3	8.8	19.5	10.6
7	no herbicide	15.5	18.0	9.5	9.8	14.5	20.0	12.0
14	atrazine	0	0	2.3	0.3	0	0	0.8
14	oryzalin	7.0	2.8	8.5	3.3	3.0	4.8	14.3
14	DCPA	14.0	7.8	15.3	9.0	17.8	13.5	14.6
14	sulfentrazone	0.3	2.5	1.0	0	0.3	0.3	12.1
14	trifluralin	12.0	13.5	17.5	9.5	11.8	21.0	14.1
14	no herbicide	12.3	15.5	14.0	8.8	13.3	17.5	14.4
21	atrazine	0	0	0	0	0	0	0
21	oryzalin	3.3	1.8	4.8	3.5	2.3	5.0	12.8
21	DCPA	15.5	5.8	14.3	9.3	17.5	13.3	14.3
21	sulfentrazone	1.3	1.8	0	0	0	0	10.1
21	trifluralin	11.0	14.8	17.5	9.0	11.5	16.5	14.3
21	no herbicide	11.0	8.3	13.8	9.5	13.0	13.5	13.8
28	atrazine	0	0	0	0	0	0	0
28	oryzalin	3.3	0.3	4.5	3.0	1.8	4.0	11.3
28	DCPA	15.3	2.5	13.3	5.0	17.8	3.8	12.1
28	sulfentrazone	1.0	1.0	0	0	0	0	7.0
28	trifluralin	10.3	2.0	16.5	6.0	9.8	10.0	14.1
28	no herbicide	9.3	10.8	12.7	7.0	15.3	12.0	10.4
	LSD	**3.48**	**3.48**	**2.73**	**2.73**	**4.95**	**4.95**	**2.93**

TABLE 4

The mean heights of Dalea candida *and* Gaillardia aristata *and shoot dry mass of* Ratibida columnifera *seedlings grown on soil treated with herbicides. Oryzalin was not included in the ANOVA model for* D. candida *height and* Ratibida columnifera *shoot dry weight because of lack of survivors. See Table 1 for herbicide rates.*

Herbicide	***Dalea candida* height (mm)**	***Gaillardia aristata* height (mm)**	***Ratibida columnifera* shoot dry mass (mg)**
oryzalin	NA	16.1	NA
DCPA	35.6	12.3	127
trifluralin	17.6	16.3	100
control	32.9	23.8	158
LSD	13.6	6.2	31

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