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Short title: Geyer larkspur control

Evaluation of herbicides for Geyer larkspur (*Delphinium geyeri*) control

Clinton A. Stonecipher[1], Kevin D. Welch[2], Justin D. Derner[3], Dale R. Gardner[4], Corey Ransom[5], Daniel Cook[6]

[1]Rangeland Scientist (ORCID 0000-0003-1864-9257), United States Department of Agriculture-Agricultural Research Service, Poisonous Plant Research Laboratory, Logan, UT 84341, USA;
[2]Toxicologist, United States Department of Agriculture-Agricultural Research Service, Poisonous Plant Research Laboratory, Logan, UT 84341, USA;
[3]Rangeland Scientist, United States Department of Agriculture-Agricultural Research Service, Rangeland Resources and Systems Research Unit, Cheyenne, WY 82009, USA;
[4]Chemist, United States Department of Agriculture-Agricultural Research Service, Poisonous Plant Research Laboratory, Logan, UT 84341, USA;
[5]Associate Professor, Plant, Soils, and Climate Department, Utah State University, Logan, UT 84322, USA; and
[6]Plant Physiologist, United States Department of Agriculture-Agricultural Research Service, Poisonous Plant Research Laboratory, Logan, UT 84341, USA.

Author for correspondence: Clint Stonecipher: clint.stonecipher@usda.gov

Abstract:

Geyer larkspur is a native perennial forb toxic to cattle. Herbicide control of Geyer larkspur is variable and most likely attributable to the growth stage of the plant when herbicide is applied. The objectives of this study were to (1) evaluate aminopyralid, aminopyralid + florpyrauxifen-benzyl, aminopyralid + 2,4-D, aminopyralid + metsulfuron-methyl, metsulfuron-methyl, triclopyr, and triclopyr + 2,4-D for efficacy in controlling Geyer larkspur; (2) determine if plant growth stage (vegetative or flowering) at the time of herbicide application influences herbicide effectiveness; and (3) determine whether herbicide treatment alters norditerpenoid alkaloid content of Geyer larkspur. Plots were established in eastern Wyoming (2021) and northern Colorado (2022). Herbicide application at the different phenological stages did not affect Geyer larkspur density at the Wyoming site (P = 0.1065; data not shown). Geyer larkspur density at the Wyoming site was reduced by all herbicide treatments 1 year after treatment (YAT) at the vegetative stage and by all herbicides except for triclopyr 2 YAT (P = 0.0249). At the flowering stage, Geyer larkspur density was reduced by all herbicides except metsulfuron-methyl, triclopyr, and triclopyr + 2,4-D at 1 YAT and triclopyr and triclopyr + 2,4-D at 2 YAT. In contrast, there were no differences in Geyer larkspur density across treatments at the Colorado site (P = 0.9621). Precipitation was below average several months prior to herbicide application, which may have affected herbicide effectiveness. The metsulfuron-methyl treatment resulted in the highest total alkaloid concentrations of Geyer larkspur at the vegetative stage and the lowest concentrations at the flowering stage at the Wyoming site. Control efforts of Geyer larkspur in semiarid rangelands can be effectively accomplished with aminopyralid herbicides across vegetative and flowering growth stages provided environmental conditions prior to herbicide application are sufficient for plant growth and uptake of the herbicide.

Nomenclature: 2,4-D; aminopyralid; florpyrauxifen-benzyl; metsulfuron-methyl; triclopyr; Geyer’s larkspur, *Delphinium geyeri* Greene

Key words: Alkaloids, Plains larkspur, plant growth stage, poisonous plant, semiarid rangeland

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Introduction

Larkspurs (*Delphinium* spp.) are typically organized into three basic categories: plains, low, and tall larkspur (Green et al. 2009). Geyer larkspur is classified as plains larkspur and is a native perennial forb in the *Ranunculaceae* family found in semiarid rangelands primarily in the High Plains of Wyoming, Colorado, Nebraska, and Utah (Burrows and Tyrl 2013; Green et al. 2009). Stems are erect and can vary from 20-80 cm. They are topped with terminal raceme inflorescences consisting of many flowers (Burrows and Tyrl 2013). Roots are thick, woody-fibrous with tuberous short vertical rootstock branching downward from a crown (Barr 1983; Whitson and Burrill 2002). Foliage emerges each year from rootstock buds (Hyder and Sabatka 1972), and the plant reproduces from the seed.

Geyer larkspur growth typically begins early in the spring, before perennial cool-season grasses and other forbs, and can often be the only green forage available to cattle (Green et al. 2009; Pfister et al. 2002). *Delphinium* species contain alkaloids that occur in two types: the *N*-(methylsuccinimido) anthranoyllycoctonine (MSAL)-type and the non-MSAL-type alkaloids (Pfister et al. 1999; Panter et al. 2002). The MSAL-type alkaloids are highly toxic, whereas the non-MSAL-type alkaloids are much less toxic (Welch et al., 2008, 2010, 2012). The principal toxins in Geyer larkspur are methyllycaconitine (MLA), nudicauline, and geyerline (Manners et al. 1995; Gardner and Pfister 2007).

Research on herbicide control of larkspur has mainly focused on the tall larkspur species (Mickelsen et al. 1990; Ralphs et al. 1990, 1991, 1992) with limited research on plains larkspur. Picloram + 2,4-D has been a commonly recommended herbicide for Geyer larkspur control (Ralphs et al. 1991), but efficacy varies depending on the timing of application and growing conditions (Hyder 1971; Hyder and Sabatka 1972). Therefore, more work is needed to understand herbicide efficacy before and after flowering. Contemporary herbicide options for Geyer larkspur control are limited. Aminopyralid is a common herbicide that lists several plants from the *Ranunculaceae* family on the herbicide label for control. Several herbicides developed for rangeland use contain aminopyralid in combination with other active ingredients and were selected for evaluation in this study: aminopyralid +florypyrauxifen-benzyl, aminopyrlid + 2,4-D, and aminopyralid + metsulfuron-methyl. The herbicide triclopyr has recently been shown to

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control another poisonous plant, death camas [*Zigadenus paniculatus* (Nutt.) S. Watson] (Stonecipher et al. 2021) but its ability to control Geyer larkspur remains unknown.

Land managers often use herbicides to decrease Geyer larkspur density (Green et al. 2009), thereby lowering the potential for livestock poisoning, but the palatability and toxicity of remaining plants can be altered due to herbicide applications (Green et al. 2009; Stonecipher et al. 2021) through changes in alkaloid content. For example, Ralphs et al. (1998) showed that toxic alkaloid concentrations in tall larkspur (*Delphinium barbeyi* (Huth) Huth) plants treated with metsulfuron-methyl increased; however, applications of glyphosate and picloram did not alter alkaloid concentrations. How alkaloid concentrations in Geyer larkspur are affected by herbicide applications has not been evaluated, but it could be valuable information to livestock producers to help reduce the risk of toxicity.

The objectives of this study were to (1) evaluate aminopyralid, aminopyralid + florpyrauxifen-benzyl, aminopyralid + 2,4-D, aminopyralid + metsulfuron-methyl, metsulfuron-methyl, triclopyr, and triclopyr + 2,4-D for their efficacy in controlling Geyer larkspur; (2) determine if plant growth stage at the time of herbicide application influences herbicide effectiveness; and (3) determine whether herbicide treatment alters alkaloid content of Geyer larkspur when applied in either the vegetative or flowering stage.

Materials and Methods

Study Site

Plots were established at sites in eastern Wyoming and northern Colorado. The Wyoming site was located just west of Cheyenne, Wyoming (41°10.393’N;104°53.131’W) at an elevation of 1893m. The soil is fine-loamy over sandy or sandy-skeletal, mixed, mesic Aridic Argiustolls (Loamy). The ecological site is an upland site characterized by perennial cool-season mid-height bunchgrasses and rhizomatous grasses, and the perennial warm-season shortgrass blue grama (*Bouteloua gracilis* [Willd. Ex Kunth] Lag. Ex Griffiths) (Soil Survey Staff 2024). The 50-yr mean (1974-2024) annual precipitation for the site is 381 mm (PRISM Climate Group, 2024). The site was located on the USDA-ARS Rangeland Resources and Systems Research Unit and was chosen for ease of accessibility and for grazing could be prevented in the pasture where the

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plots were established during the trial period. A voucher specimen was collected and deposited in the Poisonous Plant Research Laboratory Herbarium (#4979).

The Colorado site was located 8 km east of Virginia Dale, Colorado (40°56.496'N; 105°15.658'W) at an elevation of 2203 m. The soil is loamy-skeletal, mixed, shallow Aridic Argiborolls (Rocky loam). The ecological site is classified as mountain big sagebrush [*Artemisia tridentata* Nutt. ssp. *vaseyana* (Rydb.) Beetle] (Soil Survey Staff 2024). The 50-yr mean (1974-2024) annual precipitation for the site is 435 mm (PRISM Climate Group, 2024). The site was located on Colorado State University Maxwell Ranch and was chosen for ease of accessibility, as grazing could be prevented in the pasture where the plots were established during the trial period. A voucher specimen was collected and deposited in the Poisonous Plant Research Laboratory Herbarium (#4982).

Experimental Design

Treatments were arranged factorially in a randomized complete block design with four blocks at each site. Each block consisted of 15 plots (3 x 9 m) with seven herbicide treatments (Table 1) applied at two timings, vegetative and flowering growth stages, and one non-treated control plot. Herbicide rates were chosen based on manufacturer recommendations for closely related plant species. A nonionic surfactant (0.25% v/v) was included with each herbicide treatment.

At the Wyoming site, herbicides were applied at the vegetative growth stage of Geyer larkspur on May 26, 2021. The height of Geyer larkspur was 25 ± 3 cm at application. Herbicide application at the flowering growth stage occurred on June 23, 2021, when Geyer larkspur plants were 40 ± 5 cm. At the Colorado site, herbicide application at the vegetative growth stage of Geyer larkspur occurred the following year on June 8, 2022. Larkspur plants were much shorter at 11 ± 2 cm than the Wyoming site. Herbicide application at the flowering growth stage occurred on June 28, 2022, again with much shorter plant heights, 28 ± 4 cm, compared to the Wyoming site. Herbicides were applied using a CO_2-pressurized backpack sprayer at a rate of 168 L ha^{-1} at 207 kPa at 4.0 km h^{-1}. The spray boom consisted of six XR8002 flat-fan nozzles (Spraying Systems Co, Wheaton, IL) spaced 51 cm apart.

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Plant Measurements

The total number of Geyer larkspur plants in each plot was counted before herbicide application and again one and two years after treatment (YAT). Aboveground biomass production was measured at 2 YAT for both sites by clipping all the vegetation in a 0.25 m x 0.5 m frame to a 3-cm stubble height. Plots at the Wyoming site were clipped on June 12, 2023, and plots at the Colorado site on June 24, 2024. Two frames were clipped in each plot at random locations approximately 3 m and 6 m within the plot. Clipped biomass was separated into plant functional groups: perennial grass, annual grass, perennial forb, annual forb, and Geyer larkspur. Biomass was dried in a forced-air oven at 60 C for 96 h and weighed.

Six individual Geyer larkspur plants were collected per plot, harvested at ground level, 15 to 28 days after herbicide application, at both vegetative and flowering growth stages, and dried at 60 C for 96 h and ground in a Wiley mill to pass through a 1-mm screen. Two of the six plants collected from each plot were randomly selected for alkaloid analysis, and the two plants from each plot were analyzed individually. The concentration of MSAL alkaloids and total alkaloids were determined as previously described using flow injection electrospray mass spectrometry (Gardner et al. 2021).

Data Analyses

Geyer larkspur plant density, biomass, and alkaloid concentration were analyzed using a generalized linear mixed model (PROC GLIMMIX) method in a mixed model analysis of variance with repeated measures in SAS v. 9.4 (SAS Institute, Cary, NC). Geyer larkspur density, biomass, and alkaloid concentration values were averaged for each plot and the means used for analysis. Plots were the experimental units, and the four blocks were replicates. Herbicide treatment, application timing, and year were the fixed effects factors and block, and repeated measures were incorporated as random effects factors. Biomass and Geyer larkspur density were square root transformed, and alkaloid concentration was log-transformed to meet assumptions of normality and homogeneity of variance. Treatment means are reported as original, nontransformed data with standard errors ($\bar{x} \pm$ SEM). Treatment means were separated using the LSMEANS method, and main effects were adjusted for Type I error inflation using the Tukey method. Geyer larkspur control was evaluated at two different growth stages, vegetative

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and flowering. The two sites were analyzed separately. Geyer larkspur plant counts were converted to the number of plants m^{-2}.

Results and Discussion

Precipitation at the Wyoming site was below the 50-yr mean (381 mm) the year herbicides were applied (339 mm). However, precipitation for the months immediately preceding the herbicide applications (February to June) was at or above average (Table 2). At the Colorado site, precipitation in the year that herbicides were applied was 364 mm, well below the 50-yr mean (435 mm). Precipitation was below the 50-yr average for March through June, the year that herbicides were applied (Table 2).

Geyer larkspur density prior to herbicide application was 2.5 ± 0.16 and 3.7 ± 0.26 plants m^{-2} at the Wyoming and Colorado sites, respectively. Geyer larkspur density in the non-treated control plots at the Wyoming site was similar prior to herbicide treatment and 1 YAT but decreased by 40% at 2 YAT (P = 0.0001; data not shown). The density of Geyer larkspur did not change in the non-treated plots at the Colorado site (P = 0.0651; data not shown).

Herbicide application at the different phenological stages did not have an effect on Geyer larkspur density at the Wyoming site (P = 0.1065; data not shown). Geyer larkspur density at the Wyoming site was reduced by all herbicide treatments applied at the vegetative stage 1 YAT and all herbicides except triclopyr 2 YAT (P = 0.0249; Table 3). When applied at the flowering stage, Geyer larkspur density was reduced by all herbicides except metsulfuron-methyl, triclopyr, and triclopyr + 2,4-D at 1 YAT and triclopyr and triclopyr + 2,4-D at 2 YAT (Table 3).

In contrast to the Wyoming site (P = 0.0249), there were no differences in Geyer larkspur density across treatments at the Colorado site (P = 0.9621; data not shown). There were no differences in Geyer larkspur density between herbicide applications at the different phenological stages (P = 0.9875). We suspect that the efficacy of the herbicides was significantly reduced compared to the Wyoming site due to low precipitation at the Colorado site. Abiotic factors, such as drought, cause water stress and affect plant responses to herbicides, principally reducing efficacy. Water stress has been shown to reduce herbicide efficacy on both monocots and dicots (Miller and Norsworthy 2018; Benedetti et al. 2020), and translocation of herbicides can be reduced during times of moisture stress (Reynolds et al. 1988).

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At the Wyoming site, there was a difference in MSAL and total alkaloid concentration between non-treated Geyer larkspur plants collected at the vegetative and flowering stages of phenological development ($P < 0.0490$). MSAL concentrations of non-treated Geyer larkspur were 1.4 times greater at the vegetative (4.4 ± 0.40 mg g^{-1}) than the flowering (3.2 ± 0.13 mg g^{-1}) stage. Total alkaloid concentrations of non-treated larkspur plants were 1.6 times greater at the vegetative (10.8 ± 0.75 mg g^{-1}) than the flowering (6.6 ± 0.58 mg g^{-1}) stage ($P < 0.001$; Figure 1). Total alkaloid concentrations of all samples analyzed were 1.6-times greater at the vegetative (11.4 ± 0.25 mg g^{-1}) phenological stage than the flowering (7.2 ± 0.26 mg g^{-1}) stage ($P <0.001$) and MSAL alkaloids were 1.5-times greater at the vegetative (4.3 ± 0.15 mg g^{-1}) phenological stage than flowering (2.8 ± 0.16 mg g^{-1}) stage ($P < 0.001$). Plants treated with metsulfuron-methyl had at least 2.9 times greater total alkaloid concentrations when treated at the vegetative growth stage than the flowering stage ($P < 0.001$; Figure 1). Conversely, plants treated with this herbicide at the flowering stage contained 30% lower total alkaloids than those treated with a herbicide containing 2,4-D; there were no differences in total alkaloid concentrations of Geyer larkspur plants receiving any herbicide treatment or the non-treated controls at the flowering stage. Total alkaloid concentrations were 1.2 times greater in the aminopyralid + metsulfuron-methyl treatment than the non-treated controls when applied at the vegetative phenological stage with all other herbicide treatments, except for metsulfuron-methyl, having total alkaloid concentrations similar to the non-treated controls.

No differences in MSAL or total alkaloid concentrations of non-treated Geyer larkspur plants were collected between vegetative and flowering stages at the Colorado site ($P > 0.1182$; data not shown). Total alkaloid concentrations for non-treated larkspur plants were 1.4times greater at the vegetative (10.9 ± 0.53 mg g^{-1}) than the flowering (7.8 ± 0.54 mg g^{-1}) phenological stage ($P =0.001$). There were no differences in MSAL alkaloid concentrations of non-treated larkspur plants between phenological stages ($P = 0.0624$; data not shown). There was no difference in MSAL concentrations across herbicide treatments ($P = 0.1699$), but there was a difference in total alkaloid concentrations ($P = 0.0357$; Figure 2). Total alkaloid concentrations were increased in the metsulfuron-methyl treatment applied at the vegetative stage, which was similar to what was observed at the Wyoming site. Total alkaloids in the aminopyralid + metsulfuron-methyl treated plants were also high but were not statistically different from those collected from the non-treated controls.

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In greenhouse studies with tall larkspur, total alkaloid concentrations increased twofold in plants treated with metsulfuron-methyl compared with non-treated controls seven days after herbicide treatment (Ralphs et al., 1998). In the same study, total alkaloid concentration of Geyer larkspur plants treated with picloram were similar to non-treated plants. In field trials, total alkaloid concentrations were greater in Geyer larkspur plants treated with metsulfuron-methyl than in plants treated with picloram or non-treated plants (Ralphs et al. 1998). Herbicides can increase, decrease, or not affect the concentration of toxic compounds in plants (Williams and James 1983). Stonecipher et al. (2021) observed no change in the alkaloid concentration of death camas plants treated with various herbicides. In the current study, most herbicides tested did not affect alkaloid concentrations of treated plants; the exceptions were that metsulfuron-methyl and aminopyralid + metsulfuron-methyl increased alkaloid concentrations.

Vegetation was clipped 2 YAT at both sites to determine if herbicide treatment altered vegetation biomass. Biomass production of Geyer larkspur at the Wyoming site differed at herbicide application, with a 1.9 times greater larkspur biomass produced at the flowering than the vegetative stage (P = 0.0126; data not shown). There was a treatment by herbicide application timing interaction for Geyer larkspur biomass (P = 0.0381) with triclopyr + 2,4-D producing less Geyer larkspur biomass at the vegetative than flowering stage (data not shown). Aminopyralid, aminopyralid + florpyrauxifen-benzyl, and aminopyralid + 2,4-D reduced Geyer larkspur biomass below the non-treated plots (P = 0.0128; Table 4). Perennial grasses produced the most biomass of all vegetation groups at both sites (P < 0.0001; Tables 4 & 5). At the Wyoming site, aminopyralid + florypyrauxifen-benzyl had greater perennial grass biomass production than the non-treated controls (P = 0.0147; Table 4). The increase in perennial grass production could be due to competitive release following control of Geyer larkspur as similar results have been observed with high seral perennial grass species increasing in biomass production following treatment with aminopyralid to control Canada thistle (*Cirsium arvense* (L.) Scop.; Almquist and Lym 2010). Grass cover increased in duncecap larkspur (Mickelsen et al., 1990) and tall larkspur (Ralphs et al. 1990) when treated with metsulfuron-methyl. However, metsulfuron-methyl in combination with aminocyclopyrachlor did not affect grass production when applied to control duncecap larkspur (Greet et al. 2016).

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There was a tendency for annual grass biomass production to be lower in the non-treated control plots than the herbicide-treated plots at the Wyoming site (*P* = 0.0463; Table 4). There was a treatment by herbicide application time interaction for perennial forb biomass production, with metsulfuron-methyl producing more biomass at the flowering stage than both the non-treated controls and at the vegetative stage (*P* = 0.0383; data not shown).

At the Colorado site, there was a treatment by herbicide application timing interaction (*P* = 0.0084) for biomass of Geyer larkspur with triclopyr having lower biomass at the vegetative stage than the non-treated controls and all other treatments similar to the non-treated controls. At the flowering stage the aminopyralid + metsulfuron-methyl and triclopyr-treated plots were similar to non-treated control plots with aminopyralid, aminopyralid + florpyrauxifen-benzyl, aminopyralid + 2,4-D, metsulfuron-methyl, and triclopyr + 2,4-D having lower Geyer larkspur biomass production than the non-treated controls (data not shown). Perennial grass biomass production was greater in the aminopyralid + florpyrauxifen-benzyl treatment than in the non-treated controls, and all other treatments were similar to the non-treated controls (*P* = 0.0147; Table 5). Although herbicides did not completely control Geyer larkspur at the Colorado site, the herbicides could have reduced the density of Geyer larkspur to a level that competition with perennial grasses was reduced, which allowed perennial grass production to increase. There was little or no annual grass biomass production at the Colorado site, resulting in no differences between treatments. There were also no differences between herbicide treatments in perennial forb biomass production (*P* = 0.4953). Annual forb biomass was greatest in the non-treated control and lowest in the metsulfuron-methyl treatments (*P* = 0.0438; Table 5).

Overall, aminopyralid, aminopyralid + florpyrauxifen-benzyl, aminopyralid + 2,4-D, aminopyralid + metsulfuron-methyl, and metsulfuron-methyl demonstrated good control of Geyer larkspur applied at both phenological growth stages at the Wyoming site. A concern that was observed is that annual grass production did increase in all plots that were treated with herbicides at the Wyoming site. If annual grasses are present, applying the herbicides used in this study may increase annual grasses in treated areas. It may be necessary to add an additional herbicide to control annual grasses or apply an herbicide in the fall or following spring to reduce annual grasses. Palatability and toxicity of Geyer larkspur plants treated with herbicides can be altered. Alkaloid content can increase or decrease as was observed with the mestulfuron-methyl

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treatment. Palatability can increase in herbicide-treated plants even if the alkaloid concentration is not changed, resulting in increased preference and consumption by livestock. Limit livestock access to Geyer larkspur plants that have been treated with herbicides the year of treatment. If herbicide-treated plants remain, they pose a risk of poisoning to livestock. Results differed at the Colorado site, in which all herbicide treatments had limited efficacy due to lower precipitation in the months prior to and in the month of herbicide application, resulting in limited soil water and causing Geyer larkspur to become drought stressed. We suggest delaying Geyer larkspur's herbicide treatment under unfavorable environmental conditions, such as those experienced at the Colorado site.

Practical Implications

Control of Geyer larkspur in semiarid rangelands can be effectively accomplished with aminopyralid herbicides and metsulfuron-methyl across vegetative and flowering growth stages, provided environmental conditions prior to herbicide application are sufficient for plant growth and uptake of the herbicide. When environmental conditions are unfavorable, it is recommended that the herbicide treatment of Geyer larkspur be delayed. Perennial grass biomass increased when Geyer larkspur was controlled with herbicides. Avoid livestock grazing Geyer larkspur, which has been treated with herbicides. If herbicide-treated plants are present, there is a risk of poisoning to livestock.

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Competing interests

The authors declare no conflicts of interest.

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Table 1. Herbicides and application rates used to treat Geyer larkspur at Cheyenne, WY and Virginia Dale, CO, 2021-2022.

Treatment	Trade name	Application rate	Manufacturer
		g ai ae ha^{-1}	
Aminopyralid	Milestone®	123	Dow AgroSciences LLC, Indianapolis, IN
Aminopyralid + florpyrauxifen-benzyl	DuraCor®	117 + 12	Dow AgroSciences LLC, Indianapolis, IN
Aminopyralid + 2,4-D	GrazonNext® HL	123 + 975	Dow AgroSciences LLC, Indianapolis, IN
Aminopyralid + metsulfuron-methyl	Chaparral®	111 + 7.1	Dow AgroSciences LLC, Indianapolis, IN
Metsulfuron-methyl	Escort® XP	7.4	Bayer Environmental Sciences, Research Triangle Park, NC
Triclopyr	Remedy® Ultra	1,120	Dow AgroSciences LLC, Indianapolis, IN
Triclopyr + 2,4-D	Crossbow®	1,120 + 560	Dow AgroSciences LLC, Indianapolis, IN Distributed by: Tenkoz Inc, Alpharetta, GA

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Table 2. Monthly precipitation (mm) for the year that herbicides were applied and the two-years of data collection near Cheyenne, WY (2021-2023) and Virginia Dale, CO (2022-2024) along with the 50-year average (1974-2024) (PRISM Climate Group, 2024).

	Wyoming			
	2021	2022	2023	50-year average
October	15.5	4.4	20.9	22.0
November	8.2	16.5	13.6	15.4
December	8.9	2.9	3.6	10.9
January	2.6	17.6	34.0	8.8
February	11.3	13.1	9.6	12.1
March	53.1	18.2	10.4	25.6
April	49.5	2.3	40.3	36.5
May	78.3	37.5	56.0	64.3
June	56.8	4.3	112.3	55.6
July	22.3	65.1	95.0	48.5
August	23.5	30.1	81.6	42.7
September	9.4	24.2	16.9	38.7
	Colorado			
	2022	2023	2024	50-year average
October	13.1	12.1	3.0	26.0
November	24.8	16.9	24.2	20.5
December	12.9	10.8	3.9	13.1
January	24.9	30.0	11.9	13.3
February	19.3	11.6	37.4	16.6
March	24.8	18.0	41.0	31.5
April	6.2	45.5	39.7	54.0
May	58.6	69.2	8.7	72.6
June	27.3	127.1	26.2	46.0
July	88.5	85.2	65.8	62.7
August	31.0	73.9	48.4	40.2
September	33.0	22.5	8.7	38.9

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Table 3. Geyer larkspur density (plants m^{-2}, mean ± SE, n = 4) before herbicide treatment (pretreatment) and one and two years after treatment (YAT) near Cheyenne, WY, 2021-2023. Herbicides were applied to vegetative (May 26, 2021) and flowering (June 23, 2021) Geyer larkspur.

Treatment[a]	Pretreatment	1YAT	2YAT
	———plants m^{-2}———		
Non-treated	2.5 ± 0.40 b-f	2.2 ± 0.52 c-h	1.5 ± 0.38 e-j
	———Vegetative———		
Aminopyralid	1.7 ± 0.26 c-i	0.3 ± 0.11 m-p	0.2 ± 0.08 m-q
Aminopyralid + florpyrauxifen-benzyl	2.9 ± 0.46 a-d	0.0 ± 0.01 q	0.0 ± 0.03 pq
Aminopyralid + 2,4-D	4.5 ± 0.50 a	0.2 ± 0.09 m-q	0.1 ± 0.05 n-q
Aminopyralid + metsulfuron methyl	4.0 ± 0.59 ab	0.5 ± 0.32 m-p	0.4 ± 0.22 l-p
Metsulfuron methyl	2.8 ± 0.90 b-f	0.6 ± 0.28 k-n	0.2 ± 0.08 m-q
Triclopyr	1.4 ± 0.37 f-j	1.0 ± 0.31 i-l	0.6 ± 0.10 j-m
Triclopyr + 2,4-D	2.0 ± 0.58 c-i	0.7 ± 0.30 j-m	0.4 ± 0.21 l-p
	———Flowering———		
Aminopyralid	1.5 ± 0.48 e-j	0.3 ± 0.15 m-p	0.1 ± 0.04 m-q
Aminopyralid + florpyrauxifen -benzyl	2.4 ± 0.66 c-g	0.1 ± 0.05 o-q	0.2 ± 0.08 m-q
Aminopyralid + 2,4-D	1.7 ± 0.49 d-i	0.5 ± 0.24 l-p	0.5 ± 0.22 k-o
Aminopyralid + metsulfuron-methyl	1.3 ± 0.43 g-k	0.2 ± 0.10 m-q	0.2 ± 0.06 m-q
Metsulfuron-methyl	2.2 ± 0.54 c-i	1.0 ± 0.27 h-l	0.5 ± 0.21 k-n
Triclopyr	2.6 ± 0.45 b-e	2.2 ± 0.35 c-g	1.4 ± 0.16 f-j
Triclopyr + 2,4-D	3.4 ± 0.93 a-c	2.2 ± 0.70 c-i	1.1 ± 0.28 h-l

[a]Means followed by the same letter are not significantly different between treatment and phenological stage and data collection time (pretreatment, 1YAT, 2YAT) ($P < 0.05$).

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Table 4. Dry matter biomass (kg ha^{-1}) of rangeland components two years after POST herbicide treatment of Geyer larkspur near Cheyenne, WY, 2021-2023[a].

Treatment[b]	Perennial grass	Annual grass	Perennial forb	Annual forb	Geyer larkspur
	——kg ha^{-1}——				
Non-treated	1235 ± 121 b	14 ± 7	93 ± 29	60 ± 11 ab	189 ± 45 a
Aminopyralid	1782 ± 187 ab	318 ± 137	54 ± 17	38 ± 20 a	0 ± 0 b
Aminopyralid + florpyrauxifen-benzyl	1933 ± 207 a	42 ± 17	39 ± 17	19 ± 6 b	0 ± 0 b
Aminopyralid + 2,4-D	1643 ± 153 ab	176 ± 63	34 ± 16	41 ± 15 b	0 ± 0 b
Aminopyralid + metsulfuron-methyl	1635 ± 147 ab	162 ± 54	47 ± 18	37 ± 12 ab	31 ±16 ab
Metsulfuron-methyl	1471 ± 156 ab	118 ± 36	118 ± 52	32 ± 10 ab	28 ± 20 ab
Triclopyr	1401 ± 131 ab	60 ± 17	124 ± 39	89 ± 16 ab	96 ± 54 ab
Triclopyr + 2,4-D	1135 ± 79 b	173 ± 51	35 ± 20	197 ± 79 a	83 ± 41 ab

[a]Data are combined over application timings (vegetative and flowering).

[b]Means followed by the same letter are not significantly different within a plant functional group ($P < 0.05$).

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Table 5. Dry matter biomass (kg ha^{-1}) of rangeland components two years POST herbicide treatment of Geyer larkspur near Virginia Dale, CO, 2022-2024[a].

Treatment[b]	Perennial grass	Annual grass	Perennial forb	Annual forb	Geyer larkspur
	kg ha^{-1}				
Non-treated	227 ± 43 b	0 ± 0	37 ± 8	87 ± 18 a	27 ± 7
Aminopyralid	386 ± 45 ab	0 ± 0	37 ± 12	33 ± 12 ab	14 ± 7
Aminopyralid + florpyrauxifen-benzyl	327 ± 31 a	0 ± 0	33 ± 12	61 ± 17 ab	6 ± 6
Aminopyralid + 2,4-D	468 ± 41 ab	0 ± 0	28 ± 10	38 ± 16 ab	8 ± 4
Aminopyralid + metsulfuron-methyl	537 ± 50 ab	0 ± 0	30 ± 10	40 ± 12 ab	18 ± 8
Metsulfuron-methyl	363 ± 49 ab	9 ± 9	75 ± 30	18 ± 13 b	8 ± 4
Triclopyr	292 ± 45 ab	2 ± 2	36 ± 16	77 ± 21 ab	13 ± 7
Triclopyr + 2,4-D	347 ± 28 b	1 ± 1	29 ± 10	54 ± 20 ab	14 ± 7

[a]Data are combined over application timing (vegetative and flowering).

[b]Means followed by the same letter are not significantly different within a plant functional group ($P < 0.05$).

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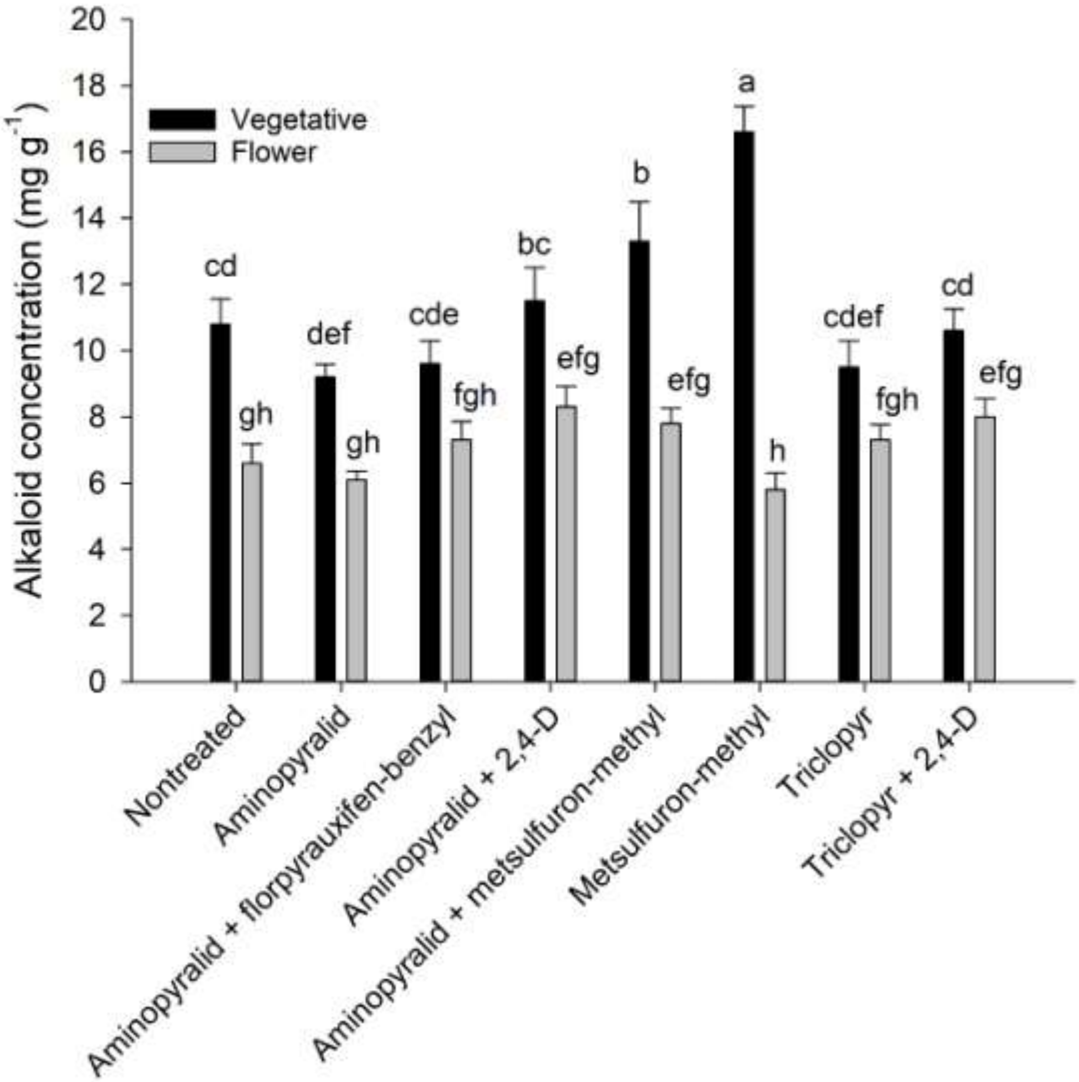

Figure 1. Total alkaloid concentration of Geyer larkspur plants treated with herbicides at vegetative and flowering stages of phenological development near Cheyenne, WY, 2021-2023.

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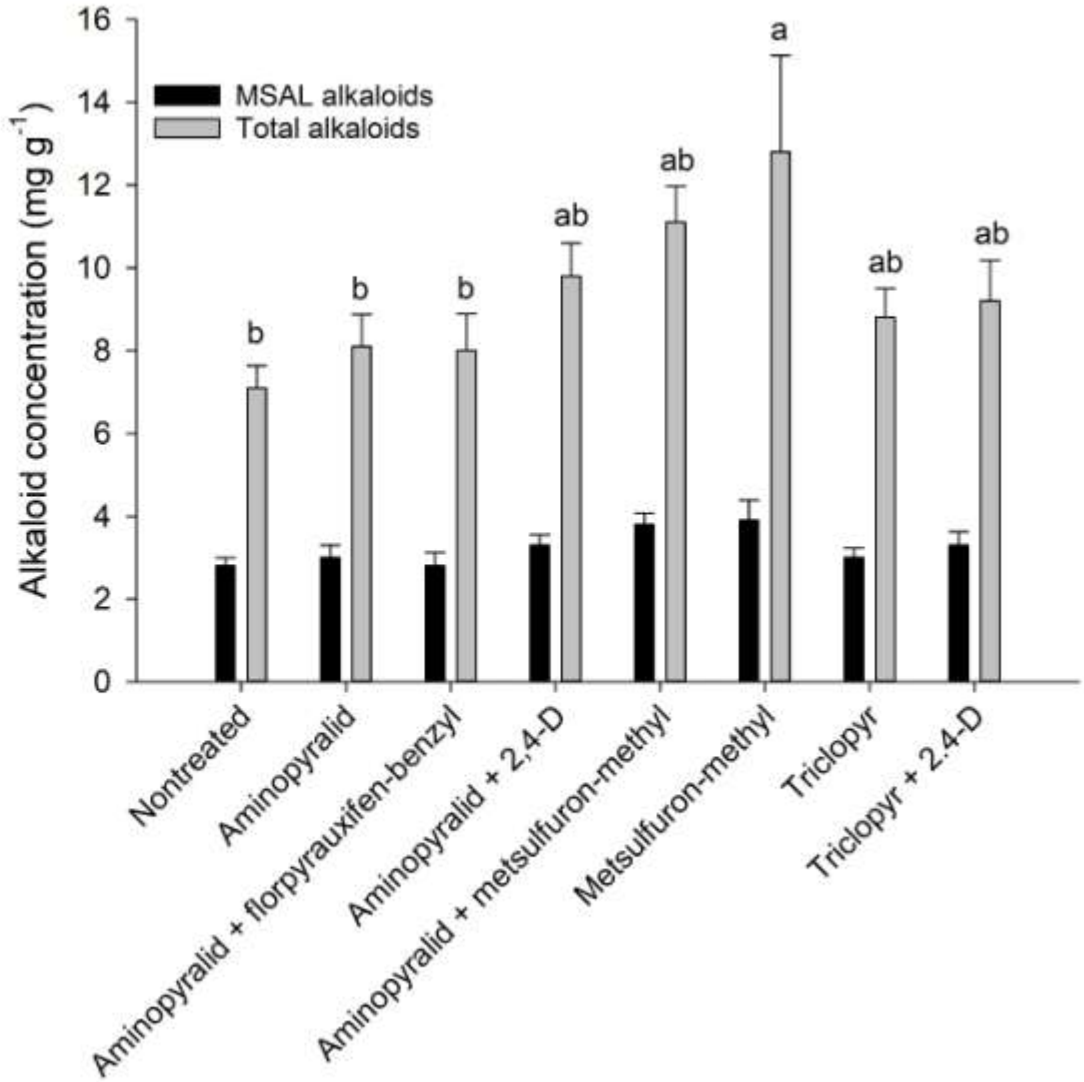

Figure 2. Total and MSAL (*N*-(methylsuccinimido) anthranoyllycoctonine) alkaloid concentrations of Geyer larkspur plants treated with herbicides near Virginia Dale, CO, 2022-2024.

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