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Small Burnet Response to Spring and Fall Postemergence Herbicide Applications

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Small burnet is a hardy, relatively long-lived evergreen forb with the potential to improve grazing lands, particularly to extend grazing into late fall and winter. Small burnet was evaluated for tolerance to spring and fall POST applications of aminopyralid, bromoxynil, clethodim, clopyralid, dicamba, dimethenamid-P, imazamox, metribuzin, pendimethalin, quinclorac, and 2,4-DB. Injury, seed yield, seed viability, and dry matter yield (DMY) were measured in the spring following application. Injury was observed in response to all spring and fall herbicide applications. Injury from aminopyralid was the highest for both spring and fall applications at 24 and 79%, respectively. Fall application of imazamox and dicamba resulted in 57 and 31% injury, respectively. Spring-applied aminopyralid and 2,4-DB both reduced DMY by 16%, whereas fall applications of imazamox, dicamba, and aminopyralid reduced DMY by 36, 12, and 67%, respectively. Fall applications of imazamox and aminopyralid reduced seed yield by 33 and 65%, respectively. Fall-applied aminopyralid reduced seed germination by 43%. None of the spring-applied herbicides affected seed yield or seed germination. Small burnet is severely injured by aminopyralid and to a lesser degree by imazamox and dicamba. Bromoxynil, clethodim, clopyralid, dimethenamid-P, metribuzin, pendimethalin, and quinclorac did not affect small burnet DMY, seed yield, or germination the year after application.
Nomenclature: 2,4-DB; aminopyralid; bromoxynil; clethodim; clopyralid; dicamba; dimethenamid-P; imazamox; metribuzin; pendimethalin; quinclorac; small burnet, *Sanguisorba minor* scop.
Keywords: Field trial, herbicide injury, seed production, seed viability, small burnet, tolerance.

Sanguisorba minor es un arbusto siempre verde de ciclo de vida relativamente largo y resistente a condiciones adversas con el potencial de mejorar tierras para pastoreo, particularmente para extender el período de pastoreo hasta el final del otoño y el invierno. Se evaluó la tolerancia de *S. minor* a aplicaciones POST en la primavera y el otoño de aminopyralid, bromoxynil, clethodim, clopyralid, dicamba, dimethenamid-P, imazamox, metribuzin, pendimethalin, quinclorac, y 2,4-DB. Se midió el daño, el rendimiento de semilla, la viabilidad de la semilla, y el rendimiento de materia seca (DMY) en la primavera siguiente a la aplicación. Se observó daño en respuesta a todas las aplicaciones hechas en la primavera y en el otoño. El mayor daño fue causado por aminopyralid siendo 24% en las aplicaciones de primavera y 79% en las de otoño. Las aplicaciones de otoño de imazamox y dicamba resultaron en 57 y 31% de daño, respectivamente. Aminopyralid y 2,4-DB aplicados en la primavera redujeron DMY en 16% mientras que las aplicaciones de otoño de imazamox, dicamba y aminopyralid redujeron DMY en 36, 15 y 67%, respectivamente. Las aplicaciones de imazamox y aminopyralid redujeron el rendimiento de semilla en 33 y 65%, respetivamente. Aplicaciones en otoño de aminopyralid redujeron la germinación de la semilla en 43%. Ninguna de los herbicidas aplicados en la primavera afectaron el rendimiento de semilla ni su germinación. *S. minor* es dañado severamente por aminopyralid en menor grado por imazamox y dicamba. Bromoxynil, clethodim, clopyralid, dimethenamid-P, metribuzin, pendimethalin, y quinclorac no afectaron DMY, el rendimiento de semilla o la germinación de *S. minor* el año siguiente a la aplicación.

Small burnet, also known as sheep's burnet, salad burnet, and lesser burnet, is a herbaceous, perennial, evergreen forb in the rose family native to Europe, Western Asia, Siberia, and northern Africa (Fryer 2008; Ogle 2002a). Small burnet is a hardy, relatively long-lived forb that grows well in most parts of North America (Ogle 2002a; Peel et al. 2009). There is evidence suggesting that small burnet is an excellent forage with high nutritive value for livestock and wildlife (Arzani et al. 2006; Fryer 2008; Viano et al. 1999), and that it can also be grazed year round or until covered by snow (Wills 2008). Small burnet averages 71 to 76 cm in height with adequate soil moisture and will establish in areas with as little as 25 to 31 cm of annual precipitation, but usually does not persist with less

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than 36 cm (Buckland et al. 1997; Ogle 2002a; Peel et al. 2009). It has excellent cold tolerance and is considered fire resistant because of the relatively high moisture content of its foliage during the fire season (Fryer 2008; Ogle 2002a).

Small burnet has excellent potential for use on grazing lands, particularly for extending grazing seasons because of its evergreen nature (Ogle 2002a). It has been observed that mule deer (*Odocoileus hemionus*) will dig through 20 to 25 cm of snow to graze on small burnet during winter months (Peel, personal communication). Welch (2004) identified small burnet as a plant species that can provide protein and energy for range animals. Goodwin et al. (2004) also identified small burnet for use in revegetation of degraded rangelands in Montana.

There is minimal information available on basic management practices for use in small burnet, particularly weed control during stand establishment and for stands intended to be grown for seed production. As is typical with most species in the year of establishment, weed invasion is problematic; in addition to reducing plant establishment, weeds can also affect stand health and subsequent seed or forage production. Available literature on the use of herbicides on small burnet is limited. Ogle (2002b) suggests that because small burnet is a broadleaf plant, 2,4-D should be avoided, whereas Carrithers (1997) lists small burnet as being tolerant to clopyralid.

With an increase in use of small burnet on grazing lands, it is important to identify its tolerance to herbicides commonly used during forage establishment and seed production. Furthermore, information on the tolerance of small burnet to various herbicides could be used to pursue product labeling. This study was conducted to determine the tolerance of small burnet to spring and fall applications of selected herbicides. The impact on small burnet seed production and germination was the primary focus of this research, with a secondary focus on plant injury and forage yield.

Materials and Methods

The study was conducted at the Utah State University Evans Research Farm in Millville, UT. Two genetically and morphologically distinct genotypes of small burnet were used: 'Delar', which is the only commercially available cultivar in the United States, and C-05, an experimental line from the U.S. Department of Agriculture–Agricultural Research Service (USDA-ARS), Forage and Range Research Laboratory, Logan, UT. Delar is tetraploid ($2n = 28$) and C-05 is octaploid ($2n = 56$) (Peel et al. 2009). Delar is a leafy herbaceous plant with a majority of its growth around the caudex in shorter stems and leaves, whereas C-05 is taller with longer stems and less leaf mass than Delar.

Plants were started in the greenhouse in conetainers (Stuewe and Sons Inc., Corvallis, OR 97333-9425) and filled with a locally purchased soil medium (Miller Companies LLC, Hyrum, UT 84319). The mixture consisted of three parts sand, one part peat moss, and one part vermiculite. Cones were hand watered with tap water until seedlings emerged and then watered as needed with 20–20–20 fertilizer (Peters Professional®, Scotts-Sierra Horticulture Products Company, Marysville, OH 43041). Each small burnet seed has two achenes per hypanthium. After germination, the smaller of the two seedlings was removed to ensure that only one plant remained in each cone. Plants were started in a greenhouse and were used because of the limited seed of C-05, and to ensure uniform numbers of plants per plot to avoid confounding effects on seed yields.

When small burnet plants were approximately 3 mo old, seedlings were transplanted to the field. Plants were transplanted in 2009 and 2010 to obtain two location years of data. The design was a randomized complete block with a split-plot arrangement and four replications. Herbicide treatments and timing represented the whole-plot and genotype the subplot. Each plot consisted of 12 plants, six Delar and six C-05 plants. A single alfalfa plant was placed between plots within rows and each plot was bordered by a row of Delar to provide a buffer between herbicide treatments. Plants within a plot were spaced 0.5 m apart within rows, with 1.0 m spacing between rows. Trials were transplanted on May 13, 2009 and May 25, 2010 in fields prepared by rototilling the previous fall. Hand weeding was done as needed.

Eleven herbicide treatments were applied during the spring and fall in the establishment year. The herbicides included aminopyralid, bromoxynil, clethodim, clopyralid, dicamba, dimethenamid-P, imazamox, metribuzin, pendimethalin, quinclorac,

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Table 1. Common and trade names, application rate, and manufacturer information for 11 herbicides applied to small burnet in 2009 and 2010.

Common name	Trade name	Application rate	Manufacturer
2,4-DB	Butyrac 200®	1,120 g ae ha^{-1}	Albaugh Inc., Ankeny IA www.albaughinc.com/
Aminopyralid	Milestone®	88 g ae ha^{-1}	Dow AgroScience, Indianapolis IN www.dowagro.com/
Bromoxynil	Buctril®	280 g ai ha^{-1}	Bayer CropScience Lp, Research Triangle Park, NC www.bayercropscience.us
Clethodim[a]	Select max®	135.8 g ai ha^{-1}	Valent U.S.A. Corporation, Walnut Creek, CA www.valent.com/
Clopyralid	Transline®	277 g ae ha^{-1}	Dow AgroScience, Indianapolis IN www.dowagro.com/
Dicamba	Banvel®	560 g ae ha^{-1}	Arysta Lifescience North America, LLC, Cary NC www.arysta-na.com/
Dimethenamid-P	Outlook®	945 g ai ha^{-1}	BASF Corporation, Agricultural products, Research Triangle Park, NC www.basf.com
Imazamox[b]	Raptor®	44 g ai ha^{-1}	BASF Corporation, Agricultural products, Research Triangle Park, NC www.basf.com
Metribuzin	Sencor®	560 g ai ha^{-1}	Bayer CropScience Lp, Research Triangle Park, NC www.bayercropscience.us
Pendimethalin	Prowl H20®	2,128 g ai ha^{-1}	BASF Corporation, Agricultural products, Research Triangle Park, NC www.basf.com
Quinclorac	Paramount®	279 g ae ha^{-1}	BASF Corporation, Agricultural products, Research Triangle Park, NC www.basf.com

[a] Clethodim application included nonionic surfactant at 0.25% v/v.

[b] Imazamox application included methylated seed oil at 1.0% v/v and AMS at 2.24 kg ha^{-1}.

and 2,4-DB (specific herbicide treatments and rates provided in Table 1). A nontreated control was also included for comparison. Herbicide treatments were applied using a CO_2-pressurized backpack sprayer calibrated to deliver 187 L ha^{-1} at 207 kPa at 4.0 km h^{-1}. The spray boom consisted of four 8002 flat-fan nozzles (Spraying Systems Company, P.O. Box 7900, North Avenue, Wheaton, IL 60188) spaced 40 cm apart.

In 2009, spring herbicide treatments were applied June 27. The late application date was due to frequent rainfall events. At the time of application, plants were mostly vegetative with flowering averaging 10%. Plant heights were 30 cm for Delar and 25 cm for C-05. In 2010, spring herbicide treatments were applied on July 6. The late herbicide application date was again a result of frequent rainfall events. Plant heights at the time of application were 15 cm for Delar and 8 cm for C-05. In preparation for fall applications, plants were cut to a uniform height of 8 cm in the last week of August with a Swift Current sickle bar harvester (Swift Machine & Welding LTD, Swift Current, SK). In 2009, fall treatments were applied November 11. Delar plants were 20 cm tall with an average width of 57 cm and C-05 plants were 13 cm tall with an average width of 56 cm. In 2010, fall treatments were applied November 3. Plant heights were 18 cm for Delar and 14 cm for C-05 at the time of application

Visual estimates of injury were recorded both in the year of and the year after application. Seed yield, seed germination, and dry matter yield (DMY) were collected the growing season after application, which would be equivalent to the first production year as detailed in Table 2. Injury was recorded on a scale of 0 to 100, where 0 = no injury and 100 = apparent mortality. Injury ratings were taken 7, 14, and 60 d after application (DAA) for the spring treatments and the spring after application, which was approximately 11 mo later. Injury ratings for fall treatments were made 7 DAA and the spring after application, which was approximately 6 mo later. In both years, snowfall occurred within 8 d after fall applications, preventing further ratings.

Spring and fall treatments from each year were harvested at the same time, but because of maturity differences between genotypes, Delar and C-05 seed were harvested separately. Delar seed was hand harvested July 21, 2010 and July 6, 2011, whereas C-05 seed was hand harvested August 5, 2010 and July 19, 2011. After harvests, seed pods were dried to approximately 11% moisture and the weight of the entire harvested material for each plot was recorded. Seed was cleaned using a stationary laboratory thresher (Wintersteiger LD 180, Wintertsteiger, Salt Lake City, UT 84116) and an air cleaner (Almaco Air Blast Seed Cleaner, Allen Machine Company, Nevada, IA 50201) and the weight of the cleaned seed recorded.

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Table 2. Summary of planting dates, herbicide application, visible injury ratings, seed harvest, and forage harvests of small burnet treated with herbicides applied POST.[a]

	2009		2010	
Procedures	Spring	Fall	Spring	Fall
Field planting date	May 13, 2009	May 13, 2009	May 25, 2010	May 25, 2010
Application date	June 27, 2009	November11, 2009	July 6, 2010	November 3, 2010
7 DAA evaluation	July 3, 2009	November 17, 2009	July 12, 2010	November 11, 2010
14 DAA evaluation	July 11, 2009	—	July 20, 2010	—
60 DAA evaluation	August 27, 2009	—	September 1, 2010	—
Spring evaluation[b]	April 27, 2010	April 27, 2010	May 17, 2011	May 17, 2011
Seed harvest[c]	July 21, 2010	July 21, 2010	July 6, 2012	July 6, 2011
Forage harvest	August 6, 2010	August 6, 2010	July 20, 2011	July 20, 2011

[a] Abbreviation: DAA, day after application.

[b] Injury ratings were taken the spring of the year after applications, approximately 11 mo after spring applications and 6 mo after fall applications.

[c] C-05 seed was harvested August 5, 2010 and July 19, 2011.

The biomass remaining after the seed harvest was harvested August 6, 2010 and July 20, 2011 using a Swift Current plot harvester. Samples of each subplot were dried in an oven at 71 C for 6 d and used to determine the dry weight of each subplot. The entire dried seed harvest weights were added to this weight to determine the total DMY of each subplot.

Since small burnet seed requires an after-ripening period (Fryer 2008; Jorgensen and Stevens 2004) and seed dormancy is reported to be an issue, small burnet seed were placed in storage for 3 mo after harvest. To determine if a freezing or cold treatment would improve the germination, three pretreatments were compared on seed from one replication. These were (1) freezing at −80 C for 1 wk followed by germination starting at 3 C and increasing 3 C daily until reaching 21 C; (2) germination starting a 3 C and increasing 3 C daily until reaching 21 C; and (3) germination starting at 21 C (no cold treatment). There was no difference in germination between the treatments; consequently all reported germination is without any pretreatment.

To complete the germination, two samples of 50 seeds of each subplot were tested for germination. Seeds were dusted with a fungicide (Thiram, Sigma-Aldrich Co., St. Louis, MO 63103) to minimize fungal growth and boxes were placed in an incubator at 21 C. Since germination occurs over an extended period, multiple count dates were utilized. The total seed germination after 28 d was reported. If one seed from a hypanthia germinated it was counted. Germinated seeds were removed during counting to simplify subsequent counts.

All data were analyzed using the PROC MIXED procedure of SAS (Littell et al. 2006). Mean comparisons were made among herbicide treatments using Fisher's Protected LSD test at the $P = 0.05$ level of probability (Steel et al. 1997).

Results and Discussion

The effects for herbicide treatment on injury, DMY, seed yield, and seed germination were significant ($P < 0.0001$). Herbicide treatment-by-timing (spring vs. fall) interactions for visible injury, DMY, seed yield, and seed germination were also significant ($P < 0.0001$). Significant year-by-herbicide treatment interactions were also observed for visible injury, DMY, seed yield, and seed germination ($P < 0.01$). Injury was less, whereas DMY, seed yield, and seed germination were higher in 2011 (in response to 2010 applications) compared with 2010 (in response to 2009 applications). These differences were likely caused by differences in precipitation between the study years (Figure 1). There were no changes in rank for injury, DMY, seed yield, or seed germination between the 2 yr and consequently data were combined over years.

Injury. Injury 7 DAA was observed in response to all spring-applied treatments (Table 3). Bromoxynil, aminopyralid, imazamox, and dicamba were the most injurious to small burnet and resulted in 50 to 61% injury. Small burnet injury was least (14

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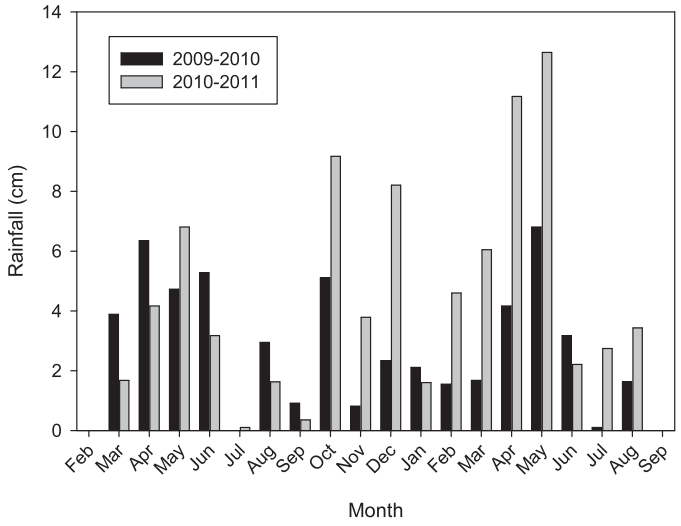


Figure 1. Monthly rainfall through the duration of small burnet herbicide tolerance trials, 2009 to 2010 and 2010 to 2011.

to 21%) in response to clethodim, dimethenamid-P, and quinclorac. Injury in response to spring treatments 60 DAA was higher than the nontreated control for all herbicides except clopyralid, dimethenamid-P, and quinclorac (Table 3). From 7 DAA to 60 DAA, the overall average injury in response to the herbicide treatments decreased from 38 to 19%. Small burnet injury ranged from 27 to 43% with aminopyralid, imazamox, and 2,4-DB 60 DAA, which was the highest observed in the experiments. Injury from clethodim was the lowest of all herbicides evaluated 7 DAA and did not change at 14 or 60 DAA. Bromoxynil and dicamba treatments initially caused high injury 7 DAA (61 and 50%, respectively) but by 60 DAA the injury was one-third that originally observed (Table 3).

Table 3. Mean observed injury to small burnet 7, 14, and 60 d after application (DAA) with spring herbicide applications in 2009 and 2010.

		Injury[c]		
Herbicides[a]	Rate[b]	7 DAA	14 DAA	60 DAA
	g ai or ae ha^{-1}		%	
Nontreated		0	0	0
2,4-DB	1,120	47	48	27
Aminopyralid	88	57	54	43
Bromoxynil	280	61	62	19
Clethodim	136	14	14	15
Clopyralid	277	32	31	11
Dicamba	560	50	49	16
Dimethenamid-P	945	16	16	5
Imazamox	44	53	51	29
Metribuzin	560	44	43	16
Pendimethalin	2,128	28	29	17
Quinclorac	279	21	22	7
LSD (0.05)		11	11	11

[a] Imazamox application included methylated seed oil at 1.0% v/v and AMS 2.24 kg ha^{-1}. Clethodim application included nonionic surfactant at 0.25% v/v.

[b] Clopyralid, 2,4D-B, aminopyralid, dicamba, and quinclorac are listed as g ae ha^{-1}; the remaining herbicide rates are g ai ha^{-1}.

[c] Injury ratings were on a scale of 0 to 100, where 0 = no injury and 100 = complete mortality.

Table 4. Mean observed injury of small burnet in the spring of the year after applications, 2010 and 2011.

		Injury[c]	
Herbicides[a]	Rate[b]	Spring[d]	Fall[e]
	g ai or ae ha^{-1}	%	
Nontreated		0	0
2,4-DB	1,120	11	12
Aminopyralid	88	24	79
Bromoxynil	280	7	7
Clethodim	136	4	7
Clopyralid	277	11	9
Dicamba	560	4	31
Dimethenamid-P	945	1	9
Imazamox	44	8	57
Metribuzin	560	11	9
Pendimethalin	2,128	8	7
Quinclorac	279	6	8
LSD (0.05)		6	

[a] Imazamox application included methylated seed oil at 1.0% v/v and AMS at 2.24 kg ha^{-1}. Clethodim application included nonionic surfactant at 0.25% v/v.

[b] Clopyralid, 2,4D-B, aminopyralid, dicamba, and quinclorac are listed as g ae ha^{-1}; the remaining herbicide rates are g ai ha^{-1}.

[c] Injury ratings were on a scale of 0 to 100, where 0 = no injury and 100 = complete mortality.

[d] Ratings taken 11 mo after application.

[e] Ratings taken 6 mo after application.

No injury was observed after fall-applied herbicide treatments 7 DAA (data not presented); however, injury from both the spring and fall applications was observed the following spring (11 and 6 mo after application, respectively) (Table 4). Overall, injury was greatest with aminopyralid, regardless of the application timing. Fall-applied dicamba and imazamox also caused substantial injury at 57 and 31%, respectively. Injury from all remaining fall-applied herbicides was less than 13% (Table 4). Injury from imazamox, pendimethalin,

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Table 5. Mean dry matter yield (DMY) and seed yield of Delar and C-05 small burnet the season after herbicide application, 2010 and 2011.

Herbicides[a]	Rate[b]	DMY		Seed yield	
		C-05	Delar	C-05	Delar
	g ai or ae ha^{-1}	Mg ha^{-1}			
Nontreated		4.93	3.92	0.73	1.02
2,4-DB	1,120	3.94	4.05	0.67	1.10
Aminopyralid	88	3.11	2.06	0.57	0.60
Bromoxynil	280	4.11	4.07	0.66	1.09
Clethodim	136	4.77	4.05	0.73	1.08
Clopyralid	277	5.04	4.06	0.81	1.07
Dicamba	560	4.33	3.70	0.76	1.06
Dimethenamid-P	945	4.49	4.14	0.71	1.14
Imazamox	44	3.45	3.40	0.53	0.96
Metribuzin	560	4.73	3.61	0.80	1.04
Pendimethalin	2,128	4.90	4.15	0.78	1.15
Quinclorac	279	4.93	4.17	0.78	1.09
LSD (0.05)		0.55		0.14	

[a] Imazamox application included methylated seed oil at 1.0% v/v and AMS at 2.24 kg ha^{-1}. Clethodim application included nonionic surfactantNIS at 0.25% v/v.

[b] Clopyralid, 2,4D-B, aminopyralid, dicamba, and quinclorac are listed as g ae ha^{-1}; the remaining herbicide rates are g ai ha^{-1}.

Table 6. Mean dry matter yield (DMY) of small burnet in response to spring- and fall-applied herbicides, 2010 and 2011.

Herbicides[a]	Rate[b]	DMY	
		Spring	Fall
	g ai or ae ha^{-1}	Mg ha^{-1}	
Nontreated		4.43	4.39
2,4-DB	1,120	3.73	4.24
Aminopyralid	88	3.72	1.44
Bromoxynil	280	3.98	4.18
Clethodim	136	4.22	4.58
Clopyralid	277	4.31	4.77
Dicamba	560	4.15	3.86
Dimethenamid-P	945	4.18	4.43
Imazamox	44	4.01	2.83
Metribuzin	560	4.06	4.26
Pendimethalin	2,128	4.52	4.50
Quinclorac	279	4.34	4.70
LSD (0.05)		0.49	

[a] Imazamox application included methylated seed oil at 1.0% v/v and AMS at 2.24 kg ha^{-1}. Clethodim application included nonionic surfactant at 0.25% v/v.

[b] Clopyralid, 2,4D-B, aminopyralid, dicamba, and quinclorac are listed as g ae ha^{-1}; the remaining herbicide rates are g ai ha^{-1}.

clopyralid, 2,4-DB, metribuzin, and bromoxynil spring applications was greater than the nontreated control and ranged from 7 to 11% (Table 4). Injury from the spring applications of dimethenamid-P, dicamba, clethodim, and quinclorac the following year did not differ from the nontreated control.

When evaluating injury the spring after herbicide treatment, fall applications of aminopyralid, imazamox, and dicamba caused more injury than spring applications. Fall-applied aminopyralid, dicamba, and imazamox were 57, 27 and 52% more injurious than when applied in the spring (Table 4). It is noteworthy that injury from spring-applied dicamba or imazamox was minor ($\leq$ 8%) compared with a fall application of either herbicide (31 and 57%, respectively) (Table 4). It is also noteworthy that although bromoxynil, clethodim, clopyralid, metribuzin, pendimethalin, quinclorac, and 2,4-DB caused injury (4 to 12%) from both spring and fall applications, the injury level was much less than that observed with aminopyralid applied in the spring or fall (24 and 79%, respectively) or fall applications of dicamba or imazamox (31 and 57%, respectively).

Dry Matter Yield. Although genotype-by-herbicide interactions for DMY were significant ($P = 0.0019$), this was not unexpected because of the genetic differences between the genotypes tested. With the exception of bromoxynil, imazamox, and 2,4-DB treatments, C-05 consistently produced higher DMY than Delar (Table 5). Furthermore, for these three herbicides, DMY of C-05 was less than the nontreated control, suggesting that C-05 may be more sensitive to these herbicides than Delar. DMY of both genotypes in response to aminopyralid was substantially lower than the nontreated control (Table 5).

There was a significant herbicide treatment-by-timing interaction ($P < 0.0001$) for DMY. Plots treated in the spring with aminopyralid and 2,4-DB both had 16% lower DMY than the nontreated (Table 6). DMY from spring applications of bromoxynil, clethodim, clopyralid, dicamba, dimethenamid-P, imazamox, pendimethalin, metribuzin, and quinclorac were not different from the nontreated control and ranged from 3.98 to 4.52 Mg ha^{-1} (Table 6). Fall-applied aminopyralid, dicamba, and imazamox reduced DMY 67, 12, and 36%, respectively. DMY after fall applications of aminopyralid, imazamox, and 2,4-DB was different from the DMY of the respective spring applications. Furthermore, the DMY after fall applications of aminopyralid and imazamox was 61 and 29% less

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Table 7. Mean seed yield and germination of small burnet after spring- and fall-applied herbicides, 2010 and 2011.

Herbicides[a]	Rate[b]	Seed yield		Germination	
		Spring	Fall	Spring	Fall
	g ai or ae ha^{-1}	—Mg ha^{-1}—		——%——	
Nontreated		0.90	0.85	64	63
2,4-DB	1,120	0.84	0.93	68	62
Aminopyralid	88	0.86	0.29	58	35
Bromoxynil	280	0.85	0.89	65	64
Clethodim	136	0.90	0.89	64	62
Clopyralid	277	0.92	0.96	66	65
Dicamba	560	0.95	0.87	67	58
Dimethenamid-P	945	0.92	0.92	64	61
Imazamox	44	0.90	0.57	65	57
Metribuzin	560	0.94	0.90	65	62
Pendimethalin	2,128	1.00	0.93	63	61
Quinclorac	279	0.89	0.94	62	66
LSD (0.05)		0.15		8	

[a] Imazamox application included methylated seed oil at 1.0% v/v and AMS at 2.24 kg ha^{-1}. Clethodim application included nonionic surfactant at 0.25% v/v.

[b] Clopyralid, 2,4D-B, aminopyralid, dicamba, and quinclorac are listed as g ae ha^{-1}; the remaining herbicide rates are g ai ha^{-1}.

than their respective spring applications. Conversely, small burnet treated with 2,4-DB in the fall yielded 12% more than small burnet treated with 2,4-DB in the spring (Table 6).

The injury consistently observed from the aminopyralid was also reflected in the reduction in DMY from both fall and spring applications (Tables 4 and 6). Similarly, imazamox and dicamba caused injury to small burnet plants as well as having the second and third lowest DMYs of the fall-applied herbicides. Although there was nothing noteworthy about the injury from the 2,4-DB, there was a reduction in DMY from the spring application.

Seed Yield. A genotype-by-herbicide interaction ($P = 0.0065$) for seed yield was observed, which, as mentioned previously, reflects the genetic differences between the two genotypes (Table 5). Imazamox reduced seed yield of C-05 but did not affect Delar seed yield, whereas both Delar and C-05 seed yields were reduced by the aminopyralid (Table 5). It is also noteworthy that aminopyralid resulted in a greater reduction in seed yield of Delar than C-05 (41 vs. 22%).

As observed for both injury and DMY, a significant ($P < 0.0001$) timing-by-herbicide interaction for seed yield was observed. Whereas no spring-applied herbicides were different from the nontreated control, fall applications of aminopyralid and imazamox reduced seed yield by 66 and 33%, respectively (Table 7). Furthermore, spring-applied aminopyralid and imazamox resulted in 66 and 36% higher yields, respectively, than when these same herbicide treatments were applied in the fall. Seed yield for all other spring and fall treatments were similar (Table 7).

The spring-applied herbicides that resulted in injury and reduced DMY did not affect seed yield. However, the fall applications of aminopyralid and imazamox that resulted in the most injury and lowest DMY also resulted in reduced seed yield. Conversely, the dicamba treatments that resulted in injury and reduced DMY did not affect seed yield.

Germination. Overall seed germination was relatively low, averaging 62% (Table 7). As observed with each of the other traits examined, there was a significant herbicide-by-timing interaction for seed germination ($P > 0.0001$). Among the spring-applied herbicide treatments, none differed from the nontreated control. However, seed germination from the fall-applied aminopyralid plots was 44% less than the nontreated control (Table 7). Germination of seed from plots treated in the fall with aminopyralid and dicamba averaged 40 and 13% less than the same herbicides applied in the spring.

When comparing germination with injury, DMY, and seed yield, only the fall-applied aminopyralid negatively affected all traits. However, at the $P = 0.07$ level, fall applications of imazamox and dicamba as well as spring applications of aminopyralid also reduced germination, similar to the observations for visible injury, DMY, and seed yield. Although clopyralid and aminopyralid are in the same chemical family and have similar chemical structures and weed-control spectrum (Bukun et al. 2009), aminopyralid had a negative impact on all traits, whereas clopyralid did not affect DMY, seed yield, or germination. This response was unexpected but does support Carrithers' (1997) report that small burnet is tolerant to clopyralid.

All of the herbicides tested resulted in injury to small burnet. For the spring-applied herbicides this was observed within 7 to 60 DAA, and with aminopyralid, bromoxynil, clopyralid, imazamox, metribuzin, pendimethalin, and 2,4-DB the following spring. For the fall-applied herbicides, the injury was observed the following spring. However, it was

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demonstrated that an application of bromoxynil, clethodim, clopyralid, dimethenamid-P, metribuzin, pendimethalin, and quinclorac in the year of establishment did not negatively affect seed or forage production the following year even though there was injury. This group of seven herbicides has potential for use in assisting in the establishment of small burnet either for seed production or forage production on grazing lands. This information could also be useful to managers of Conservation Reserve Program land, ranglelands, or pastures, which contain small burnet, as some of these herbicides are labeled for these sites.

The reduction in DMY from dicamba and imazamox after fall application and 2,4-DB after spring application suggest crop safety concerns. Furthermore, the reduction in seed yield after fall applications of dicamba and imazamox are additional evidence of the injury potential of these two herbicides. Although it appears from the spring applications that small burnet likely recovered from dicamba and imazamox, the injury from fall applications is an indicator that crop safety will be a concern. Spring and fall applications of aminopyralid consistently reduced DMY, seed yield, and germination, and its use should be avoided in small burnet.

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