Boulder County Parks and Open Space Small Grants 2007

Broadleaf Rangeland Herbicide Effects on Established and Seedling Native Forbs, Shrubs, and Grasses

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Section 1. Abstract

Herbicides are commonly used to control invasive and common weeds on native rangeland and natural areas, but not enough is known about their potential to cause injury to native shrubs, forbs, and grasses. Experiments were conducted to evaluate 16 different herbicides at single high rates for their potential injury and effects on species composition. During the year of application, injury was ranked on a scale of 0-10 where 0-2 was considered as no injury, 3-6 as acceptable injury from which plants would recover, and 7-10 as unacceptable from which most plants would not recover. All plant species were inventoried in all plots approximately 1 year after herbicides were applied to determine any population shifts. Injury during the year of application was very difficult to discern from plants drying down after flowering or because of drought. Data taken 1 year after herbicides were applied was much more revealing as to the potential injury and population shifts that could be caused by different herbicides used to control weeds. One-sided penstemon was the only species to be dramatically affected by most of the herbicides tested where 11 herbicides decreased its populations an average of 87%. Telar and Cimarron Max caused a decline of about 18% in native forb composition whereas native forb composition within other herbicide treated plots did not differ from the untreated plots. No herbicide caused a change in native shrub composition except Telar, which increased forb composition about 8%. Telar and Cimarron Max treated plots displayed increased grass composition and oddly enough, Escort and Cimarron

Max treated plots showed an increase in weedy species composition. Data will be collected again in spring 2008 from the study established in 2007 to create another data set 1 year from the time of application.

Section 2. Introduction and literature review:

Weeds commonly infest pastures and rangeland particularly those that have been degraded by overgrazing, fire, flooding, or drought. Weed occurrence on rangeland and pastures decreases the carrying capacity and some weeds are poisonous to grazing animals. Broadleaf herbicides often are used to control weedy forbs and because these herbicides are selective, they do not injure perennial grasses, which dominate most western rangeland and pastures. However, native forbs and shrubs are essential components of healthy rangeland plant communities and native forbs compete directly with weedy forbs. To maintain healthy native rangeland plant communities, weeds must be controlled and while herbicides typically are used in this battle, very little is known about the injury potential they pose to native forbs and shrubs as seedlings or established plants.

Invasive and common weeds that infest pastures and rangeland dramatically affect productivity. Over $2 billion are lost each year in the U.S. because of weeds invading pastures causing decreased carrying capacity and plant poisonings (Pimentel et al. 2000). Selective broadleaf herbicides often are used to control weedy forbs in rangeland and such herbicides usually do not injure perennial rangeland grasses, which is highly essential so they compete effectively with recovering weedy forbs or those that subsequently recruit from the soil seed reserve after initial treatment. Many experiments have shown the importance of effective competition from perennial grasses when managing weeds in rangeland using a successional weed management approach (Benz, et al 1999**;** Biesboer et al 1993; Sheley et al 1996). Perennial grasses often dominate western rangeland, but most healthy plant communities typically have an abundance of native forbs and shrubs and the latter usually are sown as part of the seed mixture. Porkony (2002) showed that native forbs compete directly with weedy forbs because they belong to the same plant functional group. Thus, it also is important not to injure established or seedling native forbs when controlling weedy forbs to create an effective successional weed management program where grass competition is augmented by native forbs.

Very little data are available to document the level of injury to native forbs when using selective broadleaf herbicides to control weedy forbs on rangeland whether the target area has been recently seeded to desirable species or is an established parcel of rangeland. Rice (1997) found that picloram did not injure all established native forbs in Montana when it was used to control spotted knapweed. But because very little is known about other herbicides relative to native forb and shrub injury, land managers often postpone the decision to use a herbicide thus, providing weeds with additional time to spread and dominate plant communities. Or land managers may choose to use physical methods such as mowing or hand pulling to manage weeds. Mowing is a disturbance and has been shown to stimulate weed recruitment and seldom is mowing commonly recommended as a control measure because its effects are inconsistent (Beck and Sebastian 2000; Sebastian and Beck 1999**)**. Hand pulling is an option on established rangeland, but it is very expensive compared to herbicide use and it also disturbs the soil dramatically thereby stimulating recruitment of more weeds (Sebastian and Beck 1999; Brown et al. 1999). Hand pulling is not a viable option on newly seeded sites because of the potential tremendous injury to seeded species by trampling, much less the subsequent weed recruitment that would occur because of the disturbance. Native forbs and shrubs are essential components of healthy native plant communities particularly relative to competing with weeds. Because herbicides are the most effective and least costly of the weed control methods, it is essential that we better understand the injury risk to established or seedling native forbs and shrubs from herbicides used to control invasive weeds on rangeland.

Section 3. Materials and methods:

We proposed to repeat two field experiments to better describe the potential injury from rangeland herbicides. One was conducted on established forbs and shrubs (***Established FS 2007***) and the second was to be conducted on seedling forbs, shrubs, and grasses (***Seedling FSG 2007***). However, a suitable site could not be found for the seedling study and no species were drilled therefore, this study was eliminated.

Established FS 2007: This experiment was designed as randomized complete block and herbicide treatments were replicated four times. Non-herbicide-treated control plots were included as references for no injury. Data were subjected to analysis of variance. Plot size was10 by 30 ft and the entire experiment was about 0.67 acres in size.
This experiment was conducted at one native rangeland site in 2007 adjacent to the identical experiment initiated in 2006. Herbicides and rates tested in 2007 (identical to 2006) included aminopyralid at 0.11 lb ai/A (7 fl oz of Milestone/A); clopyralid at 0.38 lb ai/A (1 pt Transline/A); picloram at 0.25 lb ai/A (1 pt Tordon 22K/A); triclopyr at 0.75 lb ai/A (2 pt Garlon 3A/A); dicamba at 1.0 lb ai/A (1 qt Vanquish/A); 2,4-D amine at 1.5 lb ai/A (1.5 qt 2,4-D Amine/A); 2,4-D ester at 1.5 lb ai/A (1.5 qt 2,4-D LV4/A); quinclorac at 0.28 lb ai/A (6 oz of Paramount/A), chlorsulfuron at 0.94 oz ai/A (1.25 oz Telar XP/A); metsulfuron at 0.6 oz ai/A (1 oz Escort XP/A); imazapic at 0.19 lb ai/A (12 fl oz Plateau/A); and the tank mixes clopyralid plus 2,4-D at 0.29 + 1.5 lb ai/A (3 qt Curtail/A); clopyralid plus triclopyr at 0.28 + 0.84 lb ai/A (3 pt Redeem/A); picloram plus 2,4-D at

0.27 + 1.0 lb ai/A (2 qt Grazon P+D/A); dicamba plus diflufenzopyr at 0.25 lb ai of dicamba/A (equivalent to 8 oz Overdrive/A); metsulfuron plus dicamba plus 2,4-D at 0.6 oz + 0.5 lb + 1.44 lb ai/A (Rate III of Cimarron Max); and two non-treated controls in each replicate of treatments. The first eight herbicides are classified as growth regulators and the next three inhibit the synthesis of the amino acids valine, leucine, and isoleucine (Hatzios et al. 1998). Diflufenzopyr is an additive that enhances the activity of several growth regulator herbicides, particularly dicamba (Lym and Diebert, 2005). We applied only one rate of each herbicide or tank mix to keep the size of the experiment at a minimum so native forb and shrub species distribution was optimized. This approach allowed us to evaluate potential injury from more commonly used rangeland herbicides than would have a rate response approach. Rates chosen for this experiment were toward the high end of the registered and recommended rate range, but we avoided rates where selectivity would have been questionable. Herbicides were applied on May 25, 2007 with a CO_2 backpack sprayer using water as a carrier at 21 gallons per acre. This roughly coincided with the optimal timing to control diffuse knapweed in spring.

We determined baseline populations of established native forbs and shrubs by counting each plant by species in each plot. A list of all species present at application and throughout the remainder of the growing season can be found in Table 1. Growth stage and size at application are included only for those species present at application. Visual estimates of percent injury to native forbs, shrubs, and desirable grasses were collected in October, 2007 based on a scale of 1 to 10 where 0 equaled no injury and 10 represented a dead plant. Generally, injury ratings from 0-2 were assigned when plants displayed no response to treatment or were slightly stunted or chlorotic and these ratings would be classified as no injury; injury ratings from 3-6 were assigned where up to half the leaves had died yet the remaining were green and alive, or plants were necrotic but showed substantial recovery, or if plants did not flower or set seed depending on the proportion for each situation and these ratings were classified as acceptable because injured plants recovered; ratings from 7-10 were assigned when injured plants had about 20% or less green tissue apparent with a 10 assigned to those plants that had died. These latter ratings would be classified as unacceptable injury because plants would not recover by the end of the growing season.

Plans to collect injury data at 4 week intervals after application were aborted because it was impossible to discern injury due to herbicides from injury due to drought. We will collect data from this experiment in spring 2008 and 2009 to determine any long-term species shifts that may have been caused by herbicide treatments. Data from the 2007 study will be combined with data from the 2006 study, if possible (i.e. no year main effect or interactions), to create a much larger data set, which may provide a refined look at the results.

Table 1. Forb and grass species present at the 2007 established site and growth stage information at herbicide application.

Native Forbs

Scientific name	Common name	Growth Stage at Application
Adenolinum lewisii	Blue flax	3-14" tall, vegetative to flower
Allium textile	Wild onion	4-6" tall, flower
Aphyllon fasciculatum	Broomrape	
Argemone polyanthemos	Prickly poppy	
Asclepias pumila	Plains milkweed	1 to 2" tall, vegetative
Calylophus serrulatus	Yellow sundrop	
Castilleja sessiliflora	Plains paintbrush	6 to 8" tall, full bloom
Cirsium undulatum	Native thistle (waveyleaf)	2 to 10" rosettes, 4 to 10" tall bolting
Dalea Purpurea	Purple prairie clover	
Evolvulus nuttallianus	Dwarf morning glory	
Erigeron colomexicanus	Running fleabane	
Erysium capitatium	Sanddune wallflower	6 to 13" tall, flower
Erysium inconspicuum	Shy wallflower	
Gaillardia aristata	Blanket flower	2 to 8" tall, vegetative to bud
Gaura coccinea	Scarlet beeblossum	4 to 8" tall, bud to early flower
Helianthus pumilus	Little sunflower	3 to 7" tall, vegetative
Hymenopappus filifolius	Fineleaf hymenopappus	1 to 7" tall, bolting
Lesquerella montana	Mountain bladderpod	
Leucocrinum montanum	Sand lily	3 to 7" diameter rosettes, post flower
Liatris punctata	Gay feather	4 to 6" tall, bolting
Lithospermum incisum	Narrowleaf puccoon	1 to 3" tall, late flower
Lomatium orientale	Parsley	
Mertensia lanceolata	Chiming bell	8 to 10" tall, late flower
Musineon dwaricatum	Wild parsley	
Oenothera howardii	Howard's evening primrose	2 to 4" tall, vegetative to early flower
Oligosporus dracunculus	Wild tarragon	
Opuntia polyacantha	Pricklypear cactus	3 to 6" tall, vegetative
Oxybaphus sp.	Umbrellawort	
Oxytrophis sericea	Locoweed	3 to 9" tall, post flower
Penstemon secundiflorus	One-sided penstemon	6-13" tall, full bloom
Phacelia heterophylla	Scorpionweed	2 to 7" tall, bolting
Psoralea lanceolata	Slimflower scurfpea	
Pterogonum alatum	Winged buckwheat	2 to 5" diameter rosettes, 4 to 8" tall
Ratibula columnifera	Prairie coneflower	3 to 6" tall, bolting
Senecio spartioides	Butterweed	
Senecio sp.		
Sphaeralcea coccinea	Scarlet globemallow	2 to 4" tall, vegetative to early flower

Tithymalus brachyceras	Robust spurge	4-8" tall, late flower
Thelesperma megapotamicum	Navajo tea	1 to 7" tall, bolting
Viola nuttallii	Nuttall’s violet	3 to 5" tall, vegetative

Grass

Scientific name	**Common name**	**Growth Stage at Application**
Andropogon gerardii	Big bluestem	
Aristida purpurea	Purple threeawn	3 leaf, 1 to 3" tall
Bouteloua curtipendula	Sideoats grama	
Bromus inermus	Smooth brome	
Bromus japonicus	Japanese brome	
Bromus tectorum	Downy brome	
Chondrosum gracile	Blue grama	
Critesion jubatum	Foxtail	
Hesperostipa comata	Needleandthread	2 to 3" tall, vegetative
Pascopyrum smithii	Western wheatgrass	
Schedonnardus paniculatus	Common tumblegrass	
Schizachyrium scoparium	Little Bluestem	

Non-native or weedy

Scientific name	**Common name**	**Growth Stage at Application**
Alyssum alyssoides	Yellow alyssum	
Ambrosia psilostachya	Western ragweed	
Convolvulus arvensis	Field bindweed	
Descurainia sophia	Flixweed/tansy mustard	
Erodium cicutarium	Redstem filaree	
Euphorbia humistrata	Prostrate spurge	
Lactuca seriola	Prickly lettuce	2 to 4" tall, bolting
Physalis heterophylla	Clammy groundcherry	
Salvia aethiopsis	Mediterranean sage	
Sisymbrium altissimum	Tumble mustard	
Taraxacum officinale	Dandelion	
Tragapogon dubius	Western salsify	
Verbascum thapsus	Common mullein	

Brush or brush-like

Scientific name	**Common name**	**Growth Stage at Application**
Artemesia frigida	Fringe sage	1 1/2 to 3 1/2" tall, vegetative
Artemesia ludoviciana	Louisiana sage	1 to 2 1/2" tall, vegetative
Gutierrezia sarothrae	Broom snakeweed	3 to 6" tall, vegetative
Heterotheca villosa	Hairy golden aster	4 to 8" tall, vegetative
Prunus americana	American plum	N/A
Rhus aromatica	Skunkbush	N/A
Rosa woodsii	Wood's rose	4 to 7" tall, vegetative
Yucca glauca	Yucca	14 to 30" tall, vegetative

Established FS 2006: We inventoried all plots from the experiment initiated in 2006 approximately 1 year after herbicides were applied. Forbs, shrubs, grasses, and weedy plants were counted by species in each entire plot as well as estimating cover of bare ground. Plants that grew as individuals were counted as plants per plot (e.g. purple threeawn, broom snakeweed, fringed sage) whereas plants that are clonal in nature or tiller were counted as shoots per plot. These data were subjected to analysis of variance and represent the selection pressures of each herbicide that may or may not have caused any species shifts to occur. We anticipate collecting data again from this experiment in spring 2008 about 2 years after the herbicides were applied, again to detect any long-term species shifts that may have been caused by herbicides. At this time, we anticipate publishing our results in a refereed scientific journal and a manuscript will be provided to Boulder County Open Space personnel before submission for their input.

Section 4. Results:

Established FS 2007

Little sunflower (Helianthus pumilus)

Injury data were collected for six forb and four shrub/brush species. Paramount and Plateau caused no injury to little sunflower whereas Milestone, Telar, and Transline caused injury ratings of 4 and this was acceptable as we anticipate plants will recover (Table 2). All other herbicides caused injury of 7 to 9 and were considered unacceptable because many of these plants most likely will die over winter.

Winged buckwheat (Pterogonum alatum)

Paramount, Transline, and Telar caused minimal injury to winged buckwheat (range 0 to 2). Overdrive, Plateau, Curtail, 2,4-D amine, and Redeem caused acceptable injury to winged buckwheat (range 4 to 6). All other herbicides caused excessive and unacceptable injury to this native forb. One interesting contrast was the difference in injury caused by the two different 2,4-D formulations. The water soluble 2,4-D amine caused an injury level of only 4 while 2,4-D ester caused an injury level of 8 thus, demonstrating how formulation of identical herbicides can dramatically influence injury.

Gayfeather (Liatris punctata)

Paramount and Garlon 3A caused injury levels of 0 and 1, respectively, to gayfeather. All other herbicides, except Cimarron Max, caused acceptable levels of injury to gayfeather (range 3 to 6) from which it most likely will recover. Cimarron Max caused an injury rating of 7 to gayfeather. It is interesting to note that only the “no injury” levels differed statistically from all other ratings, which were statistically similar.

Blue flax (Adenolinum lewisii)

Injury to blue flax also ranged from none to unacceptable. Paramount caused no injury to blue flax while Plateau, Transline, Garlon 3A, Tordon, Milestone, and Telar caused acceptable injury to blue flax (range 3 to 5). The remaining herbicides caused unacceptable injury to blue flax (range 7 to 8).

Dwarf morning-glory (Evolvulus nuttallianus)

Dwarf morning-glory injury from herbicides ranged from none to unacceptable with the majority of ratings falling in the acceptable range. Paramount and Transline caused no injury (0 and 2, respectively) while Overdrive, Plateau, 2,4-D amine, Grazon P+D, Redeem, Tordon, Milestone, Telar, and Escort caused acceptable injury (range 4 to 6). Vanquish, Curtail, 2,4-D ester, Garlon 3A, and Cimarron Max caused unacceptable injury to dwarf morning-glory.

Purple threeawn (Aristida purpurea) and *Yucca (Yucca glauca)*

Purple threeawn was not injured by any herbicide treatment (Table 3). Similarly, yucca was not injured by any herbicide treatment (range 0 to 2).

Fringed sage (Artemesia frigida)

Injury to fringed sage ranged from 1 to 9. Paramount, Plateau, and Milestone caused no injury (range 1 to 2). Acceptable injury was caused by Overdrive, Transline, Garlon 3A, Tordon, Telar, and Escort (range 3 to 5). All other herbicide treatments caused unacceptable injury to fringed sage (range 7 to 9) where 2,4-D ester caused more injury than most other treatments. Interestingly, the latter is seldom recommended anymore to control fringed sage when such occasions arise.

Broom snakeweed (Gutierrezia sarothrae)

Most treatments badly injured broom snakeweed and none caused zero injury. Only Paramount, Plateau, Transline, 2,4-D ester, and Telar caused acceptable injury (range 3 to 6) whereas the remaining herbicide treatments caused unacceptable injury (range 7 to 9). Several of these latter herbicides are commonly recommended to control broom snakeweed when its populations burgeon to such necessity including Tordon, Grazon P+D, Escort, and Cimarron Max.

Wood's rose (Rosa woodsii)

Wood's rose populations at Wolf Run were noticeably high in 2007. Only Paramount caused no injury (rating of 0) while Vanquish, Garlon 3A, Grazon P+D, Redeem, Tordon, Milestone, and Cimarron Max caused unacceptable injury (range 7 to 9). All other herbicides caused acceptable injury to Wood's rose.

Table 2. Percent injury[1] in October, 2007 to established native forb and grass species from commonly used herbicides.

Herbicide[2]	**Rate Product/A**	**Little sunflower**	**Winged buckwheat**	**Gayfeather**	**Blue flax**	**Dwarf morninglory**	**Purple threeawn**
Overdrive	8 oz	7 ab[3]	6 a	5 a	7 a	4 bcd	0 a
Vanquish	1 qt	9 a	8 a	6 a	8 a	7 ab	0 a
Paramount	6 oz	0 d	0 b	0 c	0 c	0 e	0 a
Plateau	12 fl oz	1 d	5 a	6 a	5 ab	4 bcd	0 a
Transline	1 pt	4 c	2 b	5 a	3 bc	2 de	0 a
Curtail	3 qt	9 a	6 a	6 a	7 a	7 abc	0 a
2,4-D amine	1.5 qt	9 a	4 c	4 ab	7 a	5 a-d	0 a
2,4-D ester	1.5 qt	9 a	8 a	3 ab	7 a	8 a	0 a
Garlon 3A	2 pt	7 ab	8 a	1 bc	5 ab	7 abc	0 a
Grazon P+D	2 qt	9 a	8 a	6 a	7 a	6 abc	0 a
Redeem	3 pt	8 a	6 a	6 a	8 a	6 abc	0 a
Tordon	1 pt	6 bc	7 a	3 ab	5 ab	6 abc	0 a
Milestone	7 fl oz	4 c	7 a	4 a	5 ab	5 a-d	0 a
Telar	1.25 oz	4 c	1 b	5 a	5 ab	4 cd	0 a
Escort	1 oz	8 ab	7 a	6 a	8 a	5 a-d	0 a
Cimarron Max	Rate III	9 a	8 a	7 a	8 a	7 abc	0 a

[1]Injury rated from 0 to 10 where 0 equals no injury and 10 equals dead plant.
[2]Non-ionic surfactant added to all treatments at 0.25% v/v.
[3]Means within a column followed by the same letter are not statistically different, LSD (0.05).

Table 3. Percent injury[1] in October, 2007 to established native shrub species from commonly used herbicides.

Herbicide[2]	**Rate Product/A**	**Yucca**	**Fringed sage**	**Broom snakeweed**	**Wild rose**
Overdrive	8 oz	0 a	5 c[3]	7 ab	4 c
Vanquish	1 qt	0 a	7 b	8 ab	7 ab
Paramount	6 oz	0 a	1 f	3 d	0 d
Plateau	12 fl oz	0 a	2 de	4 d	4 c
Transline	1 pt	1 a	4 cd	5 c	3 c
Curtail	3 qt	0 a	7 ab	8 ab	4 c
2,4-D amine	1.5 qt	1 a	8 ab	7 bc	4 c
2,4-D ester	1.5 qt	1 a	9 a	6 bc	4 c
Garlon 3A	2 pt	1 a	3 cde	7 ab	8 ab
Grazon P+D	2 qt	1 a	7 b	8 ab	8 ab
Redeem	3 pt	1 a	7 b	8 ab	8 ab
Tordon	1 pt	1 a	3 cde	8 ab	8 ab
Milestone	7 fl oz	0 a	2 e	7 bc	7 ab
Telar	1.25 oz	0 a	4 cd	6 bc	5 c
Escort	1 oz	1 a	4 c	7 ab	6 b
Cimarron Max	Rate III	2 a	8 ab	9 a	9 a

[1]Injury rated from 0 to 10 where 0 equals no injury and 10 equals dead plant.
[2]Non-ionic surfactant added to all treatments at 0.25% v/v.
[3]Means within a column followed by the same letter are not statistically different, LSD (0.05).

Established FS 2006

Sand lily (Leucocrinum montanum)

Density of sand lily almost doubled in Transline and Tordon treated plots about 1 year after herbicides were applied (Table 4). At this same evaluation, sand lily populations decreased about 50% in Plateau and Curtail treated plots. However, the most dramatic response occurred in plots treated with the sulfonylurea herbicides where Telar, Escort, and Cimarron Max decreased sand lily by over 90%.

Little sunflower (Helianthus pumilus)

Populations of little sunflower decreased about 50% in Vanquish and Tordon treated plots approximately 1 year after herbicides were applied. Little sunflower decreased about 65 to 70% in Transline and Grazon P+D treated plots; about 80% in 2,4-D amine treated plots; and 85 to 93% in Curtail, 2,4-D ester, and Redeem treated plots. The most striking contrast in effects occurred again with the sulfonylurea chemistry where little sunflower more than doubled in Telar treated plots but was decreased by 65% in Escort treated plots and was totally absent from plots treated with Cimarron Max.

Winged buckwheat (Pterogonum alatum)

Most herbicide treated plots did not influence winged buckwheat populations and none statistically decreased its populations, although its populations varied widely throughout the study area. Winged buckwheat populations doubled in plots treated with Garlon 3A and increased 278% in Overdrive treated plots about 1 year after herbicides were applied.

Slimflower scurfpea (Psoralea lanceolate)

No herbicide decreased scurfpea poplulations 1 year after treatments were applied. Scurfpea populations almost doubled, however, in plots treated with Tordon and Cimarron Max.

Navaho tea (Thelesperma megapotamicum)

Navaho tea decreased 54% in plots treated with Redeem while this native forb decreased by about 72 and 76% in Vanquish and Escort treated plots respectively. Navaho tea populations decreased about 85% in plots treated with Curtail and the two formulations of 2,4-D. In contrast, Navaho tea increased 167% in Milestone treated plots.

Purple prairie coneflower (Ratibula columnifera)

Only one herbicide influenced populations of purple prairie coneflower 1 year after herbicides were applied. Its populations increased 333% in plots treated with 2,4-D amine whereas purple prairie coneflower density was similar in all other plots.

Howard's evening primrose (Oenothera howardii)

Density of Howard's evening primrose varied across the study area and no herbicide treatment statistically caused a decrease in its populations (Table 5). Howard's evening primrose increased 282%, 376%, and 411% in Curtail, Transline, and Redeem treated plots, respectively.

Robust spurge (Tithymalus brachyceras)

Most of the robust spurge in the study area was unaffected by herbicides 1 year after treatements were applied. However, robust spurge increased 200% in plots treated with

Tordon, 240% in plots treated with Vanquish, and 280% in plots treated with Redeem. Robust spurge populations were similar in remaining plots even where their populations were not evident.

Narrowleaf puccoon (Lithospermum incisum)

Populations of narrowleaf puccoon were fairly low and quite variable across the study area. No herbicide treatment affected its populations statistically even where narrowleaf puccoon density doubled in Redeem treated plots or in several other plots where narrowleaf puccoon was not present.

One-sided penstemon (Penstemon secundiflorus)

One-sided penstemon apparently was sensitive to many of the herbicides that were applied. The average density of one-sided penstemon in untreated plots was 14.5 plants per plot. One-sided penstemon populations were decreased from 45 to 93% in plots treated with Transline, Plateau, Vanquish, Paramount, Curtail, 2,4-D amine, Garlon 3A, Grazon P+D, Tordon, Telar, and Escort treated plots. Its populations were eliminated in plots treated with 2,4-D ester and Cimarron Max.

Shy wallflower (Erysium inconspicuum)

Shy wallflower populations were very low in the study area. There were no plants in any of the untreated plots and most other plots had similar densities. However, an average of two shy wallflower plants occurred in Tordon treated plots 1 year after applications were made.

Running fleabane (Erigeron colomexicanus)

Running fleabane densities also were extremely low across the study area and most plots had none. Untreated plots, on average, had 0.5 running fleabane plants per plot and its populations increased by 400% in plots treated with Tordon.

Nuttall's violet (Viola nuttallii)

Almost all plots had similar densities of Nutall's violet present. Only two plots showed decreased populations of Nutall's violet compared to untreated plots. Density of Nutall's violet decreased 78 and 89% in Cimarron Max and 2,4-D ester treated plots, respectively.

Blue flax (Adenolinum lewisii)

Blue flax populations were fairly consistent across the study area. Blue flax density averaged 69 plants per untreated plot and while populations were similar to the untreated in most herbicide treated plots, blue flax density in Telar treated plots decreased by 80% (Table 6).

Dwarf morning-glory (Evolvulus nuttallianus)

Dwarf morning-glory was found throughout the study area at fairly high densities. Nine of the herbicide treatments apparently did not influence dwarf morning-glory populations 1 year after applications were made but the remainder decreased its populations. Density of dwarf morning-glory decreased 47% in Tordon treated plots, about 40% in plots treated with Vanquish or Garlon 3A, and 64% in Cimarron Max treated plots. Dwarf morning-glory density decreased 88% in plots treated with 2,4-D ester and 93% in plots treated with Plateau.

Scarlet beeblossum (Gaura coccinea)

Scarlet beeblossum populations varied across the study area and masked what might otherwise have manifested as statistical differences. No treated plots differed from the untreated plots even though populations varied from 0 per plot (Grazon P+D treated plots) to 72 per plot (Paramount treated plots). Untreated plots had an average of 24 plants per plot.

Gay feather (Liatris punctata)

Gay feather densities were consistent across the study area but low. Untreated plots averaged 2.5 plants per plot and all herbicide treated plots had similar densities even though none were found in Telar treated plots and four were found in Overdrive treated plots. Herbicide treatments did not influence gay feather populations 1 year after applications were made.

Yellow sunflower (Calylophus serrulatus) and *Scarlet globemallow (Sphaeralcea coccinea)*

Similar to gay feather, yellow sundrop and scarlet globemallow populations were unaffected by herbicide treatments 1 year after they were applied.

Wood’s rose (Rosa woodsii)

Wood’s rose was very widespread throughout the study area and had an average density of 209.5 shoots per plot (Table 7). Wood’s rose density increased 157% in plots treated with 2,4-D amine. Wood’s rose populations decreased 69% in Plateau treated plots, 72% in Vanquish treated plots, 75% in Tordon treated plots, 80% in Telar treated plots, 87% in Cimarron Max treated plots, and 98% in Escort treated plots. The sulfonylurea herbicides had the greatest impact although not always different from other herbicide treatments.

Broom snakeweed (Gutierrezia sarothrae)

Broom snakeweed populations were consistent across the study area. There was substantial variation among the treatments. Untreated plots averaged 21 plants per plot and many treatments decreased its populations. Twelve of the sixteen treatments caused broom snakeweed densities to decline. The greatest declines occurred in plots treated with Vanquish (81%), Grazon P+D (86%), Escort (76%), and Cimarron Max (95%).

Louisana sage (Artemesia ludoviciana), *fringed sage (Artemesia frigida),* and *yucca (Yucca glauca)*

Louisiana sage, fringed sage, and yucca populations were not influenced by herbicide treatment 1 year after applications were made. Variation in Louisiana sage populations was substantial across the study area as it tends to be clumped and this may have influenced the outcome.

Purple threeawn (Aristida purpurea)

Purple threeawn populations were consistent across the study area. Threeawn density in untreated plots averaged 25.5 plants and its populations increased in about half of the herbicide treated plots and none showed decreases (Table 8). Threeawn increased 207% in Telar and Redeem treated plots, 215% in Curtail treated plots, 243% in Vanquish treated plots, 294% in Grazon P+D and Cimarron Max treated plots, and 459% in plots treated with Escort.

Little bluestem (Schizachyrium scoparium)

Little bluestem was found throughout the study area in 2007. Untreated plots had a average of 6.5 plants per plot and nine treated plots had similar densities indicating that these herbicides did not influence little bluestem populations. However, little bluestem increased substantially in Vanquish (630%), Plateau (569%), Transline (1,385%), Garlon 3A (523%), Escort (508%), and Cimarron Max (1,523%) treated plots.

Big bluestem (Andropogon gerardii)

Big bluestem varied across the study area but the results are worth noting. There were no big bluestem plants in the untreated plots and most other plots had zero to 2 plants per plot. However, big bluestem increased to 28 plants per plot in Cimarron Max treatments.

Native forb and shrub composition and diversity

The site at Wolf Run is dominated by forbs where their composition in untreated plots averaged 63% (Table 9). Grass and shrub composition in untreated plots averaged 8.5 and 17.5%, respectively. Native forb composition in treated plots only differed from untreated plots where Telar (42%) and Cimarron Max (47%) were sprayed. Native shrub composition in treated plots only differed from untreated plots where Telar (26%) was sprayed and apparently caused an increase. Grass composition in 2,4-D ester (15%), Telar (13%), and Cimarron Max (14%) treated plots was more than in untreated plots. Interestingly, composition of weedy species increased only in Escort (200%) and Cimarron Max (255%) treated plots. Native forb diversity in untreated plots averaged 21 plants per plot (Table 10) and native shrub density in untreated plots averaged 6 plants per plot. Native forb diversity decreased in Telar (48%), Escort (37%), and Cimarron

Max (38%) treated plots. Native shrub diversity was decreased only in the Cimarron Max (50%) treated plots.

Table 4 Density (plants/plot) of established native forb species in 2007 approximately 1 year after treatment with commonly used herbicides.

Herbicide[1]	**Rate Product/A**	**Sand lilly**	**Little sunflower**	**Winged buckwheat**	***Scurfpea***	**Navaho tea**	**Purple prairie coneflower**
Overdrive	8 oz	12 bcd[2]	18 bc	32 a	16 b-g	85 bcd	2 bc
Vanquish	1 qt	16 bc	6 ef	1 c	24 abc	23 gh	3 bc
Paramount	6 oz	16 bc	17 bc	7 c	8 efg	67 c-f	4 bc
Plateau	12 fl oz	6 de	15 c	8 c	16 b-g	106 b	6 b
Transline	1 pt	29 a	4 ef	9 c	12 d-g	111 b	1 c
Curtail	3 qt	6 de	1 f	4 c	20 a-d	15 h	2 bc
2,4-D amine	1.5 qt	9 cde	3 ef	6 c	7 g	10 h	10 a
2,4-D ester	1.5 qt	9 cde	1 f	2 c	7 fg	11 h	6 b
Garlon 3A	2 pt	8 cde	18 bc	23 b	13 d-g	54 def	2 bc
Grazon P+D	2 qt	19 b	5 ef	5 c	14 d-g	63 c-f	1 c
Redeem	3 pt	16 bc	2 ef	10 c	15 c-g	38 fgh	2 bc
Tordon	1 pt	27 a	7 def	5 c	26 a	69 c-f	2 c
Milestone	7 fl oz	18 bc	24 ab	4 c	18 a-e	137 a	5 bc
Telar	1.25 oz	1 e	29 a	10 c	17 b-f	91 bc	1 c
Escort	1 oz	0 e	5 ef	8 c	17 b-g	20 gh	2 bc
Cimarron Max	Rate III	2 e	0 f	3 c	25 ab	47 efg	2 c
Untreated 1		14 bcd	11 cde	10 c	12 d-g	87 bcd	3 bc
Untreated 2		`15 bcd	14 cd	13 c	15 c-g	77 b-e	3 bc

[1]Non-ionic surfactant added to all treatments at 0.25% v/v.
[2]Means within a column followed by the same letter are not statistically different, LSD (0.05).

Table 5. Density (plants/plot) of established native forb species in 2007 approximately 1 year after treatment with commonly used herbicides.

Herbicide[1]	**Rate Product/A**	**Evening primrose**	**Robust spurge**	***Narrowleaf* puccoon**	**One-sided penstemon**	***Shy* Wallflower**	***Running* fleabane**	***Nuttall's* violet**
Overdrive	8 oz	15 cde[2]	3 b	0 c	13 bc	0 b	1 bc	10 ab
Vanquish	1 qt	3 e	6 a	1 bc	2 d	0 b	0 bc	9 abc
Paramount	6 oz	4 e	2 bcd	0 c	4 d	1 b	1 bc	7 a-d
Plateau	12 fl oz	1 e	0 cd	1 bc	7 cd	0 b	0 c	7 a-e
Transline	1 pt	32 ab	2 bcd	1 c	8 cd	1 ab	1 bc	10 a
Curtail	3 qt	24 abc	0 cd	1 bc	3 d	0 b	0 bc	10 ab
2,4-D amine	1.5 qt	5 e	1 bcd	0 c	1 d	1 b	0 bc	6 a-e
2,4-D ester	1.5 qt	9 de	0 cd	0 c	0 d	1 b	0 bc	1 e
Garlon 3A	2 pt	8 de	1 bcd	3 ab	2 d	1 b	0 bc	8 a-d
Grazon P+D	2 qt	4 e	1 bcd	0 c	3 d	0 b	0 c	3 cde
Redeem	3 pt	35 a	7 a	4 a	21 a	0 b	0 c	3 b-e
Tordon	1 pt	13 cde	5 a	1 bc	3 d	2 a	2 a	8 a-d
Milestone	7 fl oz	21 bcd	1 bcd	2 bc	18 ab	0 b	0 c	9 abc
Telar	1.25 oz	1 e	0 cd	0 c	2 d	0 b	0 c	6 a-e
Escort	1 oz	1 e	0 cd	0 c	3 d	0 b	0 c	9 abc
Cimarron Max	Rate III	4 e	0 cd	0 c	0 d	0 b	0 c	2 de
Untreated 1		8 de	3 bc	2 abc	17 ab	0 b	0 bc	9 abc
Untreated 2		9 de	2 bcd	2 bc	12 bc	0 b	1 ab	9 abc

[1]Non-ionic surfactant added to all treatments at 0.25% v/v.
[2]Means within a column followed by the same letter are not statistically different, LSD (0.05).

Table 6. Density (plants/plot) of established native forb species in 2007 approximately 1 year after treatment with commonly used herbicides.

Herbicide[1]	**Rate Product/A**	**Blue flax**	**Dwarf morninglory**	**Scarlet beeblossum**	***Gay feather***	***Yellow sundrop***	***Scarlet* globemallow**
Overdrive	8 oz	70 a-d[2]	86 ab	26 ab	4 a	7 ab[2]	11 a
Vanquish	1 qt	72 a-d	33 fg	31 a	3 ab	5 ab	2 b
Paramount	6 oz	64 a-d	72 a-d	72 a-d	1 abc	3 b	1 b
Plateau	12 fl oz	34 cde	6 h	1 c	2 abc	5 ab	2 b
Transline	1 pt	60 a-d	64 a-e	19 abc	3 ab	14 a	1 b
Curtail	3 qt	48 b-e	72 a-d	10 abc	3 abc	2 b	0 b
2,4-D amine	1.5 qt	88 abc	55 c-f	19 abc	3 ab	4 b	1 b
2,4-D ester	1.5 qt	111 a	10 gh	3 c	2 abc	2 b	0 b
Garlon 3A	2 pt	86 abc	32 fg	22 abc	2 abc	4 b	1 b
Grazon P+D	2 qt	64 a-d	45 def	0 c	3 ab	2 b	2 b
Redeem	3 pt	78 a-d	47 c-f	7 bc	3 abc	4 b	1 b
Tordon	1 pt	103 a	39 ef	26 ab	1 abc	8 ab	1 b
Milestone	7 fl oz	90 ab	74 a-d	3 c	1 abc	8 ab	2 b
Telar	1.25 oz	14 e	54 c-f	3 c	0 c	7 ab	0 b
Escort	1 oz	28 de	57 b-f	9 bc	1 bc	5 ab	2 b
Cimarron Max	Rate III	36 b-e	30 fg	2 c	2 abc	2 b	1 b
Untreated 1		71 a-d	89 a	21 abc	2 abc	7 ab	5 b
Untreated 2		67 a-d	76 abc	27 ab	3 ab	6 ab	5 b

[1]Non-ionic surfactant added to all treatments at 0.25% v/v.
[2]Means within a column followed by the same letter are not statistically different, LSD (0.05).

Table 7. Density (plants/plot) of established native shrub species in 2007 approximately 1 year after treatment with commonly used herbicides.

Herbicide[1]	Rate Product/A	Wood's rose	Broom snakeweed	Louisiana sage	Fringed sage	*Yucca*
Overdrive	8 oz	223 b[2]	13 bcd	15 a	3 a	9 a
Vanquish	1 qt	59 def	4 fgh	8 a	2 a	4 a
Paramount	6 oz	231 b	9 d-g	19 a	1 a	8 a
Plateau	12 fl oz	64 def	6 e-h	12 a	3 a	7 a
Transline	1 pt	201 bc	16 bc	3 a	1 a	6 a
Curtail	3 qt	265 ab	7 d-g	37 a	1 a	5 a
2,4-D amine	1.5 qt	329 a	19 ab	15 a	2 a	7 a
2,4-D ester	1.5 qt	274 ab	8 d-g	12 a	0 a	6 a
Garlon 3A	2 pt	111 de	10 c-f	11 a	1 a	8 a
Grazon P+D	2 qt	118 de	3 gh	11 a	1 a	6 a
Redeem	3 pt	139 cd	9 d-g	22 a	2 a	8 a
Tordon	1 pt	53 ef	12 cde	12 a	3 a	8 a
Milestone	7 fl oz	121 de	24 a	1 a	2 a	7 a
Telar	1.25 oz	42 ef	10 c-f	35 a	4 a	8 a
Escort	1 oz	4 f	5 e-h	31 a	2 a	8 a
Cimarron Max	Rate III	27 f	1 h	10 a	1 a	7 a
Untreated 1		195 bc	19 ab	3 a	2 a	6 a
Untreated 2		224 b	23 a	1 a	2 a	6 a

[1]Non-ionic surfactant added to all treatments at 0.25% v/v.
[2]Means within a column followed by the same letter are not statistically different, LSD (0.05).

Table 8. Density (plants/plot) of established native grass species in 2007 approximately 1 year after treatment with commonly used herbicides.

Herbicide[1]	**Rate Product/A**	**Purple threeawn**	**Little bluestem**	**Big bluestem**
Overdrive	8 oz	17 f[2]	22 cde	0 b
Vanquish	1 qt	62 bc	41 b	2 b
Paramount	6 oz	23 ef	3 e	0 b
Plateau	12 fl oz	43 cd	37 bc	0 b
Transline	1 pt	24 ef	90 a	0 b
Curtail	3 qt	55 cd	8 e	2 b
2,4-D amine	1.5 qt	34 de	22 cde	0 b
2,4-D ester	1.5 qt	28 ef	7 e	1 b
Garlon 3A	2 pt	30 ef	34 bcd	0 b
Grazon P+D	2 qt	76 b	15 de	13 ab
Redeem	3 pt	53 cd	5 e	2 b
Tordon	1 pt	37 de	18 cde	0 b
Milestone	7 fl oz	40 c-f	19 cde	0 b
Telar	1.25 oz	53 cd	9 e	0 b
Escort	1 oz	117 a	33 bcd	0 b
Cimarron Max	Rate III	75 b	99 a	28 a
Untreated 1		29 ef	5 e	0 b
Untreated 2		22 ef	8 e	0 b

1non-ionic surfactant added to all treatments at 0.25% v/v.
[2]Means within a column followed by the same letter are not statistically different, LSD (0.05).

Table 9. Percent composition of established native grass, forbs, shrubs, weedy species, and bare ground in 2007 approximately 1 year after treatment with commonly used herbicides.

Herbicide[1]	Rate Product/A	% Composition grasses	% Composition forbs	% Composition shrubs	% Composition weedy species	% Bare ground
Overdrive	8 oz	9 b-e[2]	65 a	16 c-f	11 cd	21 bcd
Vanquish	1 qt	11 a-e	55 abc	16 c-f	18 bc	29 b
Paramount	6 oz	8 de	65 a	15 c-f	12 cd	14 d
Plateau	12 fl oz	9 cde	52 a-d	21 b	18 bc	21 bcd
Transline	1 pt	7 e	65 a	15 c-f	13 bcd	19 bcd
Curtail	3 qt	11 a-e	52 a-d	19 bc	18 bc	26 b
2,4-D amine	1.5 qt	11 a-e	65 a	17 b-f	8 d	20 bcd
2,4-D ester	1.5 qt	15 a	56 abc	13 ef	16 bcd	25 bc
Garlon 3A	2 pt	13 abc	60 ab	15 c-f	12 cd	26 b
Grazon P+D	2 qt	12 a-e	56 abc	21 b	12 cd	24 bcd
Redeem	3 pt	11 a-e	65 a	14 def	11 cd	24 bcd
Tordon	1 pt	8 de	60 ab	19 bcd	13 bcd	23 bcd
Milestone	7 fl oz	11 a-e	55 abc	20 bc	14 bcd	23 bcd
Telar	1.25 oz	13 ab	42 d	26 a	19 bc	21 bcd
Escort	1 oz	12 a-d	51 bcd	15 c-f	22 ab	35 a
Cimarron Max	Rate III	14 a	47 cd	12 f	28 a	37 a
Untreated 1		8 de	62 ab	18 b-e	11 cd	15 cd
Untreated 2		9 cde	64 a	17 b-f	11 cd	21 bcd

[1]Non-ionic surfactant added to all treatments at 0.25% v/v.
[2]Means within a column followed by the same letter are not statistically different, LSD (0.05).

Table 10. Density (plants/plot) and diversity of established native forbs and shrub species in 2007 approximately 1 year after treatment with commonly used herbicides.

Herbicide[1]	**Rate Product/A**	**Density all native forbs**	**Native forb diversity**	**Density all native shrubs**	**Native shrub diversity**
Overdrive	8 oz	766 a[2]	20 abc	261 c	5 de
Vanquish	1 qt	374 fg	16 b-e	68 ghi	5 e
Paramount	6 oz	613 a-e	21 ab	249 c	5 cde
Plateau	12 fl oz	370 fg	15 b-e	109 fg	6 abc
Transline	1 pt	753 ab	21 ab	209 d	5 de
Curtail	3 qt	639 a-d	17 a-e	288 bc	6 a-d
2,4-D amine	1.5 qt	675 a-d	20 abc	370 a	5 cde
2,4-D ester	1.5 qt	534 b-f	16 a-e	324 b	4 ef
Garlon 3A	2 pt	522 c-g	16 a-e	144 ef	4 ef
Grazon P+D	2 qt	471 d-g	16 b-e	137 ef	6 a-d
Redeem	3 pt	573 a-f	19 abc	178 de	4 ef
Tordon	1 pt	479 d-g	21 ab	99 fg	7 a
Milestone	7 fl oz	741 abc	27 abc	184 de	6 abc
Telar	1.25 oz	412 efg	11 e	89 gh	7 a
Escort	1 oz	312 g	14 cde	47 hi	4 ef
Cimarron Max	Rate III	366 fg	13 de	40 i	3 f
Untreated 1		642 a-d	22 a	270 c	7 ab
Untreated 2		629 a-d	20 abc	282 bc	5 b-e

[1]Non-ionic surfactant added to all treatments at 0.25% v/v.
[2]Means within a column followed by the same letter are not statistically different, LSD (0.05).

Section 5. Discussion

Established FS 2007

Possibly the most important lesson from these studies the year they were sprayed is that it is extremely difficult to discern injury from drought and plants ending their life cycles from that caused by herbicides. Some may interpret the injury data as indicative of what species shifts might occur but data collected 1 year from application refute that notion. In natural systems, it is best to evaluate the outcome of herbicide application – both for control of the target species and collateral injury to desirable species – about 1 year after they are made. Even extreme injury ratings of 9 or 10 during the year of application for a particular species may not reflect its composition the year following treatment. It is simply best to monitor a sprayed site during the year of application for apparent problems but reserve final judgment until the next growing season.

Established FS 2006

Changes in population densities that were observed may be directly or indirectly related to herbicide use. If a herbicide drastically decreased the population of a particular species, the effect is primarily direct (e.g. Cimarron Max on broom snakeweed) but a minor decrease in a forb's population may be more related to an increase in another forb that then competed with the first forb. It is apparent that some herbicides caused decreases in the populations of some forb species in particular. One-sided penstemon seemed to be especially sensitive to most herbicides except Overdrive, Redeem, and Milestone. Effects of the herbicides tested on the various forbs was variable enough that the tabled data could be used as a reference when a situation is encountered where one or more of the tested species is present in an infested area to help determine which herbicide could be used effectively and do as little collateral damage as possible. The only potential generalization that could be made about testing the numerous forb species against these herbicides is that Paramount and Overdrive seemed to cause the least amount of injury to all. Upon examining the plant community composition and native diversity tables, however, some broader interpretations are possible. It appears that the sulfonylureas Telar and Cimarron Max selected for more grasses at the expense of native forbs. Oddly enough Escort and Cimarron Max appeared to select for the weedy species that were present at the site. Based upon our results, Telar, Escort, and Cimarron Max in particular may not be selective enough to use in situations where invasions are just starting to occur unless there is no reasonable and effective substitute (e.g. another herbicide, hand-pulling or some other physical means).

Section 6. Conclusion

It remains premature to provide conclusive statement about this research because we still will collect data from the 2007 study in spring 2008 about 1 year after the herbicide treatments were applied in 2007. If possible, we will combine the 2006 and 2007 data sets to create a more robust statistical analysis from which generalizations and specific statements can be generated. Even if we cannot combine data sets (e.g. a “year” effect implying climate as a partial cause of effects) having two 1 year evaluations will provide for a more sound base upon which to provide conclusive statements and advice.

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