

IRRIGATION REQUIREMENTS FOR NATIVE PERENNIAL WILDFLOWER SEED PRODUCTION IN A SEMI-ARID ENVIRONMENT

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Introduction

Native wildflower seed is needed to restore rangelands of the Intermountain West. Commercial seed production is necessary to provide the quantity of seed needed for restoration efforts. A major limitation to economically viable commercial production of native wildflower (forb) seed is stable and consistent seed productivity over years.

In native rangelands, the natural variations in spring rainfall and soil moisture result in highly unpredictable water stress at flowering, seed set, and seed development, which for other seed crops is known to compromise seed yield and quality.

Native wildflower plants are not well adapted to croplands. They often are not competitive with crop weeds in cultivated fields. Poor competitiveness with weeds could also limit wildflower seed production. Both sprinkler and furrow irrigation could provide supplemental water for seed production, but these irrigation systems risk further encouraging weeds. Also, sprinkler and furrow irrigation can lead to the loss of plant stand and seed production due to fungal pathogens. By burying drip tapes at 12-inch depth and avoiding wetting the soil surface, we hoped to assure flowering and seed set without undue encouragement of weeds or opportunistic diseases. The trials reported here tested the effects of three low rates of irrigation on the seed yield of 13 native wildflower species.

Materials and Methods

Plant Establishment

Seed of seven Intermountain West wildflower species (the first seven species in Table 1) was received in late November in 2004 from the Rocky Mountain Research Station (Boise, ID). The plan was to plant the seed in the fall of 2004, but due to excessive rainfall in October, the ground preparation was not completed and planting was postponed to early 2005. To try to ensure germination, the seed was submitted to cold stratification. The seed was soaked overnight in distilled water on January 26, 2005, after which the water was drained and the seed soaked for 20 min in a 10% by volume solution of 13% bleach in distilled water. The water was drained and the

seed was placed in thin layers in plastic containers. The plastic containers had lids with holes drilled in them to allow air movement. These containers were placed in a cooler set at approximately 34°F. Every few days the seed was mixed and, if necessary, distilled water added to maintain seed moisture. In late February, seed of *Lomatium grayi* and *L. triternatum* (see Table 1 for common names) had started to sprout.

In late February 2005, drip tape (T-Tape TSX 515-16-340) was buried at 12-inch depth between two 30-inch rows of a Nyssa silt loam with a pH of 8.3 and 1.1% organic matter. The drip tape was buried in alternating inter-row spaces (5 ft apart). The flow rate for the drip tape was 0.34 gal/min/100 ft at 8 psi with emitters spaced 16 inches apart, resulting in a water application rate of 0.066 inch/hour.

On March 3, seed of the first seven species in Table 1 was planted in 30-inch rows using a custom-made plot grain drill with disc openers. All seed was planted at 20-30 seeds/ft of row. The *Eriogonum umbellatum* and *Penstemon* spp. were planted at 0.25-inch depth and the *Lomatium* spp. at 0.5-inch depth. The trial was irrigated with a minisprinkler system (R10 Turbo Rotator, Nelson Irrigation Corp., Walla Walla, WA) for even stand establishment from March 4 to April 29. Risers were spaced 25 ft apart along the flexible polyethylene hose laterals that were spaced 30 ft apart and the water application rate was 0.10 inch/hour. A total of 1.72 inches of water was applied with the minisprinkler system. *Eriogonum umbellatum*, *Lomatium triternatum*, and *L. grayi* started emerging on March 29. All other species except *L. dissectum* emerged by late April. Starting June 24, the field was irrigated with the drip system. A total of 3.73 inches of water was applied with the drip system from June 24 to July 7. The field was not irrigated further in 2005.

Plant stands for *Eriogonum umbellatum*, *Penstemon* spp., *Lomatium triternatum*, and *L. grayi* were uneven. *Lomatium dissectum* did not emerge. None of the species flowered in 2005. In early October, 2005 we received more seed from the Rocky Mountain Research Station for replanting. The empty lengths of row were replanted by hand in the *E. umbellatum* and *Penstemon* spp. plots. The *Lomatium* spp. plots had the entire row lengths replanted using the planter. The seed was replanted on October 26, 2005. In the spring of 2006, the plant stands of the replanted species were excellent, except for *P. deustus*.

On April 11, 2006 seed of three globemallow species (*Sphaeralcea parvifolia*, *S. grossulariifolia*, *S. coccinea*), two prairie clover species (*Dalea searlsiae*, *D. ornata*), and basalt milkvetch (*Astragalus filipes*) was planted at 30 seeds/ft of row. The field was sprinkler irrigated until emergence, which was poor. In late August of 2006 seed of the three globemallow species was harvested by hand. On November 9, 2006 the six wildflowers that were planted in 2006 were mechanically flailed and on November 10, they were replanted. On November 11, the *Penstemon deustus* plots were also replanted at 30 seeds/ft of row.

Table 1. Wildflower species planted in the drip irrigation trials at the Malheur Experiment Station, Oregon State University, Ontario, OR.

Species	Common names
<i>Eriogonum umbellatum</i>	Sulphur-flower buckwheat
<i>Penstemon acuminatus</i>	Sharpleaf penstemon, sand-dune penstemon
<i>Penstemon deustus</i>	Scabland penstemon, hotrock penstemon
<i>Penstemon speciosus</i>	Royal penstemon, sagebrush penstemon
<i>Lomatium dissectum</i>	Fernleaf biscuitroot
<i>Lomatium triternatum</i>	Nineleaf biscuitroot, nineleaf desert parsley
<i>Lomatium grayi</i>	Gray's biscuitroot, Gray's lomatium
<i>Sphaeralcea parvifolia</i>	Smallflower globemallow
<i>Sphaeralcea grossulariifolia</i>	Gooseberryleaf globemallow
<i>Sphaeralcea coccinea</i>	Scarlet globemallow, red globemallow
<i>Dalea searlsiae</i>	Searls' prairie clover
<i>Dalea ornata</i>	Western prairie clover, Blue Mountain prairie clover
<i>Astragalus filipes</i>	Basalt milkvetch

Irrigation for Seed Production

In April, 2006 each planted strip of each wildflower species was divided into plots 30 ft long. Each plot contained four rows of each species. The experimental designs were randomized complete blocks with four replicates. The three treatments were a nonirrigated check, 1 inch of water applied per irrigation, and 2 inches of water applied per irrigation. Each treatment received 4 irrigations that were applied approximately every 2 weeks starting with flowering of the wildflowers. The amount of water applied to each treatment was calculated by the length of time necessary to deliver 1 or 2 inches through the drip system. Irrigations were regulated with a controller and solenoid valves. After each irrigation, the amount of water applied was read on a water meter and recorded to ensure correct water applications.

In March of 2007, the drip-irrigation system was modified to allow separate irrigation of the species due to different timings of flowering. The three *Lomatium* spp. were irrigated together and *Penstemon deustus* and *P. speciosus* were irrigated together, but separately from the others. *Penstemon acuminatus* and *Eriogonum umbellatum* were irrigated individually. In early April, 2007 the three globemallow species, two prairie clover species, and basalt milkvetch were divided into plots with a drip-irrigation system to allow the same irrigation treatments that were received by the other wildflowers.

Irrigation dates are found in Table 2. In 2007, irrigation treatments were inadvertently continued after the fourth irrigation. Irrigation treatments for all species were continued until the last irrigation on June 24, 2007.

Soil volumetric water content was measured by neutron probe. The neutron probe was calibrated by taking soil samples and probe readings at 8-, 20-, and 32-inch depths during installation of the access tubes. The soil water content was determined volumetrically from the soil samples and regressed against the neutron probe readings separately for each soil depth. Regression equations were then used to transform the neutron probe readings into volumetric soil water content.

Flowering, Harvesting, and Seed Cleaning

Flowering dates for each species were recorded (Table 2). The *Eriogonum umbellatum* and *Penstemon* spp. plots produced seed in 2006, in part because they had emerged in the spring of 2005. Each year, the middle two rows of each plot were harvested when seed of each species was mature (Table 2), using the methods listed in Table 3. The plant stand for *P. deustus* was too poor to result in reliable seed yield estimates. Replanting of *P. deustus* in the fall of 2006 did not result in adequate plant stand in the spring of 2007.

Eriogonum umbellatum seeds did not separate from the flowering structures in the combine; the unthreshed seed was taken to the U.S. Forest Service Lucky Peak Nursery (Boise, ID) and run through a dewinger to separate seed. The seed was further cleaned in a small clipper seed cleaner.

Penstemon deustus seed pods were too hard to be opened in the combine; the unthreshed seed was precleaned in a small clipper seed cleaner and then seed pods were broken manually by rubbing the pods on a ribbed rubber mat. The seed was then cleaned again in the small clipper seed cleaner.

Penstemon acuminatus and *P. speciosus* were threshed in the combine and the seed was further cleaned using a small clipper seed cleaner.

Cultural Practices in 2006

On October 27, 2006, 50 lb phosphorus (P)/acre and 2 lb zinc (Zn)/acre were injected through the drip tape to all plots of *Eriogonum umbellatum*, *Penstemon* spp., and *Lomatium* spp. On November 11, 100 lb nitrogen (N)/acre as urea was broadcast to all *Lomatium* spp. plots. On November 17, all plots of *Eriogonum umbellatum*, *Penstemon* spp. (except *P. deustus*), and *Lomatium* spp. had Prowl[®] at 1 lb ai/acre broadcast on the soil surface. Irrigations for all species were initiated on May 19 and terminated on June 30. Harvesting and seed cleaning methods for each species are listed in Table 3.

Cultural Practices in 2007

Penstemon acuminatus and *P. speciosus* were sprayed with Aza-Direct[®] at 0.0062 lb ai/acre on May 14 and 29 for lygus bug control. Irrigations for each species were initiated and terminated on different dates (Table 2). Harvesting and seed cleaning methods for each species are listed in Table 3. All plots of the *Sphaeralcea* spp. were flailed on November 8, 2007.

Cultural Practices in 2008

On November 9, 2007 and on April 15, 2008, Prowl at 1 lb ai/acre was broadcast on all plots for weed control. Capture[®] 2EC at 0.1 lb ai/acre was sprayed on all plots of *Penstemon acuminatus* and *P. speciosus* on May 20 for lygus bug control. Irrigations for each species were initiated and terminated on different dates (Table 2). Harvesting and seed cleaning methods for each species are listed in Table 3.

Cultural Practices in 2009

On March 18, Prowl at 1 lb ai/acre and Volunteer[®] at 8 oz/acre were broadcast on all plots for weed control. On April 9, 50 lb N/acre and 10 lb P/acre were applied through the drip irrigation system to the three *Lomatium* spp.

The flowering, irrigation timing, and harvest timing were recorded for each species (Table 2). Harvesting and seed cleaning methods for each species are listed in Table 3. On December 4, 2009, Prowl at 1 lb ai/acre was broadcast for weed control on all plots.

Cultural Practices in 2010

The flowering, irrigation, and harvest timing of the established wildflowers were recorded for each species (Table 2). Harvesting and seed cleaning methods for each species are listed in Table 3. On November 17, Prowl at 1 lb ai/acre was broadcast on all plots for weed control.

Cultural Practices in 2011

On May 3, 50 lb N/acre was applied to all *Lomatium* spp. plots as Uran (urea ammonium nitrate) injected through the drip tape. The timing of flowering, irrigations, and harvests varied by species (Table 2). Harvesting and seed cleaning methods for each species are listed in Table 3. On November 9, Prowl at 1 lb ai/acre was broadcast on all plots for weed control.

Cultural Practices in 2012

The soil volumetric water content was very low in 2012 prior to the onset of irrigation for each species. Iron deficiency symptoms were prevalent in 2012. On April 13, 50 lb N/acre, 10 lb P/acre, and 5 lb iron (Fe)/acre was applied to all *Lomatium* spp. plots as liquid fertilizer injected through the drip tape. On November 7, Prowl at 1 lb ai/acre was broadcast on all plots of *Eriogonum umbellatum* and all *Lomatium* spp. for weed control.

Cultural Practices in 2013

On March 29, 20 lb N/acre, 25 lb P/acre, and 5 lb Fe/acre were applied through the drip tape to all plots of all three *Lomatium* spp. On April 3, Select Max[®] at 32 oz/acre was broadcast for grass weed control on all plots of *Eriogonum umbellatum*, all *Lomatium* spp., and *Penstemon speciosus*.

Table 2. Native wildflower flowering, irrigation, and seed harvest dates by species in 2006-2012, Malheur Experiment Station, Oregon State University, Ontario, OR. Continued on next page.

Species	Flowering			Irrigation		Harvest
	start	peak	end	start	end	
	2006					
<i>Eriogonum umbellatum</i>	19-May		20-Jul	19-May	30-Jun	3-Aug
<i>Penstemon acuminatus</i>	2-May	10-May	19-May	19-May	30-Jun	7-Jul
<i>Penstemon deustus</i>	10-May	19-May	30-May	19-May	30-Jun	4-Aug
<i>Penstemon speciosus</i>	10-May	19-May	30-May	19-May	30-Jun	13-Jul
<i>Lomatium dissectum</i>				19-May	30-Jun	
<i>Lomatium triternatum</i>				19-May	30-Jun	
<i>Lomatium grayi</i>				19-May	30-Jun	
<i>Sphaeralcea parvifolia</i>						
<i>Sphaeralcea grossulariifolia</i>						
<i>Sphaeralcea coccinea</i>						
<i>Dalea searlsiae</i>						
<i>Dalea ornata</i>						
	2007					
<i>Eriogonum umbellatum</i>	25-May		25-Jul	2-May	24-Jun	31-Jul
<i>Penstemon acuminatus</i>	19-Apr		25-May	19-Apr	24-Jun	9-Jul
<i>Penstemon deustus</i>	5-May	25-May	25-Jun	19-Apr	24-Jun	
<i>Penstemon speciosus</i>	5-May	25-May	25-Jun	19-Apr	24-Jun	23-Jul
<i>Lomatium dissectum</i>				5-Apr	24-Jun	
<i>Lomatium triternatum</i>	25-Apr		1-Jun	5-Apr	24-Jun	29-Jun, 16-Jul
<i>Lomatium grayi</i>	5-Apr		10-May	5-Apr	24-Jun	30-May, 29-Jun
<i>Sphaeralcea parvifolia</i>	5-May	25-May		16-May	24-Jun	20-Jun, 10-Jul, 13-Aug
<i>Sphaeralcea grossulariifolia</i>	5-May	25-May		16-May	24-Jun	20-Jun, 10-Jul, 13-Aug
<i>Sphaeralcea coccinea</i>	5-May	25-May		16-May	24-Jun	20-Jun, 10-Jul, 13-Aug
<i>Dalea searlsiae</i>						20-Jun, 10-Jul
<i>Dalea ornata</i>						20-Jun, 10-Jul
	2008					
<i>Eriogonum umbellatum</i>	5-Jun	19-Jun	20-Jul	15-May	24-Jun	24-Jul
<i>Penstemon acuminatus</i>	29-Apr		5-Jun	29-Apr	11-Jun	11-Jul
<i>Penstemon deustus</i>	5-May		20-Jun	29-Apr	11-Jun	
<i>Penstemon speciosus</i>	5-May		20-Jun	29-Apr	11-Jun	17-Jul
<i>Lomatium dissectum</i>				10-Apr	29-May	
<i>Lomatium triternatum</i>	25-Apr		5-Jun	10-Apr	29-May	3-Jul
<i>Lomatium grayi</i>	25-Mar		15-May	10-Apr	29-May	30-May, 19-Jun
<i>Sphaeralcea parvifolia</i>	5-May		15-Jun	15-May	24-Jun	21-Jul
<i>Sphaeralcea grossulariifolia</i>	5-May		15-Jun	15-May	24-Jun	21-Jul
<i>Sphaeralcea coccinea</i>	5-May		15-Jun	15-May	24-Jun	21-Jul
<i>Dalea searlsiae</i>		19-Jun				
<i>Dalea ornata</i>		19-Jun				

Table 2. Continued. Native wildflower flowering, irrigation, and seed harvest dates by species in 2006-2013. Malheur Experiment Station, Oregon State University, Ontario, OR.

Species	Flowering			Irrigation		Harvest
	start	peak	end	start	end	
2009						
<i>Eriogonum umbellatum</i>	31-May		15-Jul	19-May	24-Jun	28-Jul
<i>Penstemon acuminatus</i>	2-May		10-Jun	8-May	12-Jun	10-Jul
<i>Penstemon deustus</i>				19-May	24-Jun	
<i>Penstemon speciosus</i>	14-May		20-Jun	19-May	24-Jun	10-Jul
<i>Lomatium dissectum</i>	10-Apr		7-May	20-Apr	28-May	16-Jun
<i>Lomatium triternatum</i>	10-Apr	7-May	1-Jun	20-Apr	28-May	26-Jun
<i>Lomatium grayi</i>	10-Mar		7-May	20-Apr	28-May	16-Jun
<i>Sphaeralcea parvifolia</i>	1-May		10-Jun	22-May	24-Jun	14-Jul
<i>Sphaeralcea grossulariifolia</i>	1-May		10-Jun	22-May	24-Jun	14-Jul
<i>Sphaeralcea coccinea</i>	1-May		10-Jun	22-May	24-Jun	14-Jul
2010						
<i>Eriogonum umbellatum</i>	4-Jun	12-19 Jun	15-Jul	28-May	8-Jul	27-Jul
<i>Penstemon speciosus</i>	14-May		20-Jun	12-May	22-Jun	22-Jul
<i>Lomatium dissectum</i>	25-Apr		20-May	15-Apr	28-May	21-Jun
<i>Lomatium triternatum</i>	25-Apr		15-Jun	15-Apr	28-May	22-Jul
<i>Lomatium grayi</i>	15-Mar		15-May	15-Apr	28-May	22-Jun
<i>Sphaeralcea parvifolia</i>	10-May	4-Jun	25-Jun	28-May	8-Jul	20-Jul
<i>Sphaeralcea grossulariifolia</i>	10-May	4-Jun	25-Jun	28-May	8-Jul	20-Jul
<i>Sphaeralcea coccinea</i>	10-May	4-Jun	25-Jun	28-May	8-Jul	20-Jul
2011						
<i>Eriogonum umbellatum</i>	8-Jun	30-Jun	20-Jul	20-May	5-Jul	1-Aug
<i>Penstemon speciosus</i>	25-May	30-May	30-Jun	20-May	5-Jul	29-Jul
<i>Lomatium dissectum</i>	8-Apr	25-Apr	10-May	21-Apr	7-Jun	20-Jun
<i>Lomatium triternatum</i>	30-Apr	23-May	15-Jun	21-Apr	7-Jun	26-Jul
<i>Lomatium grayi</i>	1-Apr	25-Apr	13-May	21-Apr	7-Jun	22-Jun
<i>Sphaeralcea parvifolia</i>	26-May	15-Jun	14-Jul	20-May	5-Jul	29-Jul
<i>Sphaeralcea grossulariifolia</i>	26-May	15-Jun	14-Jul	20-May	5-Jul	29-Jul
<i>Sphaeralcea coccinea</i>	26-May	15-Jun	14-Jul	20-May	5-Jul	29-Jul
2012						
<i>Eriogonum umbellatum</i>	30-May	20-Jun	4-Jul	30-May	11-Jul	24-Jul
<i>Penstemon speciosus</i>	2-May	20-May	25-Jun	2-May	13-Jun	13-Jul
<i>Lomatium dissectum</i>	9-Apr	16-Apr	16-May	13-Apr	24-May	4-Jun
<i>Lomatium triternatum</i>	12-Apr	17-May	6-Jun	13-Apr	24-May	21-Jun
<i>Lomatium grayi</i>	15-Mar	25-Apr	16-May	13-Apr	24-May	14-Jun
2013						
<i>Eriogonum umbellatum</i>	8-May	27-May	27-Jun	8-May	19-Jun	9-Jul
<i>Penstemon speciosus</i>	2-May	10-May	20-Jun	2-May	12-Jun	11-Jul
<i>Lomatium dissectum</i>	10-Apr		25-Apr	4-Apr	16-May	4-Jun
<i>Lomatium triternatum</i>	18-Apr		10-May	4-Apr	16-May	4-Jun
<i>Lomatium grayi</i>	15-Mar		30-Apr	4-Apr	16-May	10-Jun

Table 3. Native wildflower seed harvest and cleaning by species, Malheur Experiment Station, Oregon State University, Ontario, OR.

Species	Number of harvests/year	Harvest method	Pre-cleaning	Threshing method	Cleaning method
<i>Eriogonum umbellatum</i>	1	combine ^a	none	dewinger ^b	mechanical ^c
<i>Penstemon acuminatus</i>	1	combine ^d	none	combine	mechanical ^c
<i>Penstemon deustus</i>	1	combine ^a	mechanical ^c	hand ^e	mechanical ^c
<i>Penstemon speciosus</i> ^f	1	combine ^d	none	combine	mechanical ^c
<i>Lomatium dissectum</i>	1	hand	hand	none	mechanical ^c
<i>Lomatium triternatum</i>	1–2	hand	hand	none	mechanical ^c
<i>Lomatium grayi</i>	1–2	hand	hand	none	mechanical ^c
<i>Sphaeralcea parvifolia</i>	1–3	hand or combine ^d	none	combine	none
<i>Sphaeralcea grossulariifolia</i>	1–3	hand or combine ^d	none	combine	none
<i>Sphaeralcea coccinea</i>	1–3	hand or combine ^d	none	combine	none
<i>Dalea searlsiae</i>	0 or 2	hand	none	dewinger	mechanical ^c
<i>Dalea ornata</i>	0 or 2	hand	none	dewinger	mechanical ^c

^a Wintersteiger Nurserymaster small-plot combine with dry bean concave.

^b Specialized seed threshing machine at USDA Lucky Peak Nursery used in 2006. Thereafter an adjustable hand-driven corn grinder was used to thresh seed.

^c Clipper seed cleaner.

^d Wintersteiger Nurserymaster small-plot combine with alfalfa seed concave. For the *Sphaeralcea* spp., flailing in the fall of 2007 resulted in more compact growth and one combine harvest in 2008, 2009, and 2010.

^e Hard seed pods were broken by rubbing against a ribbed rubber mat.

^f Harvested by hand in 2007 and 2009 due to poor seed set.

Results and Discussion

Precipitation from January through April in 2013 was only 1.4 inches, substantially lower than average. The accumulated growing degree-days (50–86°F) from January through June in 2013 were higher than average (Table 4, Figs. 1 and 2).

Flowering and Seed Set

Penstemon acuminatus and *P. speciosus* had poor seed set in 2007, partly due to a heavy lygus bug infestation that was not adequately controlled by the applied insecticides. In the Treasure Valley, the first hatch of lygus bugs occurs when 250 degree-days (52°F base) are accumulated. Data collected by an AgriMet weather station adjacent to the field indicated that the first lygus bug hatch occurred on May 14, 2006; May 1, 2007; May 18, 2008; May 19, 2009; and May 29, 2010. The average (1995–2010) lygus bug hatch date was May 18. *Penstemon acuminatus* and *P. speciosus* start flowering in early May. The earlier lygus bug hatch in 2007 probably resulted in harmful levels of lygus bugs present during a larger part of the *Penstemon* spp. flowering period than normal. Poor seed set for *P. acuminatus* and *P. speciosus* in 2007 also was related to poor vegetative growth compared to 2006 and 2008. In 2009, all plots of *P. acuminatus* and *P. speciosus* again showed poor vegetative growth and seed set. Root rot affected all plots of *P. acuminatus* in

2009, killing all plants in two of the four plots of the wettest treatment (2 inches per irrigation). Root rot affected the wetter plots of *P. speciosus* in 2009, but the stand partially recovered due to natural reseeding.

The three *Sphaeralcea* spp. had a long flowering period (early May through September) in 2007. Multiple manual harvests were necessary because the seed falls out of the capsules once they are mature. The flailing of the three *Sphaeralcea* spp. was done annually starting in the fall of 2007 to induce a more concentrated flowering, allowing only one mechanical harvest. Precipitation in June of 2009 (2.27 inches) and 2010 (1.95 inches) was substantially higher than average (0.76 inches). Rust (*Puccinia sherardiana*) infected all three *Sphaeralcea* spp. in June of 2009 and 2010, causing substantial leaf loss and reduced vegetative growth. Stands of all three *Sphaeralcea* spp. deteriorated in 2011 and the plots were disked out in 2012.

Seed Yields

Eriogonum umbellatum

In 2006, seed yield of *Eriogonum umbellatum* increased with increasing water application, up to 8 inches, the highest amount tested (Tables 5 and 7). In 2007-2009, seed yield showed a quadratic response to irrigation rate (Tables 6 and 7). Seed yields were maximized by 8.1 inches, 7.2 inches, and 6.9 inches of water applied in 2007, 2008, and 2009, respectively. In 2010, there was no significant difference in yield between treatments. In 2011, seed yield was highest with no irrigation. The 2010 and 2011 seasons had unusually cool (Table 4, Fig. 2) and wet weather (Fig. 2). The accumulated precipitation in April through June of 2010 and 2011 was the highest over the years of the trial (Table 4). The relatively high seed yield of *E. umbellatum* in the nonirrigated treatment in 2010 and 2011 seemed to be related to the high spring precipitation. The negative effect of irrigation on seed yield in 2011 might have been related to the presence of rust. Irrigation could have exacerbated the rust and resulted in lower yields. In 2012, seed yield of *E. umbellatum* increased with increasing water application, up to 8 inches, the highest amount tested (Tables 6 and 7). In 2013, seed yield showed a quadratic response to irrigation rate. Seed yield was maximized by 5.6 inches of water applied in 2013. Averaged over 8 years, seed yield of *E. umbellatum* increased with increasing water applied up to 8 inches, the highest amount tested. The shape of the quadratic seed yield responses most years suggests that additional irrigation above 8 inches would not be beneficial.

Penstemon acuminatus

There was no significant difference in seed yield between irrigation treatments for *P. acuminatus* in 2006 (Table 5). Precipitation from March through June was 6.4 inches in 2006. The 64-year-average precipitation from March through June is 3.6 inches. The wet weather in 2006 could have attenuated the effects of the irrigation treatments. In 2007, seed yield showed a quadratic response to irrigation rate. Seed yields were maximized by 4.0 inches of water applied in 2007. In 2008, seed yield showed a linear response to applied water. In 2009, there was no significant difference in seed yield between treatments (Table 7). However, due to root rot affecting all plots in 2009, the seed yield results were compromised. By 2010, substantial lengths of row contained only dead plants. Measurements in each plot showed that plant death increased with increasing irrigation rate. The stand loss was 51.3, 63.9, and 88.5% for the 0-, 4-, and 8-inch irrigation treatments, respectively. The trial area was disked out in 2010. Following the 2005 planting, seed yields were substantial in 2006 and moderate in 2008. *P. acuminatus* performed as a short-lived perennial.

Penstemon speciosus

In 2006-2009 seed yield of *P. speciosus* showed a quadratic response to irrigation rate (Tables 5, 6, and 7). Seed yields were maximized by 4.3, 4.2, 5.0, and 4.3 inches of water applied in 2006, 2007, 2008, and 2009, respectively. In 2010-2012 there was no difference in seed yield between treatments. Seed yield was low in 2007 due to lygus bug damage, as discussed previously. Seed yield in 2009 was low due to stand loss from root rot. The plant stand recovered somewhat in 2010 and 2011, due in part to natural reseeding, especially in the nonirrigated plots. In 2013, seed yield increased with increasing water application, up to 8 inches, the highest amount tested. Averaged over 8 years, seed yield was maximized by 4.9 inches of water applied.

Lomatium triternatum

Lomatium triternatum showed a trend for increasing seed yield with increasing irrigation rate in 2007 (Table 5). The highest irrigation rate resulted in significantly higher seed yield than the nonirrigated check in 7 of the last 8 years. Seed yields of *L. triternatum* were substantially higher in 2008-2011 (Tables 6 and 7). In 2008-2011 seed yields of *L. triternatum* showed a quadratic response to irrigation rate. Seed yields were estimated to be maximized by 8.4, 5.4, 7.8, and 4.1 inches of water applied in 2008, 2009, 2010, and 2011, respectively. In 2012 and 2013, seed yield increased linearly with increasing water applied up to the highest amount of water applied, 8 inches. Over 7 years, seed yield of *L. triternatum* was estimated to be maximized by 6.4 inches of applied water (Table 7).

Lomatium grayi

Lomatium grayi showed a trend for increasing seed yield with increasing irrigation rate in 2007 (Table 5). The highest irrigation rate resulted in significantly higher seed yield than the nonirrigated check in six of the last eight years. Seed yields of *L. grayi* were substantially higher in 2008 and 2009. In 2008, seed yields of *L. grayi* showed a quadratic response to irrigation rate. Seed yields were estimated to be maximized by 6.9 inches of water applied in 2008. In 2009, seed yield showed a linear response to irrigation rate (Tables 6 and 7). Seed yield with the 4-inch irrigation rate was significantly higher than in the nonirrigated check, but the 8-inch irrigation rate did not result in a significant increase above the 4-inch rate. In 2010, seed yield was not responsive to irrigation, possibly caused by the unusually wet spring of 2010. A further complicating factor in 2010 that compromised seed yields was rodent damage. Extensive rodent (vole) damage occurred over the 2009-2010 winter. The affected areas were transplanted with 3-year-old *L. grayi* plants from an adjacent area in the spring of 2010. To reduce their attractiveness to voles, the plants were mowed after dormancy in early fall of 2010 and in each subsequent year. In 2011, seed yield again did not respond to irrigation. The spring of 2011 was unusually cool and wet. In 2012, seed yields of *L. grayi* showed a quadratic response to irrigation rate, with a maximum seed yield at 5.5 inches of applied water. In 2013, seed yield increased linearly with increasing water application, up to 8 inches, the highest amount applied. Over 7 years, seed yield of *L. grayi* was estimated to be maximized by 5.5 inches of applied water. Most appropriately, irrigation probably should be variable according to precipitation.

Lomatium dissectum

Lomatium dissectum had very little vegetative growth during 2006-2008, and produced only very few flowers in 2008. In 2009, vegetative growth and flowering for *L. dissectum* were greater. Seed

yield of *L. dissectum* showed a linear response to irrigation rate in 2009 (Table 7). Seed yield with the 4-inch irrigation rate was significantly higher than with the nonirrigated check, but the 8-inch irrigation rate did not result in a significant increase above the 4-inch rate. In 2010 and 2011, seed yields of *L. dissectum* showed a quadratic response to irrigation rate. Seed yields were estimated to be maximized by 5.4 and 5.1 inches of applied water in 2010 and 2011, respectively. In 2012, seed yields of *L. dissectum* were not responsive to irrigation rate. In 2013, seed yield increased linearly with increasing irrigation rate up to 8 inches, the highest amount applied. Over the 5 years, seed yield showed a quadratic response to irrigation rate and was estimated to be maximized by 5.5 inches of applied water.

All the *Lomatium* species tested were affected by *Alternaria* fungus, but the infection was greatest on the *L. dissectum* selection planted in this trial. This infection delayed *L. dissectum* plant development.

***Sphaeralcea* spp.**

In 2007-2011 there were no significant differences in seed yield among irrigation treatments for the three *Sphaeralcea* spp. (Tables 5 and 6). Stands of the three *Sphaeralcea* spp. were poor in 2012 and the plantings were eliminated.

Conclusions

Subsurface drip irrigation systems were tested for native seed production because they have two potential strategic advantages: a) low water use, and b) the buried drip tape provides water to the plants at depth, preventing most irrigation-induced weed seed germination on the soil surface and keeping water away from native plant tissues that are not adapted to a wet environment.

Due to the arid environment, supplemental irrigation may often be required for successful flowering and seed set because soil water reserves may be exhausted before seed formation. The total irrigation requirements for these arid-land species were low and varied by species (Table 7). The *Sphaeralcea* spp. and *Penstemon acuminatus* did not respond to irrigation in these trials. Natural rainfall was sufficient to maximize seed production in the absence of weed competition.

Lomatium dissectum required approximately 6 inches of irrigation. *Lomatium grayi*, *L. triternatum*, and *Eriogonum umbellatum* responded quadratically to irrigation with the optimum varying by year. *Penstemon deustus* plant stands were insufficient to reliably evaluate its response to irrigation over multiple years.

Management Applications

This report describes irrigation practices that can be immediately implemented by seed growers. Summaries of research findings are found in Tables 5-8.

Table 4. Early season precipitation and growing degree-days at the Malheur Experiment Station, Oregon State University, Ontario, OR, 2006-2013.

Year	Precipitation (inches)		Growing degree-days (50-86°F)
	Jan-Jun	Apr-Jun	Jan-Jun
2006	9.0	3.1	1120
2007	3.1	1.9	1208
2008	2.9	1.2	936
2009	5.8	3.9	1028
2010	8.3	4.3	779
2011	8.3	3.9	671
2012	5.8	2.3	979
2013	2.6	1.4	1118
70-year average	5.8	2.7	1026 ^a

^a27-year average.

Table 5. Native wildflower seed yield response to irrigation rate (inches/season) in 2006-2008. Malheur Experiment Station, Oregon State University, Ontario, OR.

Species	2006				2007				2008			
	0 inches	4 inches	8 inches	LSD (0.05)	0 inches	4 inches	8 inches	LSD (0.05)	0 inches	4 inches	8 inches	LSD (0.05)
	----- lb/acre -----											
<i>Eriogonum umbellatum</i> ^a	155.3	214.4	371.6	92.9	79.6	164.8	193.8	79.8	121.3	221.5	245.2	51.7
<i>Penstemon acuminatus</i> ^a	538.4	611.1	544.0	NS	19.3	50.1	19.1	25.5 ^b	56.2	150.7	187.1	79.0
<i>Penstemon deustus</i> ^c	1246.4	1200.8	1068.6	NS	120.3	187.7	148.3	NS	--- very poor stand ---			
<i>Penstemon speciosus</i> ^a	163.5	346.2	213.6	134.3	2.5	9.3	5.3	4.7 ^b	94.0	367.0	276.5	179.6
<i>Lomatium dissectum</i> ^d	---- no flowering ----				--- no flowering ---				--- very little flowering ---			
<i>Lomatium triternatum</i> ^d	---- no flowering ----				2.3	17.5	26.7	16.9 ^b	195.3	1060.9	1386.9	410.0
<i>Lomatium grayi</i> ^d	---- no flowering ----				36.1	88.3	131.9	77.7 ^b	393.3	1287	1444.9	141.0
<i>Sphaeralcea parvifolia</i> ^e					1062.6	850.7	957.9	NS	436.2	569.1	544.7	NS
<i>Sphaeralcea grossulariifolia</i> ^e					442.6	324.8	351.9	NS	275.3	183.3	178.7	NS
<i>Sphaeralcea coccinea</i> ^e					279.8	262.1	310.3	NS	298.7	304.1	205.2	NS

^a planted March 2005, areas of low stand replanted by hand in October 2005.

^b LSD (0.10).

^c planted March 2005, areas of low stand replanted by hand in October 2005 and whole area replanted in October 2006. Yields in 2006 are based on small areas with adequate stand. Yields in 2007 are based on whole area of very poor and uneven stand.

^d planted March 2005, whole area replanted in October 2005.

^e planted spring 2006, whole area replanted in November 2006.

Table 6. Native wildflower seed yield in response to irrigation rate (inches/season) in 2009-2013 and 2- to 8-year yield averages. Malheur Experiment Station, Oregon State University, Ontario, OR.

Species	2009				2010				2011			
	0 inches	4 inches	8 inches	LSD (0.05)	0 inches	4 inches	8 inches	LSD (0.05)	0 inches	4 inches	8 inches	LSD (0.05)
----- lb/acre -----												
<i>Eriogonum umbellatum</i> ^a	132.3	223	240.1	67.4	252.9	260.3	208.8	NS	248.7	136.9	121.0	90.9
<i>Penstemon acuminatus</i> ^a	20.7	12.5	11.6	NS	-- Stand disked out --							
<i>Penstemon speciosus</i> ^a	6.8	16.1	9.0	6.0b	147.2	74.3	69.7	NS	371.1	328.2	348.6	NS
<i>Lomatium dissectum</i> ^d	50.6	320.5	327.8	196.4 ^b	265.8	543.8	499.6	199.6	567.5	1342.8	1113.8	180.9
<i>Lomatium triternatum</i> ^d	181.6	780.1	676.1	177	1637.2	2829.6	3194.6	309.4	1982.9	2624.5	2028.1	502.3 ^b
<i>Lomatium grayi</i> ^d	359.9	579.8	686.5	208.4	1035.7	1143.5	704.8	NS	570.3	572.7	347.6	NS
<i>Sphaeralcea parvifolia</i> ^e	285.9	406.1	433.3	NS	245.3	327.3	257.3	NS	81.6	142.5	141.2	NS
<i>Sphaeralcea grossulariifolia</i> ^e	270.7	298.9	327.0	NS	310.5	351	346.6	NS	224.0	261.9	148.1	NS
<i>Sphaeralcea coccinea</i> ^e	332.2	172.1	263.3	NS	385.7	282.6	372.5	NS	89.6	199.6	60.5	NS
----- lb/acre -----												
Species	2012				2013				2- to 8-year averages			
	0 inches	4 inches	8 inches	LSD (0.05)	0 inches	4 inches	8 inches	LSD (0.05)	0 inches	4 inches	8 inches	LSD (0.05)
<i>Eriogonum umbellatum</i> ^a	61.2	153.2	185.4	84.4	113.2	230.1	219.8	77.5	146.5	192.9	211.9	32.2
<i>Penstemon speciosus</i> ^a	103.8	141.1	99.1	NS	8.7	80.7	138.6	63.7	112.5	162.8	144.9	35.9
<i>Lomatium dissectum</i> ^d	388.1	460.3	444.4	NS	527.8	959.8	1166.7	282.4	360.0	767.6	710.5	153.1
<i>Lomatium triternatum</i> ^d	238.7	603.0	733.2	323.9	153.7	734.4	1050.9	425.0	627.4	1235.7	1299.5	168.2
<i>Lomatium grayi</i> ^d	231.9	404.4	377.3	107.4	596.7	933.4	1036.3	NS	460.5	715.6	675.6	NS

^a planted March 2005, areas of low stand replanted by hand in October 2005.

^b LSD (0.10)

^c planted March 2005, whole area replanted in October 2005.

^d planted spring 2006, whole area replanted in November 2006.

^e planted spring 2006, whole area replanted in November 2006.

Table 7. Regression analysis for native wildflower seed yield response to irrigation rate (inches/season) in 2006-2013, and 2- to 8-year averages. For the quadratic equations, the amount of irrigation that resulted in maximum yield was calculated using the formula: $-b/2c$, where b is the linear parameter and c is the quadratic parameter. Malheur Experiment Station, Oregon State University, Ontario, OR. Continued on the next page.

<i>Eriogonum umbellatum</i>							
Year	intercept	linear	quadratic	R^2	P	Maximum yield lb/acre	Water applied for maximum yield inches/season
2006	137.9	27.8		0.68	0.01	360.3	8.0
2007	79.6	28.3	-1.8	0.69	0.05	194.0	8.1
2008	121.3	34.6	-2.4	0.73	0.01	246.0	7.2
2009	132.3	31.9	-2.3	0.60	0.05	242.9	6.9
2010	252.9	9.2	-1.8	0.08	NS		
2011	232.7	-16.0		0.58	0.01	232.7	0.0
2012	71.2	15.5		0.61	0.01	195.2	8.0
2013	113.2	45.2	-4.0	0.62	0.05	241.3	5.7
Average	153.6	8.7		0.71	0.001	223.2	8.0
<i>Penstemon speciosus</i>							
Year	intercept	linear	quadratic	R^2	P	Maximum yield lb/acre	Water applied for maximum yield inches/season
2006	163.5	85.1	-9.9	0.66	0.05	346.4	4.3
2007	2.5	3.2	-0.4	0.48	0.10	9.2	4.2
2008	94.1	113.7	-11.4	0.56	0.05	377.6	5.0
2009	6.8	4.4	-0.5	0.54	0.05	16.1	4.2
2010	147.2	29.8	-2.1	0.35	NS		
2011	360.6	-2.8		0.01	NS		
2012	103.8	19.3	-2.5	0.3	NS		
2013	11.0	16.2		0.77	0.001	141.0	8.0
Average	112.5	21.1	-2.1	0.45	0.10	164.8	4.9

^a not significant. There was no statistically significant difference in yield between the nonirrigated plots and the plots receiving 4 or 8 inches of water.

Table 7. Continued. Regression analysis for native wildflower seed yield response to irrigation rate (inches/season) in 2006-2013, and 2- to 8-year averages. Malheur Experiment Station, Oregon State University, Ontario, OR.

<i>Lomatium triternatum</i>							
Year	intercept	linear	quadratic	R^2	P	Maximum yield lb/acre	Water applied for maximum yield inches/season
2007	3.3	3.1		0.52	0.01	27.7	8.0
2008	195.3	283.9	-16.9	0.77	0.01	1387.6	8.4
2009	181.6	237.4	-22.0	0.83	0.001	822.0	5.4
2010	1637.2	401.5	-25.9	0.83	0.001	3193.2	7.8
2011	1982.9	315.1	-38.7	0.45	0.10	2624.3	4.1
2012	277.8	61.8		0.49	0.05	772.2	8.0
2013	197.7	112.2		0.66	0.01	1095.0	8.0
Average	627.4	220.2	-17.0	0.81	0.001	1340.4	6.5
<i>Lomatium dissectum</i>							
Year	intercept	linear	quadratic	R^2	P	Maximum yield lb/acre	Water applied for maximum yield inches/season
2009	86.4	34.6		0.31	0.10	363.2	8.0
2010	265.8	109.8	-10.1	0.68	0.01	564.2	5.4
2011	567.5	319.3	-31.4	0.86	0.001	1379.2	5.1
2012	402.7	7.0		0.04	NS		
2013	565.3	79.9		0.65	0.01	1204.2	8.0
Average	360.0	160.0	-14.5	0.80	0.001	800.7	5.5
<i>Lomatium grayi</i>							
Year	intercept	linear	quadratic	R^2	P	Maximum yield lb/acre	Water applied for maximum yield inches/season
2007	37.5	12.0		0.26	0.10	133.5	8.0
2008	393.3	315.4	-23.0	0.93	0.001	1474.6	6.9
2009	378.7	40.8		0.38	0.05	705.1	8.0
2010	1035.7	95.3	-17.1	0.22	NS		
2011	608.2	-27.8		0.07	NS		
2012	231.9	68.1	-6.2	0.66	0.01	418.9	5.5
2013	635.6	55.0		0.25	0.10	1075.3	8.0
Average	460.5	100.6	-9.2	0.43	0.10	735.2	5.5

^a not significant. There was no statistically significant difference in yield between the nonirrigated plots and the plots receiving 4 or 8 inches of water.

Table 8. Amount of irrigation water for maximum native wildflower seed yield, years to seed set, and life span. A summary of multi-year research findings, Malheur Experiment Station, Oregon State University, Ontario, OR.

Species	Optimum amount of irrigation	Years to first seed set	Life span
	inches/season	from fall planting	years
<i>Eriogonum umbellatum</i>	0 in wet years, 6-8 in dry years	1	7+
<i>Penstemon acuminatus</i>	no response	1	3
<i>Penstemon speciosus</i>	0 in wet years, 4-8 in dry years	1	3
<i>Lomatium dissectum</i>	5-8	4	7+
<i>Lomatium triternatum</i>	4-8 depending on precipitation	2	7+
<i>Lomatium grayi</i>	0 in wet years, 6-8 in dry years	2	7+
<i>Sphaeralcea parvifolia</i>	no response	1	5
<i>Sphaeralcea grossulariifolia</i>	no response	1	5
<i>Sphaeralcea coccinea</i>	no response	1	5

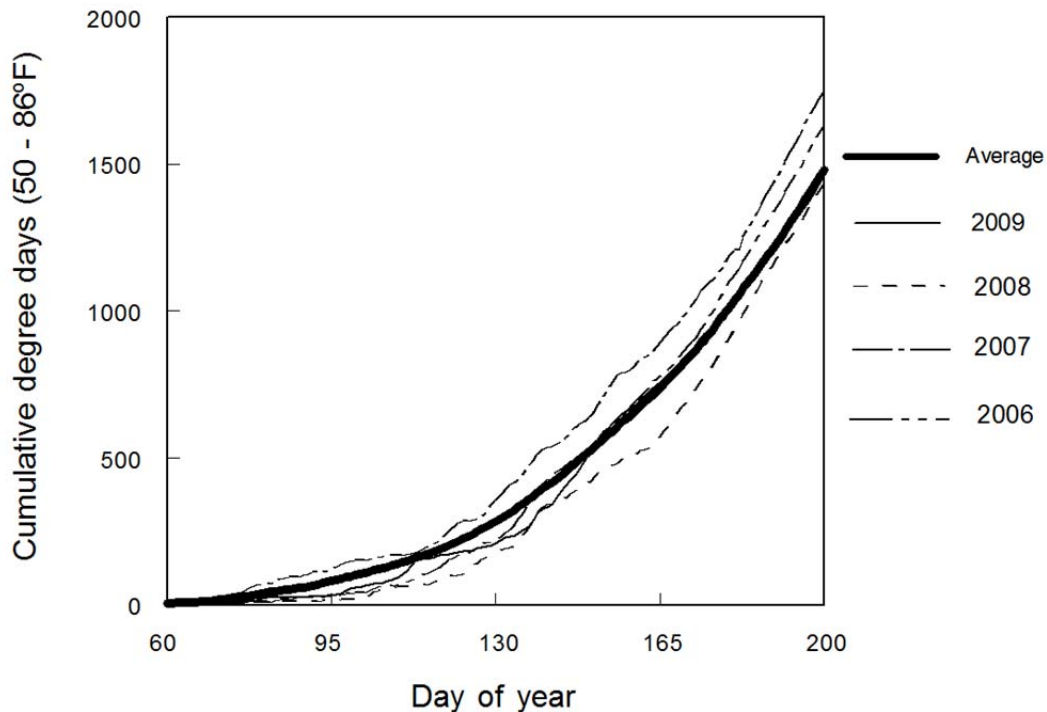


Figure 1. Cumulative annual growing degree-days for 2006-2009 compared with the 23-year average growing degree-days at the Malheur Experiment Station, Oregon State University, Ontario, OR.

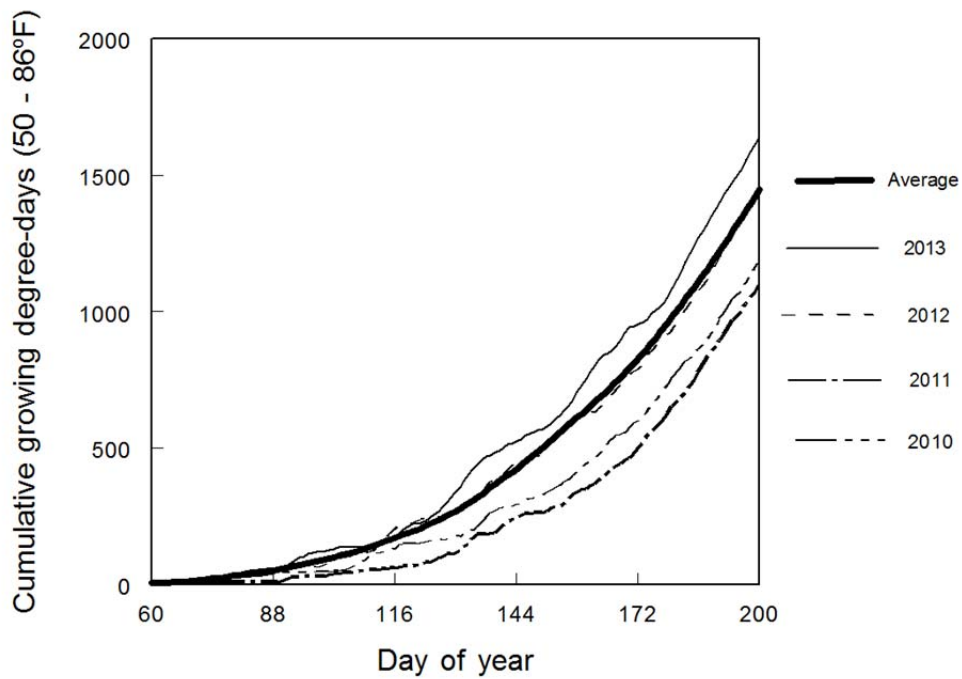


Figure 2. Cumulative annual growing degree-days for 2010-2013 compared with the 23-year average growing degree-days at the Malheur Experiment Station, Oregon State University, Ontario, OR.