EIGHT YEARS EVALUATING THE IRRIGATION REQUIREMENTS FOR NATIVE WILDFLOWER SEED PRODUCTION

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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 percent by volume solution of 13 percent 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 percent 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 all species 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 the *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 more seed was received 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. Emergence 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
Eriogonum umbellatum	Sulphur-flower buckwheat
Penstemon acuminatus	Sharpleaf penstemon, sand-dune penstemon
Penstemon deustus	Scabland penstemon, hotrock penstemon
Penstemon speciosus	Royal penstemon, sagebrush penstemon
Lomatium dissectum	Fernleaf biscuitroot
Lomatium triternatum	Nineleaf biscuitroot, nineleaf desert parsley
Lomatium grayi	Gray's biscuitroot, Gray's lomatium
Sphaeralcea parvifolia	Smallflower globemallow
Sphaeralcea grossulariifolia	Gooseberryleaf globemallow
Sphaeralcea coccinea	Scarlet globemallow, red globemallow
Dalea searlsiae	Searls' prairie clover
Dalea ornata	Western prairie clover, Blue Mountain prairie clover
Astragalus filipes	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 irrigation treatments were a nonirrigated check, 1 inch per irrigation, and 2 inches 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 March18, 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, 2011, 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.

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

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

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

Species	Flowering start	Flowering peak	Flowering end	Irrigation start	Irrigation end	Harvest
			2009			
Eriogonum umbellatum	31-May		15-Jul	19-May	24-Jun	28-Jul
Penstemon acuminatus	2-May		10-Jun	8-May	12-Jun	10-Jul
Penstemon deustus				19-May	24-Jun	
Penstemon speciosus	14-May		20-Jun	19-May	24-Jun	10-Jul
Lomatium dissectum	10-Apr		7-May	20-Apr	28-May	16-Jun
Lomatium triternatum	10-Apr	7-May	1-Jun	20-Apr	28-May	26-Jun
Lomatium grayi	10-Mar		7-May	20-Apr	28-May	16-Jun
Sphaeralcea parvifolia	1-May		10-Jun	22-May	24-Jun	14-Jul
Sphaeralcea grossulariifolia	1-May		10-Jun	22-May	24-Jun	14-Jul
Sphaeralcea coccinea	1-May		10-Jun	22-May	24-Jun	14-Jul
			2010			
Eriogonum umbellatum	4-Jun	12-19 Jun	15-Jul	28-May	8-Jul	27-Jul
Penstemon speciosus	14-May		20-Jun	12-May	22-Jun	22-Jul
Lomatium dissectum	25-Apr		20-May	15-Apr	28-May	21-Jun
Lomatium triternatum	25-Apr		15-Jun	15-Apr	28-May	22-Jul
Lomatium grayi	15-Mar		15-May	15-Apr	28-May	22-Jun
Sphaeralcea parvifolia	10-May	4-Jun	25-Jun	28-May	8-Jul	20-Jul
Sphaeralcea grossulariifolia	10-May	4-Jun	25-Jun	28-May	8-Jul	20-Jul
Sphaeralcea coccinea	10-May	4-Jun	25-Jun	28-May	8-Jul	20-Jul
			2011			
Eriogonum umbellatum	8-Jun	30-Jun	20-Jul	20-May	5-Jul	1-Aug
Penstemon speciosus	25-May	30-May	30-Jun	20-May	5-Jul	29-Jul
Lomatium dissectum	8-Apr	25-Apr	10-May	21-Apr	7-Jun	20-Jun
Lomatium triternatum	30-Apr	23-May	15-Jun	21-Apr	7-Jun	26-Jul
Lomatium grayi	1-Apr	25-Apr	13-May	21-Apr	7-Jun	22-Jun
Sphaeralcea parvifolia	26-May	15-Jun	14-Jul	20-May	5-Jul	29-Jul
Sphaeralcea grossulariifolia	26-May	15-Jun	14-Jul	20-May	5-Jul	29-Jul
Sphaeralcea coccinea	26-May	15-Jun	14-Jul	20-May	5-Jul	29-Jul
			2012			
Eriogonum umbellatum	30-May	20-Jun	4-Jul	30-May	11-Jul	24-Jul
Penstemon speciosus	2-May	20-May	25-Jun	2-May	13-Jun	13-Jul
Lomatium dissectum	9-Apr	16-Apr	16-May	13-Apr	24-May	4-Jun
Lomatium triternatum	12-Apr	17-May	6-Jun	13-Apr	24-May	21-Jun
Lomatium grayi	15-Mar	25-Apr	16-May	13-Apr	24-May	14-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
Eriogonum umbellatum	1	combine[a]	none	dewinger[b]	mechanical[c]
Penstemon acuminatus	1	combine[d]	none	combine	mechanical[c]
Penstemon deustus	1	combine[a]	mechanical[c]	hand[e]	mechanical[c]
Penstemon speciosus[f]	1	combine[d]	none	combine	mechanical[c]
Lomatium dissectum	1	hand	hand	none	mechanical[c]
Lomatium triternatum	1–2	hand	hand	none	mechanical[c]
Lomatium grayi	1–2	hand	hand	none	mechanical[c]
Sphaeralcea parvifolia	1–3	hand or combine[d]	none	combine	none
Sphaeralcea grossulariifolia	1–3	hand or combine[d]	none	combine	none
Sphaeralcea coccinea	1–3	hand or combine[d]	none	combine	none
Dalea searlsiae	0 or 2	hand	none	dewinger	mechanical[c]
Dalea ornate	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

Very low precipitation in November and December of 2011 was followed by close to average precipitation from January through June in 2012 resulting in a dry spring and lower soil volumetric water content early in the wildflower growing season. For example, the soil water in the nonirrigated plots of *Eriogonum umbellatum* in 2012 was much drier compared to wetter years such as 2006 and 2011 (Fig. 3). The soil volumetric water content for all the various species in 2012 started very dry but responded to the irrigation treatments (Figs. 4-8). The accumulated precipitation and growing degree-days (50-86°F) from January through June in 2012 were close to the average (Table 4, Figs. 1 and 2). The relatively dry soil at the beginning of the growing season may have been detrimental to the seed yield of all species in 2012.

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. showed 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. starting in the fall of 2007 was done annually 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.

Seed Yields

Eriogonum umbellatum

In 2006, seed yield of *Eriogonum umbellatum* increased with increasing water application, up to 8 inches, the highest amount tested (Table 5, Fig. 9). In 2007-2009 seed yield showed a quadratic response to irrigation rate (Tables 5 and 6). 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. 1) 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 2006, seed yield of *Eriogonum umbellatum* increased with increasing water application, up to 8 inches, the highest amount tested (Table 5, Fig. 9). Averaged over 7 years, seed yield of *E. umbellatum* increased with increasing water applied up to 8 inches, the highest amount tested (Fig. 9). 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 (Fig. 10). 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 6). 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 percent 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* is a short-lived perennial.

Penstemon speciosus

In 2006-2009 seed yield of *P. speciosus* showed a quadratic response to irrigation rate (Fig. 11, Tables 5 and 6). 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, 2011, and 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. Averaged over 7 years, seed yield was maximized by 4.5 inches of water applied.

Penstemon deustus

There was no significant difference in seed yield between irrigation treatments for *P. deustus* in 2006 or 2007. Both the replanting of the low stand areas in October 2005 and the replanting of the whole area in October 2006 resulted in very poor emergence and plots with very low and uneven stands. The planting was disked out.

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 treatments. Seed yields of *L. triternatum* were substantially higher in 2008-2011 (Tables 5 and 6). In 2008–2011 seed yields of *L. triternatum* showed a quadratic response to irrigation rate (Fig. 12). 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, seed yield increased with increasing water applied up to the highest amount of 8 inches. Averaged over 6 years, seed yield of *L. triternatum* was estimated to be maximized by 6.2 inches of applied water. Irrigation requirements were lower in 2011.

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. 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 (Fig. 13). 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. 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 becoming dormant in early fall of 2010. 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 (Fig. 13). Averaged over 6 years, seed yield of *L. grayi* was estimated to be maximized by 5.2 inches of applied water. More appropriately, irrigation probably should be variable according to precipitation.

Lomatium dissectum

Lomatium dissectum had very poor vegetative growth in 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 (Fig. 14). 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 (Fig. 14). Averaged over the 4 years, seed yield showed a quadratic response to irrigation rate and was estimated to be maximized by 5.1 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 might have 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). Stand of the three *Sphaeralcea* species was poor in 2012 and the planting was 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, precluding stimulation of 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. The other species tested had insufficient plant stands to reliably evaluate their response to irrigation.

Management Applications

This report describes practices that can be immediately implemented by seed growers. A multi-year summary of research findings is found in Table 7.

Table 4. Precipitation and growing degree-days at the Malheur Experiment Station, Ontario, OR.

	Precipitation (inches)		Growing degree-days (50-86°F)
Year	Jan-June	April-June	Jan-June
2006	9	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
67-year average	5.8	2.7	1028[a]

[a]25-year average.

Table 5. Native wildflower seed yield response to irrigation rate (inches/season) in 2006, 2007, and 2008. Malheur Experiment Station, Oregon State University, Ontario, OR.

	2006				2007				2008			
Species	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 ------------------------											
Eriogonum umbellatum[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
Penstemon acuminatus[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
Penstemon deustus[c]	1246.4	1200.8	1068.6	NS	120.3	187.7	148.3	NS	--- very poor stand ---			
Penstemon speciosus[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
Lomatium dissectum[d]	---- no flowering ----				--- no flowering ---				--- very little flowering ---			
Lomatium triternatum[d]	---- no flowering ----				2.3	17.5	26.7	16.9[b]	195.3	1060.9	1386.9	410.0
Lomatium grayi[d]	---- no flowering ----				36.1	88.3	131.9	77.7[b]	393.3	1287	1444.9	141.0
Sphaeralcea parvifolia[e]					1062.6	850.7	957.9	NS	436.2	569.1	544.7	NS
Sphaeralcea grossulariifolia[e]					442.6	324.8	351.9	NS	275.3	183.3	178.7	NS
Sphaeralcea coccinea[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 response to irrigation rate (inches/season) in 2009- 2012, and 2- to 7-year 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											
Eriogonum umbellatum[a]	132.3	223	240.1	67.4	252.9	260.3	208.8	NS	248.7	136.9	121.0	90.9
Penstemon acuminatus[a]	20.7	12.5	11.6	NS	-- Stand disked out --							
Penstemon speciosus[a]	6.8	16.1	9.0	6.0b	147.2	74.3	69.7	NS	371.1	328.2	348.6	NS
Lomatium dissectum[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
Lomatium triternatum[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]
Lomatium grayi[d]	359.9	579.8	686.5	208.4	1035.7	1143.5	704.8	NS	570.3	572.7	347.6	NS
Sphaeralcea parvifolia[e]	285.9	406.1	433.3	NS	245.3	327.3	257.3	NS	81.6	142.5	141.2	NS
Sphaeralcea grossulariifolia[e]	270.7	298.9	327.0	NS	310.5	351	346.6	NS	224.0	261.9	148.1	NS
Sphaeralcea coccinea[e]	332.2	172.1	263.3	NS	385.7	282.6	372.5	NS	89.6	199.6	60.5	NS

Species	2012				4- to 7-year averages			
	0 inches	4 inches	8 inches	LSD (0.05)	0 inches	4 inches	8 inches	LSD (0.05)
Eriogonum umbellatum[a]	61.2	153.2	185.4	84.4	154.5	194.2	217.4	30.8
Penstemon acuminatus[a]					163.8	204.8	189.9	NS
Penstemon speciosus[a]	103.8	141.1	99.1	NS	127.8	174.8	145.8	30.5[b]
Lomatium dissectum[d]	388.1	460.3	444.4	NS	318.0	719.1	596.4	179.4
Lomatium triternatum[d]	238.7	603.0	733.2	323.9	706.3	1319.3	1341.0	192.4
Lomatium grayi[d]	231.9	404.4	377.3	107.4	437.9	679.3	615.5	185.5
Sphaeralcea parvifolia[e]					449.9	495.9	495.8	NS
Sphaeralcea grossulariifolia[e]					339.5	323.4	309.4	NS
Sphaeralcea coccinea[e]					320.5	275.8	284.2	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 were based on small areas with adequate stand. Yields in 2007 were 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 7. 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
Eriogonum umbellatum	0 in wet years, 7 to 8 in dry years	1	7+
Penstemon acuminatus	no response	1	3
Penstemon speciosus	0 in wet years, 4 in dry years	1	3
Lomatium dissectum	5	4	7+
Lomatium triternatum	4 to 8 depending on precipitation	2	7+
Lomatium grayi	0 in wet years, 5 in dry years	2	7+
Sphaeralcea parvifolia	no response	1	5
Sphaeralcea grossulariifolia	no response	1	5
Sphaeralcea coccinea	no response	1	5

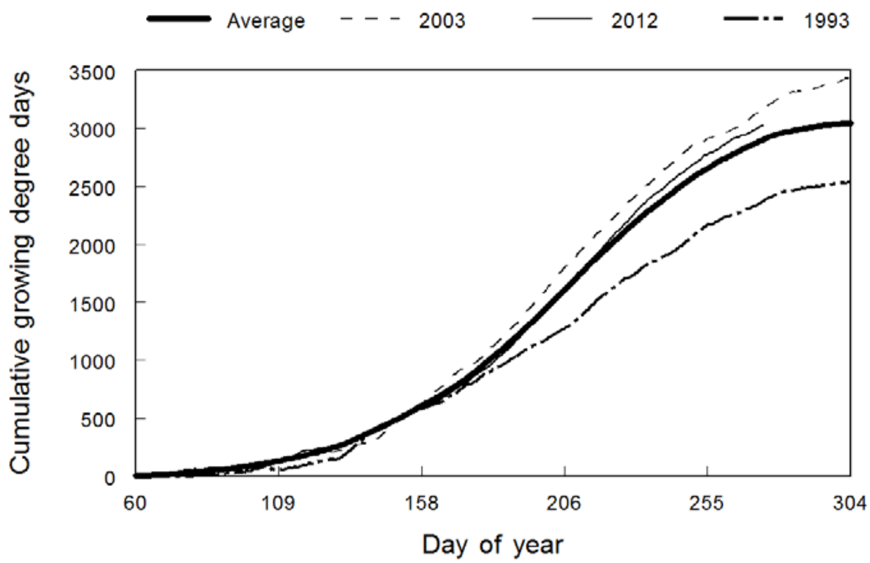

Figure 1. Cumulative annual and 22-year average growing degree-days at the Malheur Experiment Station, Oregon State University, Ontario, OR.

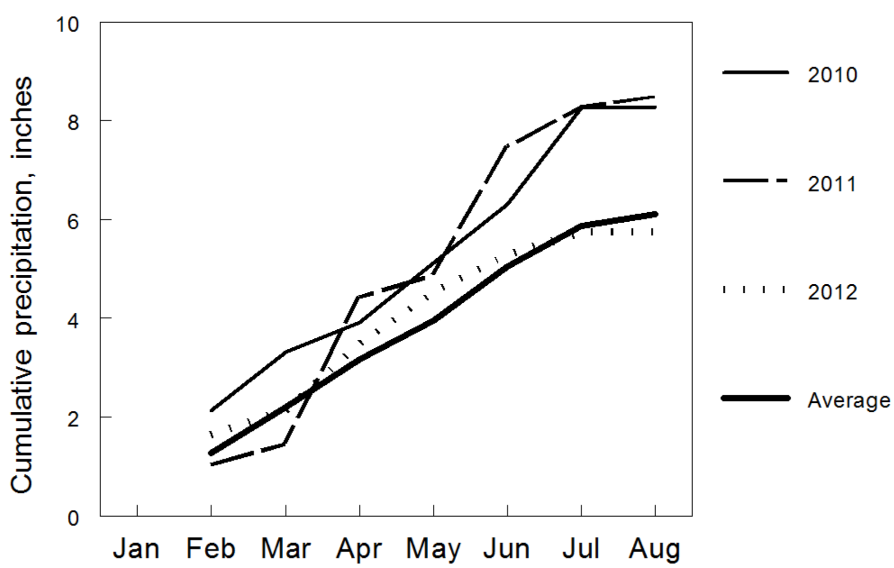

Figure 2. Cumulative annual and 68-year average precipitation from January through July at the Malheur Experiment Station, Oregon State University, Ontario, OR.

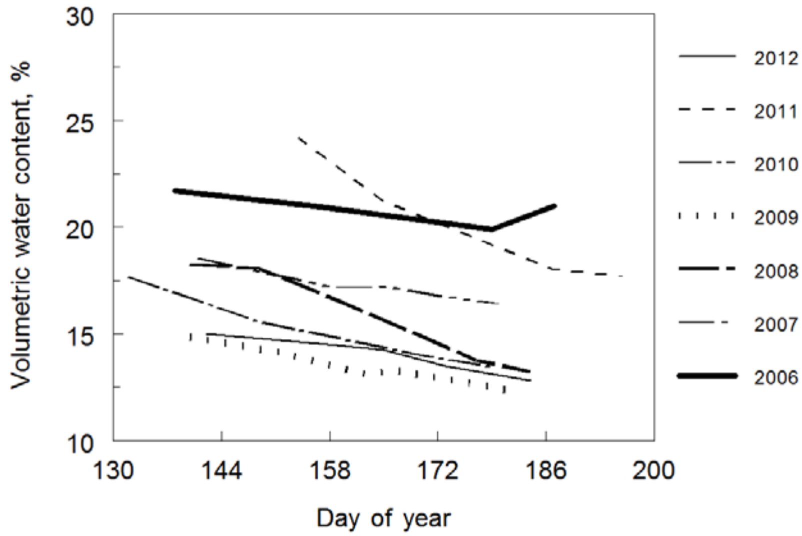

Figure 3. Soil volumetric water content in nonirrigated Eriogonum umbellatum *over 7 years. Soil volumetric water content is the combined average at the 8-, 20-, and 32-inch depths. Malheur Experiment Station, Oregon State University, Ontario, OR.*

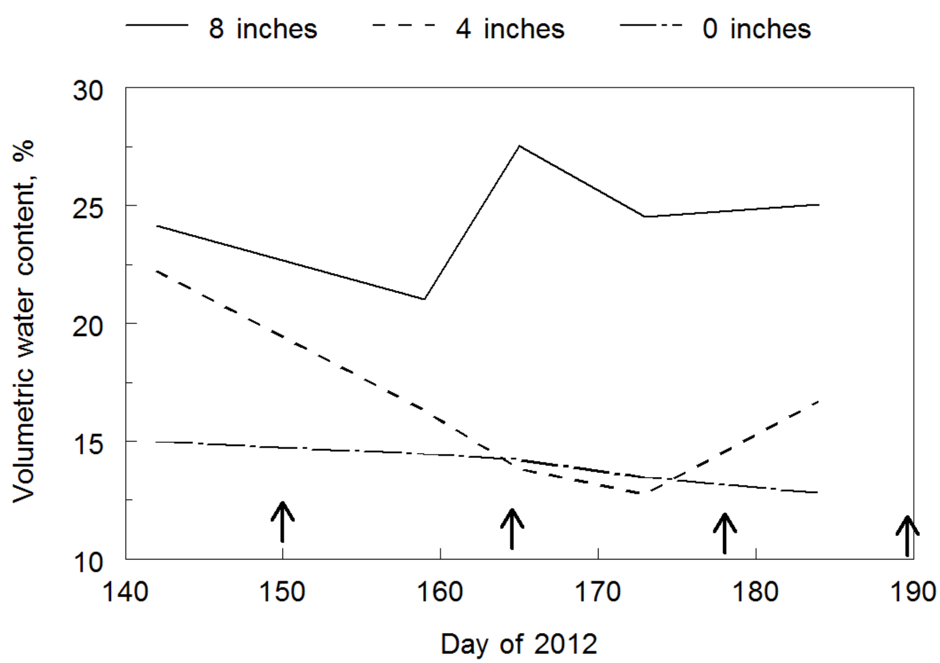

Figure 4. Soil volumetric water content for Eriogonum umbellatum *over time in 2012. Soil volumetric water content is the combined average at the 8-, 20-, and 32-inch depths. Irrigations started on May 30 and ended on July 11. Arrows denote irrigations.* E. umbellatum *was harvested on July 24 (day 205). Malheur Experiment Station, Oregon State University, Ontario, OR.*

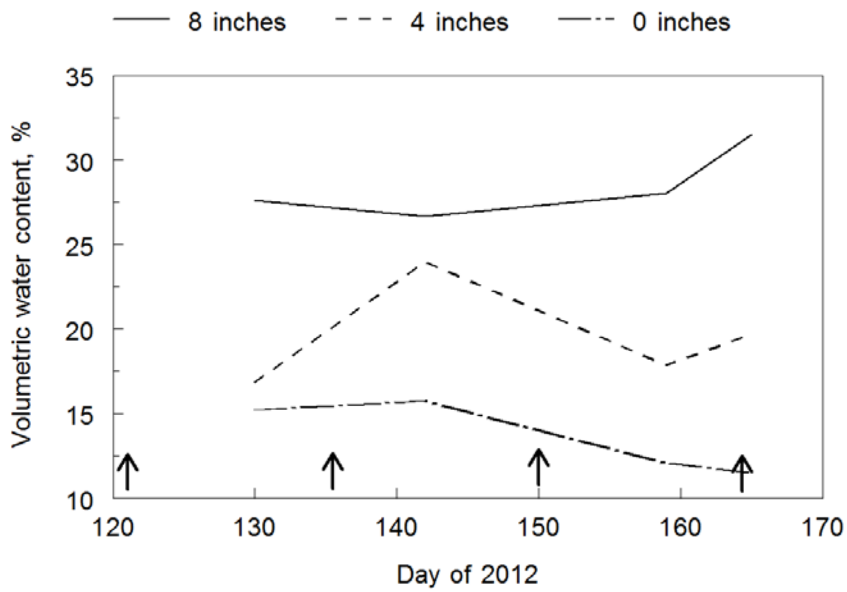

Figure 5. Soil volumetric water content for Penstemon speciosus *over time in 2012. Soil volumetric water content is the combined average at the 8-, 20-, and 32-inch depths. Irrigations started on May 2 and ended on June 13. Arrows denote irrigations.* P. speciosus *was harvested on July 13 (day 194). Malheur Experiment Station, Oregon State University, Ontario, OR.*

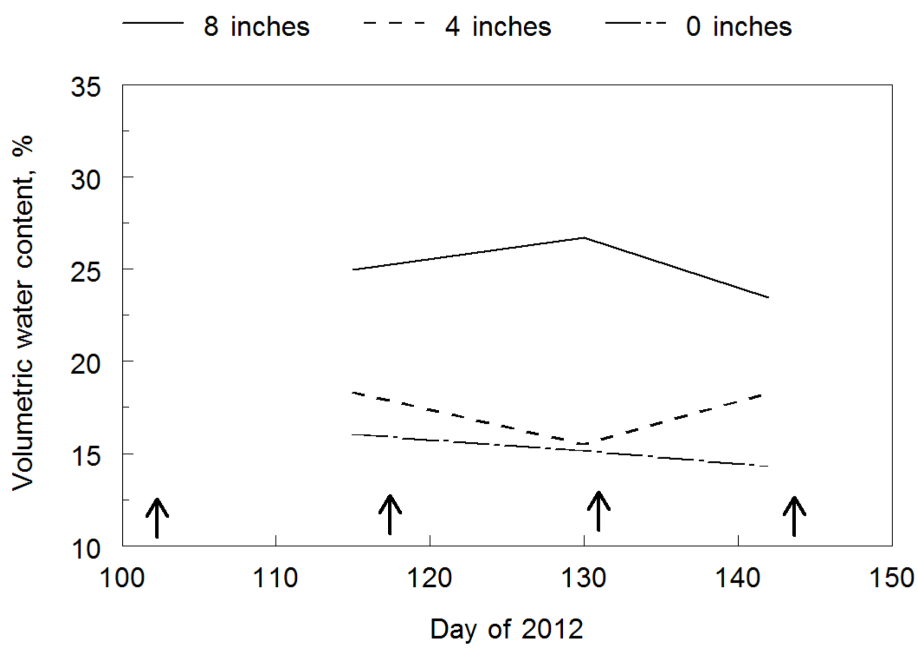

Figure 6. Soil volumetric water content for Lomatium triternatum *over time in 2012. Soil volumetric water content is the combined average at the 8-, 20-, and 32-inch depths. Irrigations started on April 13 and ended on May 24. Arrows denote irrigations.* L. triternatum *was harvested on June 21 (day 172). Malheur Experiment Station, Oregon State University, Ontario, OR.*

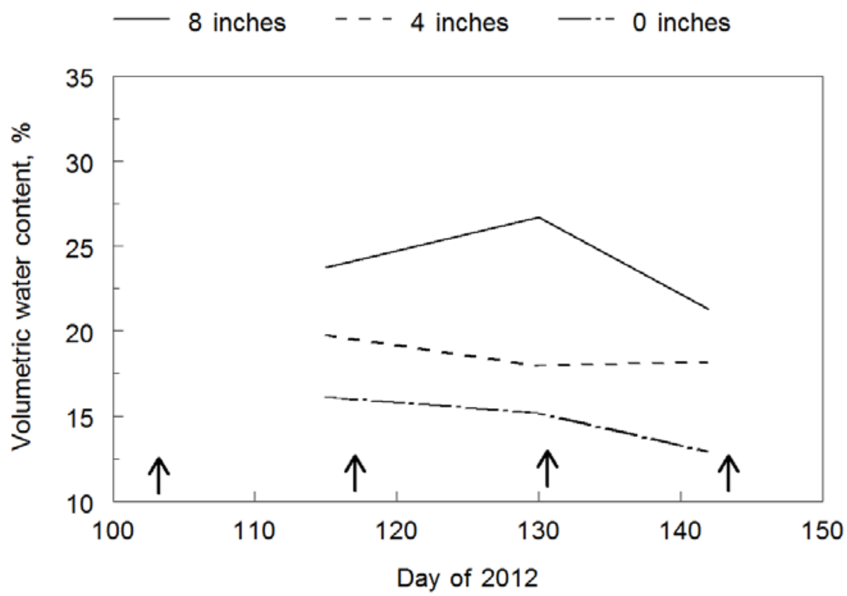

Figure 7. Soil volumetric water content for Lomatium grayi *over time in 2012. Soil volumetric water content is the combined average at the 8-, 20-, and 32-inch depths. Irrigations started on April 13 and ended on May 24. Arrows denote irrigations.* L. grayi *was harvested on June 14 (day 165). Malheur Experiment Station, Oregon State University, Ontario, OR.*

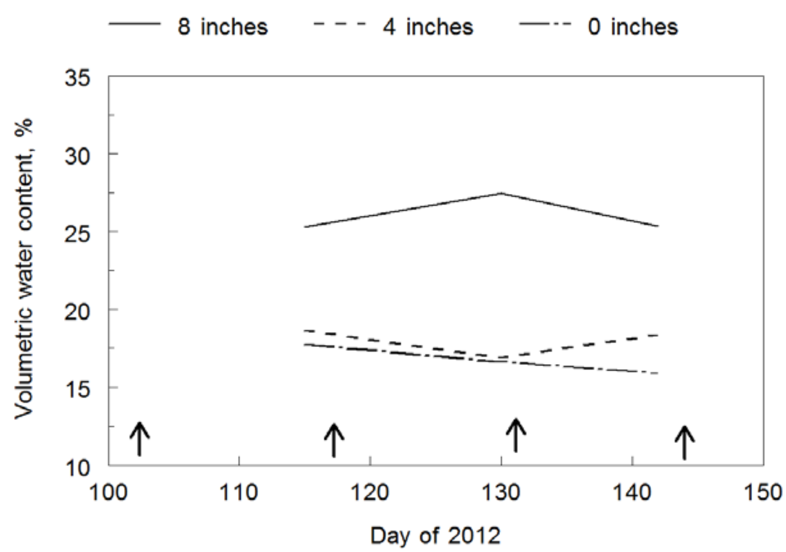

Figure 8. Soil volumetric water content for Lomatium dissectum *over time in 2012. Soil volumetric water content is the combined average at the 8-, 20-, and 32-inch depths. Irrigations started on April 13 and ended on May 24. Arrows denote irrigations.* L. dissectum *was harvested on June 4 (day 155). Malheur Experiment Station, Oregon State University, Ontario, OR.*

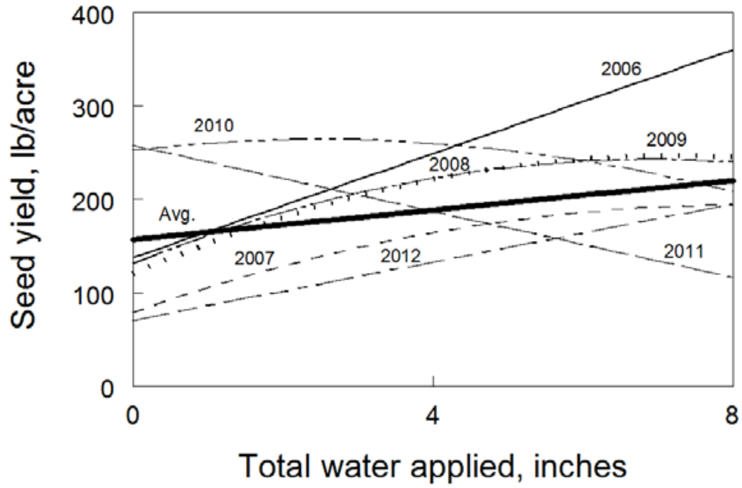

Figure 9. Average annual Eriogonum umbellatum *seed yield response to irrigation water applied in 7 years and averaged over 7 years, Malheur Experiment Station, Oregon State University, Ontario, OR, 2012. Regression equations: 2006, $Y = 137.9 + 27.8X$, $R^2 = 0.68$, $P = 0.01$; 2007, $Y = 79.6 + 28.3X – 1.75X^2$, $R^2 = 0.69$, $P = 0.05$; 2008, $Y = 121.3 + 34.6X – 2.4X^2$, $R^2 = 0.73$, $P = 0.01$; 2009, $Y = 132.3 + 31.9X – 2.3X^2$, $R^2 = 0.60$, $P = 0.05$; 2010, $Y = 252.9 + 9.21X – 1.8X^2$, $R^2 = 0.08$, P = NS; 2011, $Y = 232.7 – 16.0X$, $R^2 = 0.58$, $P = 0.01$; 2012, $71.2 + 15.5X$, $R^2 = 0.61$, $P = 0.01$; 7-year average, $Y = 157.2 + 7.9X$, $R^2 = 0.68$, $P = 0.01$.*

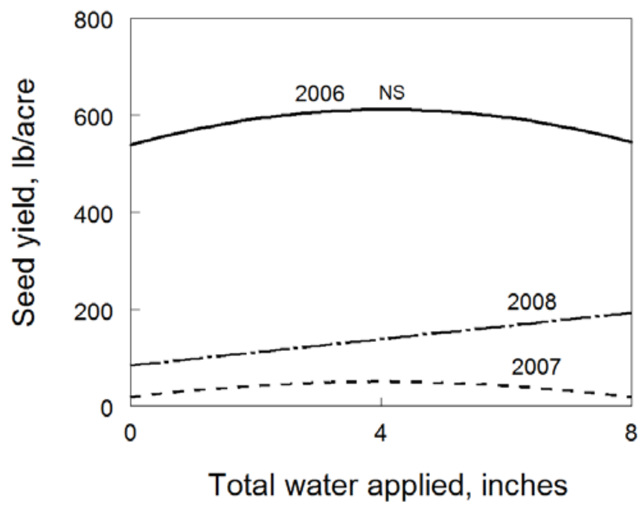

Figure 10. Annual Penstemon acuminatus *seed yield response to irrigation water from 2006 to 2008. Malheur Experiment Station, Oregon State University, Ontario, OR. Regression equations: 2006, $Y = 538.4 + 35.6X – 4.4X^2$, $R^2 = 0.03$, P = NS; 2007, $Y = 19.3 + 15.4X – 1.9X^2$, $R^2 = 0.44$, $P = 0.10$; 2008, $Y = 84.5 + 13.6X$, $R^2 = 0.49$, $P = 0.05$.*

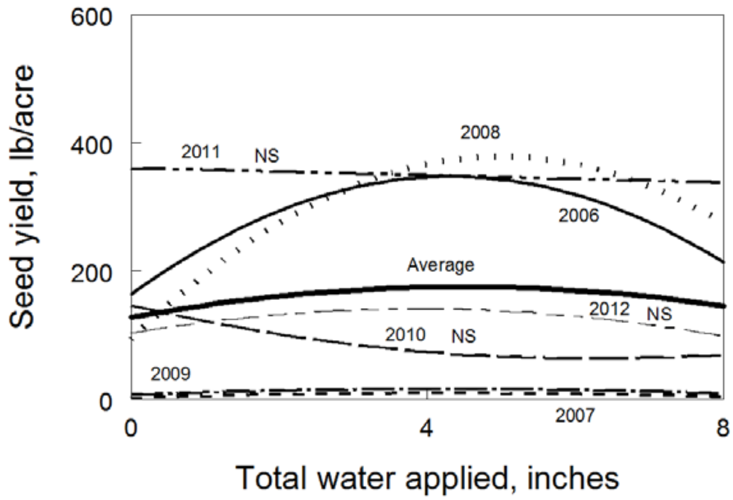

Figure 11. Annual and 7-year (2006-2012) average Penstemon speciosus *seed yield response to irrigation water, Malheur Experiment Station, Oregon State University, Ontario, OR, 2012. Regression equations: 2006, $Y = 163.5 + 85.1X – 9.9X^2$, $R^2 = 0.66$, $P = 0.05$; 2007, $Y = 2.5 + 3.2X – 0.38X^2$, $R^2 = 0.48$, $P = 0.10$; 2008, $Y = 94.1 + 113.7X – 11.4X^2$, $R^2 = 0.56$, $P = 0.05$; 2009, $Y = 6.8 + 4.4X – 0.52X^2$, $R^2 = 0.54$, $P = 0.05$; 2010, $Y = 147.2 + 29.81X – 2.1X^2$, $R^2 = 0.35$, P = NS; 2011, $Y = 360.6 – 2.82X$, $R^2 = 0.01$, P = NS; 2012, $103.8 + 19.3X – 2.5X^2$, $R^2 = 0.30$, P = NS; 7-year average, $Y = 127.8 + 21.2X – 2.4X^2$; $R^2 = 0.37$, P = NS.*

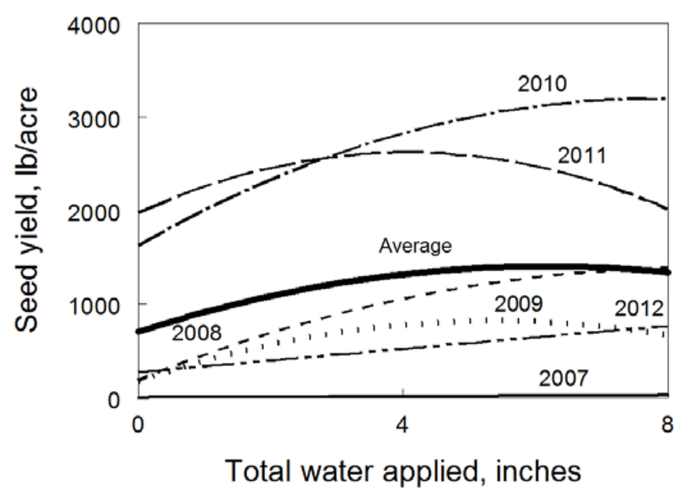

Figure 12. Annual and 6-year (2007-2012) average Lomatium triternatum *seed yield response to irrigation water applied, Malheur Experiment Station, Oregon State University, Ontario, OR, 2012. Regression equations: 2007, $Y = 3.26 + 3.06X$, $R^2 = 0.52$, $P = 0.01$; 2008, $Y = 195.3 + 283.9X – 16.9X^2$, $R^2 = 0.77$, $P = 0.01$; 2009, $Y = 181.6 + 237.4X – 22.0X^2$, $R^2 = 0.83$, $P = 0.001$; 2010, $Y = 1637.2 + 401.5X – 25.9X^2$, $R^2 = 0.83$, $P = 0.001$; 2011, $Y = 1982.932 + 315.1X – 38.7X^2$, $R^2 = 0.45$, $P = 0.10$; 2012, $277.8 + 61.8X$, $R^2 = 0.49$, $P = 0.05$; 6-year average, $Y = 706.3 + 227.1X – 18.5X^2$, $R^2 = 0.80$, $P = 0.001$.*

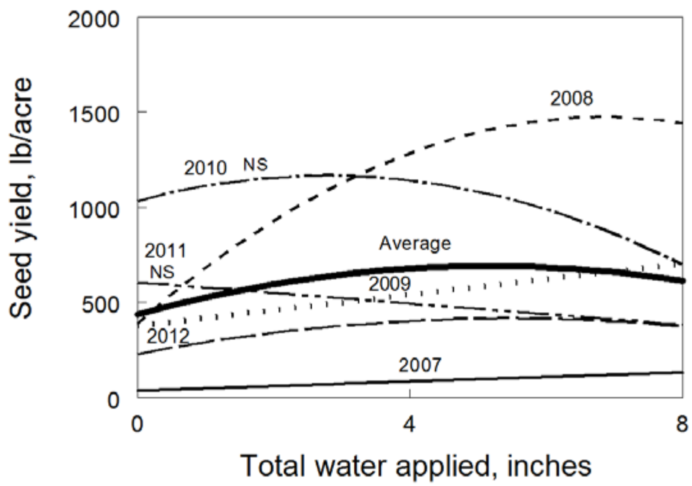

Figure 13. Annual and 6-year (2007-2012) average Lomatium grayi *seed yield response to irrigation water applied, Malheur Experiment Station, Oregon State University, Ontario OR, 2012. Regression equations: 2007, Y = 37.5 + 12.0X, R^2 = 0.26, P = 0.10; 2008, Y = 393.3 + 315.4X – 23.0X^2, R^2 = 0.93, P = 0.001; 2009, Y = 378.7 + 40.8X, R^2 = 0.38, P = 0.05; 2010, Y = 1035.7 + 95.3X – 17.1X^2, R^2 = 0.22, P = NS; 2011, Y = 608.2 – 27.8X, R^2 = 0.07, P = NS; 2012, Y = 231.9 + 68.1X – 6.2X^2, R^2 = 0.66, P = 0.01; 6-year average, Y = 437.9 + 98.5X – 9.5X^2, R^2 = 0.49, P = 0.05.*

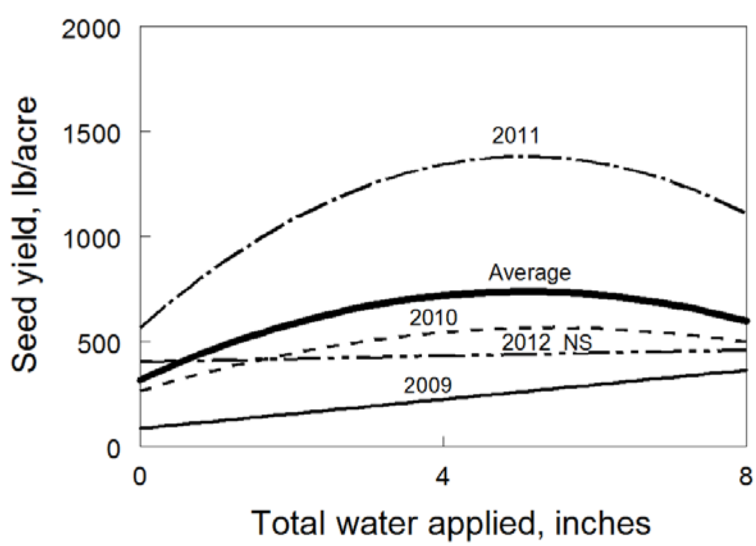

Figure 14. Annual and 4-year (2009-2012) average Lomatium dissectum *seed yield response to irrigation water, Malheur Experiment Station, Oregon State University, Ontario, OR, 2012. Regression equations: 2009, Y = 86.4 + 34.6X, R^2 = 0.31, P = 0.10; 2010, Y = 265.8 + 109.8X – 10.1X^2, R^2 = 0.68, P = 0.01; 2011, Y = 567.5 + 319.3X – 31.4X^2, R^2 = 0.86, P = 0.001; 2012, Y = 402.7 + 7.0X, R^2 = 0.04, P = NS; 4-year average, Y = 318.0 + 165.7X – 16.4X^2, R^2 = 0.79, P = 0.001.*