NATIVE WILDFLOWER SEED PRODUCTION WITH LIMITED SUBSURFACE DRIP IRRIGATION

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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. 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 often not competitive with crop weeds in cultivated fields, which also limits seed production. Both sprinkler and furrow irrigation could promote seed production, but these 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 of the soil surface, we hope to assure flowering and seed set without encouraging weeds or opportunistic diseases. This trial tested the effects of three irrigation intensities on the seed yield of 13 native forb species.

Materials and Methods

Plant Establishment
Seed of the seven Intermountain West forb 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 ensure germination the seed was submitted to a cold stratification treatment. The seed was soaked overnight in distilled water on January 26, 2004, 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 placed in a thin layer in plastic containers. The plastic containers

had lids with holes drilled 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 moist seed. In late February, seed of *Lomatium grayi* and *L. triternatum* had started sprouting.

In late February, 2005 drip tape (T-Tape TSX 515-16-340) was buried at 12-inch depth between two rows (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 disk 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. Thereafter the field was not irrigated.

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 blank lengths of row were replanted by hand in the *Eriogonum 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, plant stand of the replanted species was 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 (Table 1). 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 forbs were flailed. On November 10, 2006 the six forbs were replanted. On November 11, the *Penstemon deustus* plots were replanted at 30 seeds/ft of row.

Table 1. Forb species planted at the Malheur Experiment Station, Oregon State University, Ontario, OR (U.S. Department of Agriculture, Natural Resources Conservation Service. 2009).

Species	Common names
Eriogonum umbellatum	Sulfur-flower buckwheat
Penstemon acuminatus	Sharpleaf penstemon, sand-dune penstemon
Penstemon deustus	Scabland penstemon, hot-rock 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
Astragalus filipes	Basalt milkvetch

Irrigation for Seed Production
In April, 2006 the field was divided into plots 30 ft long. Each plot contained 4 rows each of *Eriogonum umbellatum, P. acuminatus, P. speciosus, P. deustus, L. dissectum, L. triternatum, and L. grayi.* The experimental design was a randomized complete block with four replicates. The three irrigation treatments were a non-irrigated check, 1 inch per irrigation, and 2 inches per irrigation. Each treatment received four irrigations that were applied approximately every 2 weeks starting with flowering of the forbs. The amount of water applied to each treatment was measured by a water meter and recorded after each irrigation to ensure correct water applications (Table 4).

In March of 2007, the drip-irrigation system was modified to allow separate irrigation of the species due to different growth habits. 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 forbs.

Irrigation dates can be found in Table 3 and irrigation amounts in Table 4. In 2007, irrigation treatments were inadvertently continued after the four irrigations were applied, as in 2006. Irrigation treatments for all species were continued until the last irrigation on June 24 in 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. The regression equations were then used to transform the neutron probe readings during the season into volumetric soil water content.

Flowering, Harvesting, and Seed Cleaning
Flowering dates for each species are found in Table 2. The *Eriogonum umbellatum* and *Penstemon* spp. plots produced seed in 2006, probably because they had emerged in the spring of 2005. 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. Each year, the middle two rows of each plot were harvested when seed of each species was mature (Table 2) using the methods listed on Table 3.

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 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.

Cultural Practices in 2007
Penstemon acuminatus and *P. speciosus* were sprayed with Aza-Direct® at 0.0062 lb ai/acre on May 14 and May 29 for lygus bug control. All plots of the three *Sphaeralcea* species 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 0.1lb ai/acre was sprayed on all plots of *Penstemon acuminatus* and *P. speciosus* on May 20 for lygus bug control.

Table 2. Native forb 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
Penstemon acuminatus	1	combine[c]	none	combine	mechanical
Penstemon deustus	1	combine[a]	mechanical[d]	hand[e]	mechanical
Penstemon speciosus[f]	1	combine[c]	none	combine	mechanical
Lomatium dissectum	0	na	na	na	na
Lomatium triternatum	2	hand	hand	none	mechanical
Lomatium grayi	2	hand	hand	none	mechanical
Sphaeralcea parvifolia	1 – 3	hand or combine[c]	none	combine	none
Sphaeralcea grossulariifolia	1 – 3	hand or combine[c]	none	combine	none
Sphaeralcea coccinea	1 – 3	hand or combine[c]	none	combine	none
Dalea searlsiae	0 or 2	hand	none	dewinger	mechanical
Dalea ornate	0 or 2	hand	none	dewinger	mechanical

[a] Wintersteiger Nurserymaster small-plot combine with dry bean concave.
[b] Specialized seed threshing machine at USDA Lucky Peak Nursery. In 2007 and 2008, an adjustable hand-driven corn grinder was used to thresh seed.
[c] Wintersteiger Nurserymaster small-plot combine with alfalfa seed concave. For the *Sphaeralcea* species, flailing in the fall of 2007 resulted in more compact growth and one combine harvest in 2008.
[d] Clipper seed cleaner.
[e] Hard seed pods were broken by rubbing against a ribbed rubber mat.
[f] Harvested by hand in 2007 due to poor seed set.

Table 3. Native forb flowering, irrigation, and seed harvest dates by species in 2006, 2007, and 2008, Malheur Experiment Station, Oregon State University, Ontario, OR.

	Flowering			Irrigation		
Species	start	peak	end	start	end	Harvest
				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				

Results and Discussion

The soil volumetric water content responded to the irrigation treatments (Figs. 1-5).

Flowering and Seed Set

Emergence for the two prairie clover (*Dalea* spp.) species in the spring of 2007 was again poor. Emergence for *Penstemon deustus* and for basalt milkvetch (*Astragalus filipes*) was extremely poor; *A. filipes* produced negligible amounts of seed in 2007.

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 indicate that the first lygus bug hatch occurred on May 14 in 2006, on May 1 in 2007, and on May 18 in 2008. *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 in 2006 or 2008. Poor seed set for *P. acuminatus* and *P. speciosus* also was related to poor vegetative growth in 2007 compared to 2006 and 2008.

The three *Sphaeralcea* species (globemallow) showed a long flowering period (early May through September) in 2007. Multiple harvests were necessary because the seed falls out of the capsules once they are mature. The flailing of the three *Sphaeralcea* species in the fall of 2007 resulted in a more concentrated flowering in 2008, which allowed one mechanical harvest.

Seed Yields

In 2006, seed yield of *Eriogonum umbellatum* increased with increasing water application, up to 8 inches, the highest amount tested (Table 5, Fig. 6). In 2007 and 2008, seed yield showed a quadratic response to irrigation rate (Table 5, Figs. 7-8). Seed yields were maximized by 8.1 inches and 7.2 inches of water applied in 2007 and 2008, respectively. Averaged over 3 years, seed yield of *Eriogonum umbellatum* increased with increasing water applied up to 8 inches, the highest amount tested (Fig. 9).

There was no significant difference in seed yield between irrigation treatments for *Penstemon 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 and 2008, seed yield showed a quadratic response to irrigation rate (Table 5, Figs. 10-11). Seed yields were maximized by 4.0 and 8.5 inches of water applied in 2007 and 2008, respectively.

In 2006, 2007, and 2008, seed yield of *Penstemon speciosus* showed a quadratic response to irrigation rate (Table 5, Figs. 12-14). Seed yields were maximized by 4.3, 4.2, and 5.0 inches of water applied in 2006, 2007, and 2008, respectively. Averaged over 3 years, seed yield of *Penstemon speciosus* was maximized by 4.8 inches of water applied (Fig. 15).

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 in plots with very low and uneven stands.

Of the three *Lomatium* species, *L. grayi* had the most vigorous vegetative growth in 2007 and 2008. *L. dissectum* had very poor vegetative growth in 2006, 2007, and 2008, and produced only very small amounts of flowers in 2008. *Lomatium grayi* and *L. triternatum* showed a trend for increasing seed yield with increasing irrigation rate in 2007. The highest irrigation rate resulted in significantly higher seed yield than the nonirrigated check. Seed yields of *L. grayi* and *L. triternatum* were substantially higher in 2008. In 2008, seed yields of *L. grayi* and *L. triternatum* showed a quadratic response to irrigation rate (Table 5, Figs. 16-17). Seed yields were maximized by 8.4 and 6.9 inches of water applied in 2008 for *L. triternatum* and *L. grayi*, respectively. Averaged over 2 years, seed yield of *L. triternatum* and *L. grayi* were maximized by 8.5 and 7.1 inches of water applied, respectively.

In 2007 and 2008, there was no significant difference in seed yield among irrigation treatments for the three *Sphaeralcea* species, with *S. parvifolia* having the highest seed yield. Seed yields for the three *Sphaeralcea* species were lower in 2008 than 2007.

In 2007, there was no significant difference in seed yield among irrigation treatments for the two *Dalea* species, with *D. ornata* having the highest seed yield. Emergence for the two *Dalea* species was poor, and plots had poor and uneven stands. The stand of the three *Dalea* species declined and was too poor for seed harvest in 2008. The three *Dalea* species were replanted in the fall of 2008.

Conclusions

Subsurface drip irrigation systems are being 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.

Knowledge about native forb seed production would help make commercial production of this seed feasible. Irrigation methods are being developed at the Oregon State University Malheur Experiment Station to help assure reliable seed production with reasonably high seed yields. Growers need to have economic return on their seed plantings, but forbs may not produce seed every year. Due to the arid environment, supplemental irrigation may be often required for successful flowering and seed set because soil water reserves may be exhausted before seed formation. The total irrigation water requirements for these arid-land species has been shown to be low, but it varied by species.

References

USDA, NRCS. 2009. The PLANTS Database (http://plants.usda.gov, 13 March 2009). National Plant Data Center, Baton Rouge, LA 70874-4490 USA.

Table 4. Irrigation treatments and actual amounts of water applied to native forbs in 2006, 2007, and 2008. Malheur Experiment Station, Oregon State University, Ontario, OR.

		Actual amount of water applied				
	Irrigation	*Lomatium* spp.	*Penstemon deustus*	*Penstemon* spp.	*Eriogonum umbellatum*	*Sphaeralcea* spp.
Date	inches per irrigation					
2006						
19 May	2	2.23	2.23	2.23	2.23	
19 May	1	1.31	1.31	1.31	1.31	
2 Jun	2	2.16	2.16	2.16	2.16	
2 Jun	1	1.23	1.23	1.23	1.23	
20 Jun	2	2.04	2.04	2.04	2.04	
20 Jun	1	1.23	1.23	1.23	1.23	
30 Jun	2	2.26	2.26	2.26	2.26	
30 Jun	1	1.12	1.12	1.12	1.12	
total	2	8.69	8.69	8.69	8.69	
total	1	4.89	4.89	4.89	4.89	
2007						
5 Apr	2	2.00				
5 Apr	1	1.28				
19 Apr	2	2.78	2.78			
19 Apr	1	1.34	1.34			
2 May	2	2.70	2.70	2.70	2.70	
2 May	1	1.40	1.40	1.40	1.40	
16 May	2	2.62	2.62	2.62	2.62	2.62
16 May	1	1.42	1.42	1.42	1.42	1.42
30 May	2	2.49	2.49	2.49	2.49	2.49
30 May	1	1.22	1.22	1.22	1.22	1.22
10 Jun	2	2.46	2.46	2.46	2.46	2.46
10 Jun	1	1.09	1.09	1.09	1.09	1.09
24 Jun	2	2.59	2.59	2.59	2.59	2.59
24 Jun	1	1.41	1.41	1.41	1.41	1.41
total	2	17.6	15.6	12.9	12.9	10.2
total	1	9.2	7.9	6.5	6.5	5.1
2008						
10-Apr	2	2.34				
10-Apr	1	1.81				
29-Apr	2	2.02	2.02	2.02		
29-Apr	1	1.02	1.02	1.02		
15-May	2	2.09	2.09	2.09	2.09	2.09
15-May	1	1.10	1.10	1.10	1.10	1.10
29-May	2	2.15	2.15	2.15	2.15	2.15
29-May	1	1.48	1.48	1.48	1.48	1.48
11-Jun	2		2.06	2.06	2.06	2.06
11-Jun	1		1.16	1.16	1.16	1.16
24-Jun	2				2.10	2.10
24-Jun	1				1.00	1.00
total	2	8.59	8.31	8.31	8.38	8.38
total	1	5.41	4.75	4.75	4.74	4.74

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

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											
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	1287.0	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
Dalea searlsiaee[e]					11.5	10.2	16.4	NS	---- very poor stand ----			
Dalea ornatae[e]					47.4	27.3	55.6	NS	---- very poor stand ----			

[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.

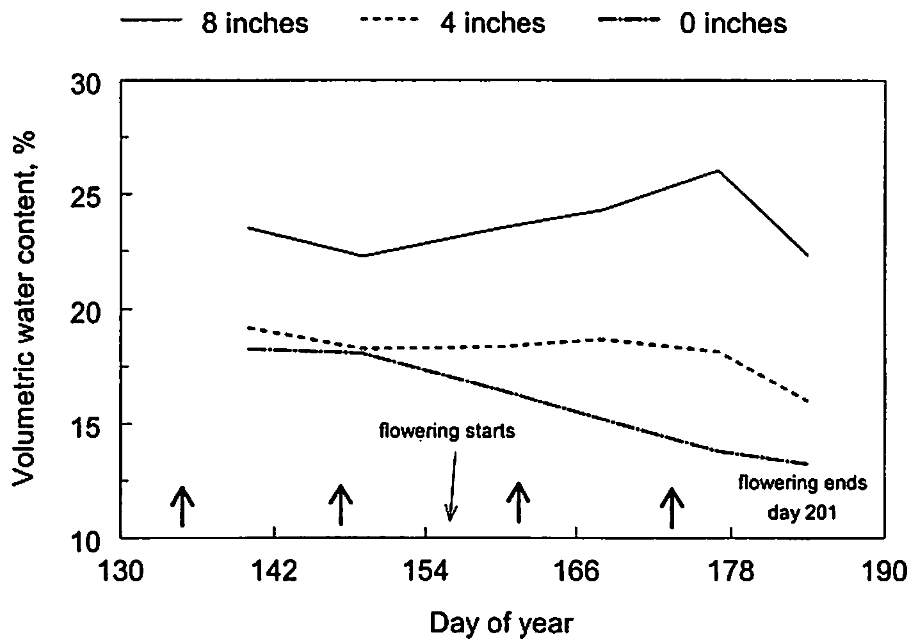

Figure 1. Soil volumetric water content for *Eriogonum umbellatum* over time in 2008. Soil volumetric water content is the combined average at the 8-, 20-, and 32-inch depths. Irrigations started on May 15 and ended on June 24. Arrows denote irrigations. *E. umbellatum* was harvested on July 24 (day 205). Malheur Experiment Station, Oregon State University, Ontario, OR, 2008.

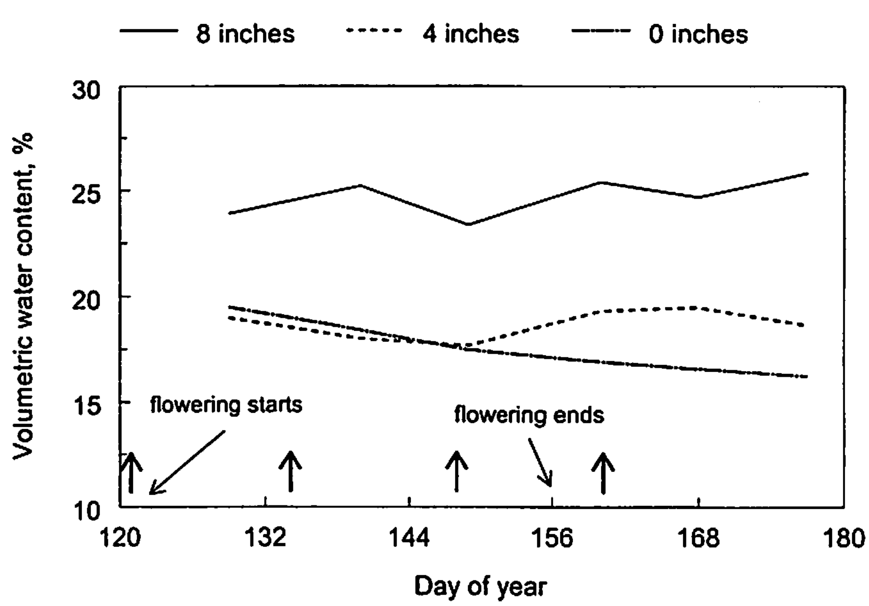

Figure 2. Soil volumetric water content for *Penstemon acuminatus* over time in 2008. Soil volumetric water content is the combined average at the 8-, 20-, and 32-inch depths. Irrigations started on April 29 and ended on June 11. Arrows denote irrigations. *P. acuminatus* was harvested on July 11 (day 192). Malheur Experiment Station, Oregon State University, Ontario, OR, 2008.

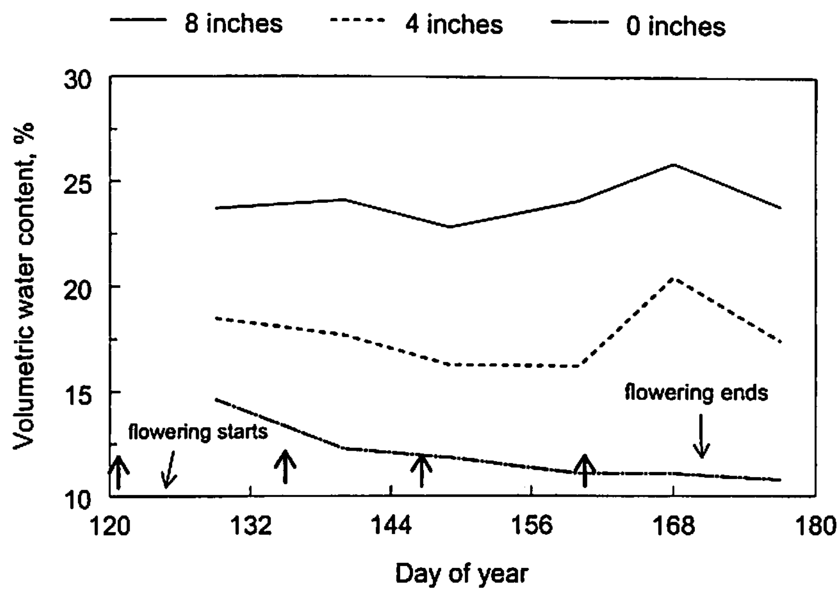

Figure 3. Soil volumetric water content for *Penstemon speciosus* over time in 2008. Soil volumetric water content is the combined average at the 8-, 20-, and 32-inch depths. Irrigations started on April 29 and ended on June 11. Arrows denote irrigations. *P. speciosus* was harvested on July 17 (day 198). Malheur Experiment Station, Oregon State University, Ontario, OR, 2008.

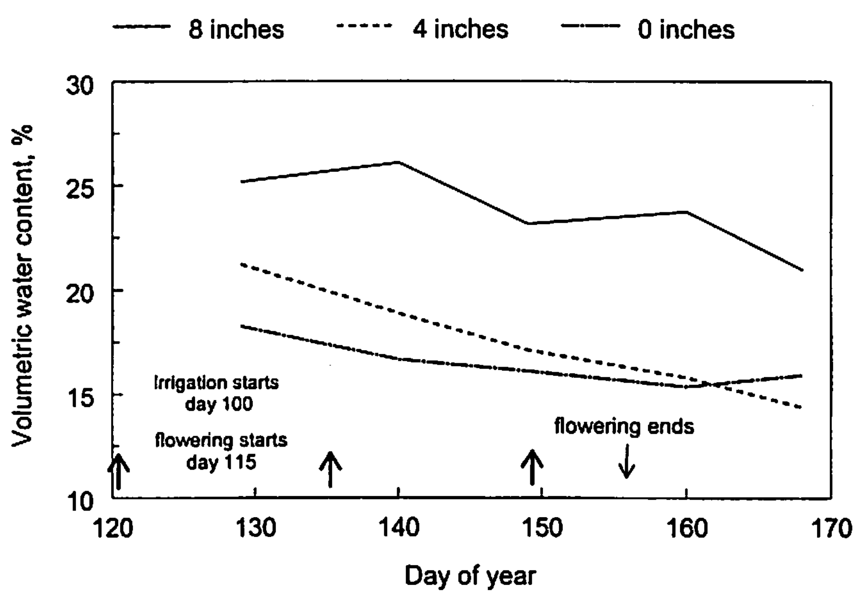

Figure 4. Soil volumetric water content for *Lomatium triternatum* over time in 2008. Soil volumetric water content is the combined average at the 8-, 20-, and 32-inch depths. Irrigations started on April 10 and ended on May 29. Arrows denote irrigations. *L. triternatum* was harvested on July 3 (day 184). Malheur Experiment Station, Oregon State University, Ontario, OR, 2008.

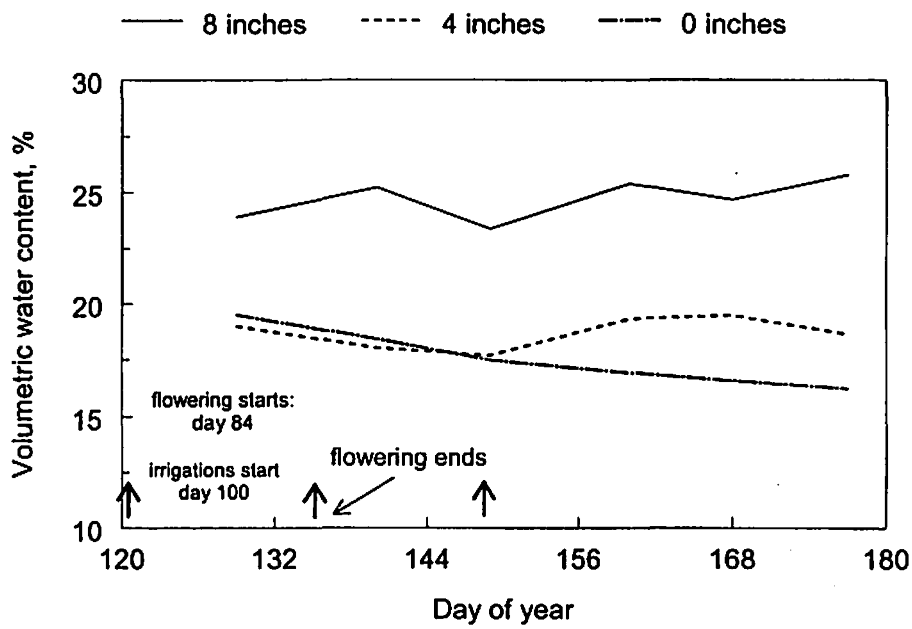

Figure 5. Soil volumetric water content for *Lomatium grayi* over time in 2008. Soil volumetric water content is the combined average at the 8-, 20-, and 32-inch depths. Irrigations started on April 10 and ended on May 29. Arrows denote irrigations. *L. grayi* was harvested on May 30 (day 151) and June 19 (day 170). Malheur Experiment Station, Oregon State University, Ontario, OR, 2008.

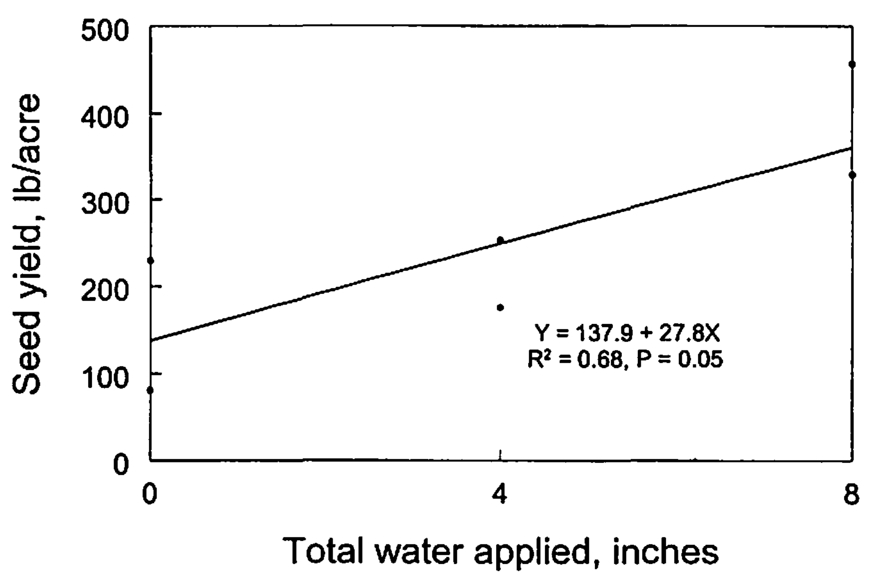

Figure 6. *Eriogonum umbellatum* seed yield response to irrigation water applied in 2006. Malheur Experiment Station, Oregon State University, Ontario, OR, 2008.

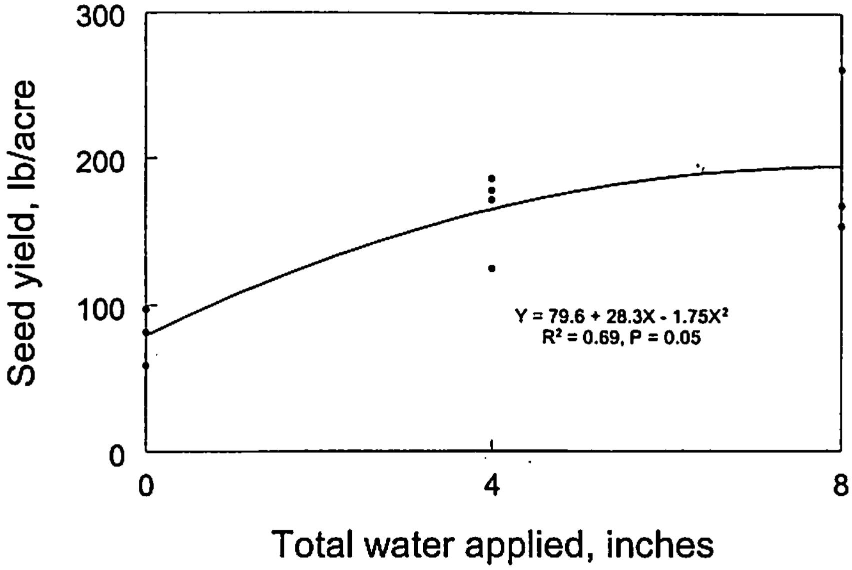

Figure 7. *Eriogonum umbellatum* seed yield response to irrigation water applied in 2007. Malheur Experiment Station, Oregon State University, Ontario, OR, 2008.

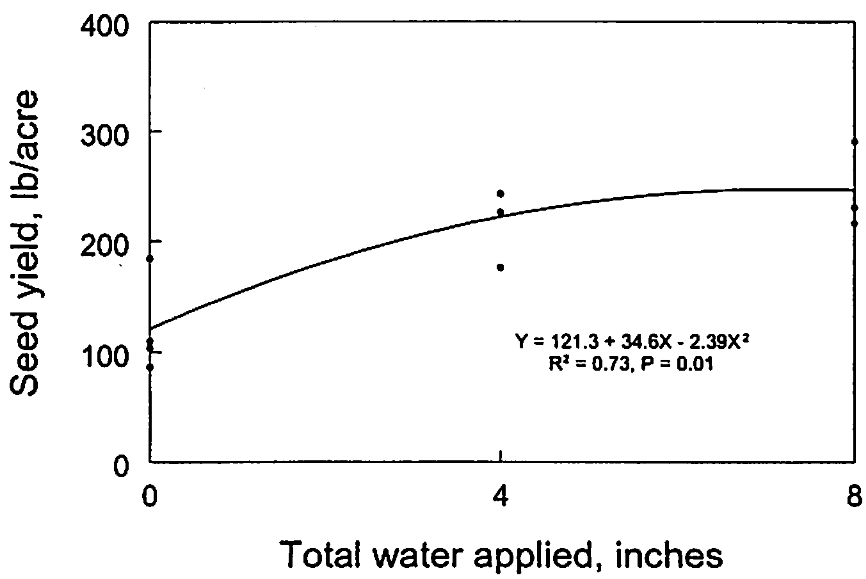

Figure 8. *Eriogonum umbellatum* seed yield response to irrigation water applied in 2008. Malheur Experiment Station, Oregon State University, Ontario, OR, 2008.

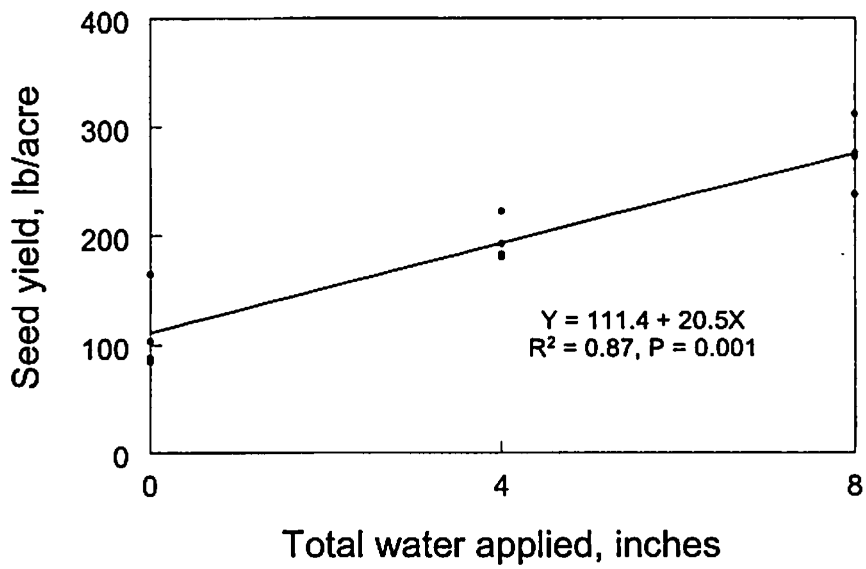

Figure 9. Average annual *Eriogonum umbellatum* seed yield response to irrigation water applied averaged over 3 years, Malheur Experiment Station, Oregon State University, Ontario, OR, 2008.

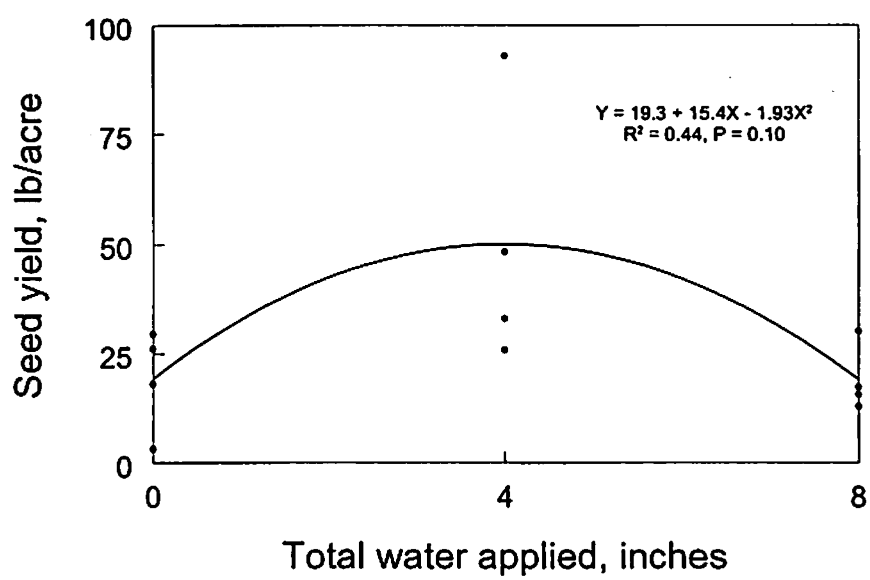

Figure 10. *Penstemon acuminatus* seed yield response to irrigation water applied in 2007, Malheur Experiment Station, Oregon State University, Ontario, OR, 2008.

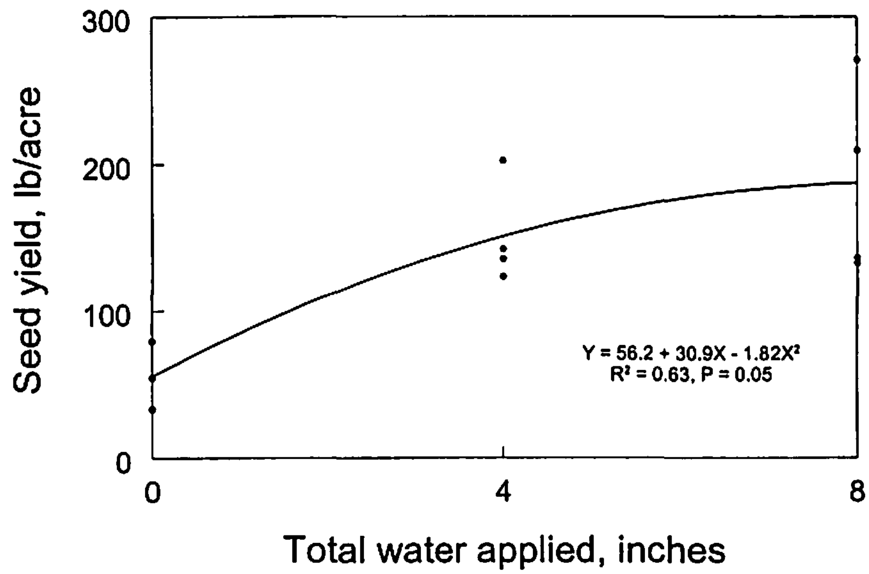

Figure 11. *Penstemon acuminatus* seed yield response to irrigation water applied in 2008, Malheur Experiment Station, Oregon State University, Ontario, OR, 2008.

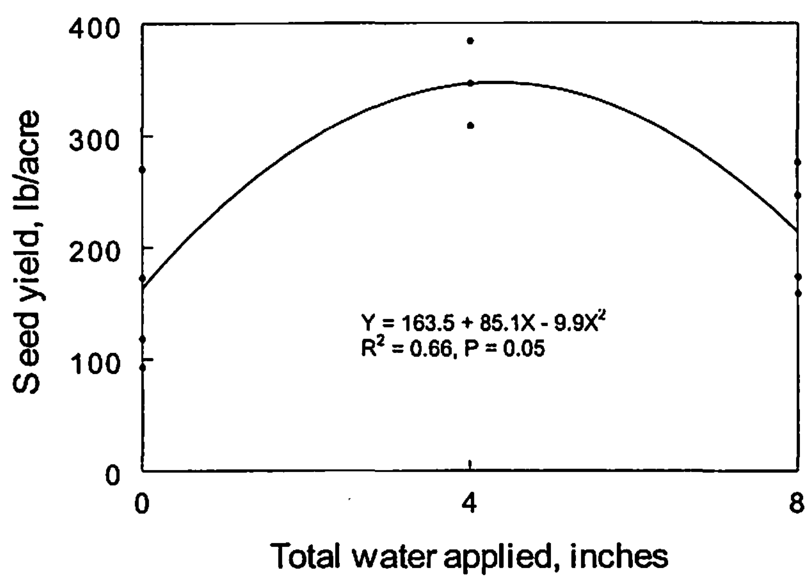

Figure 12. *Penstemon speciosus* seed yield response to irrigation water applied in 2006, Malheur Experiment Station, Oregon State University, Ontario, OR, 2008.

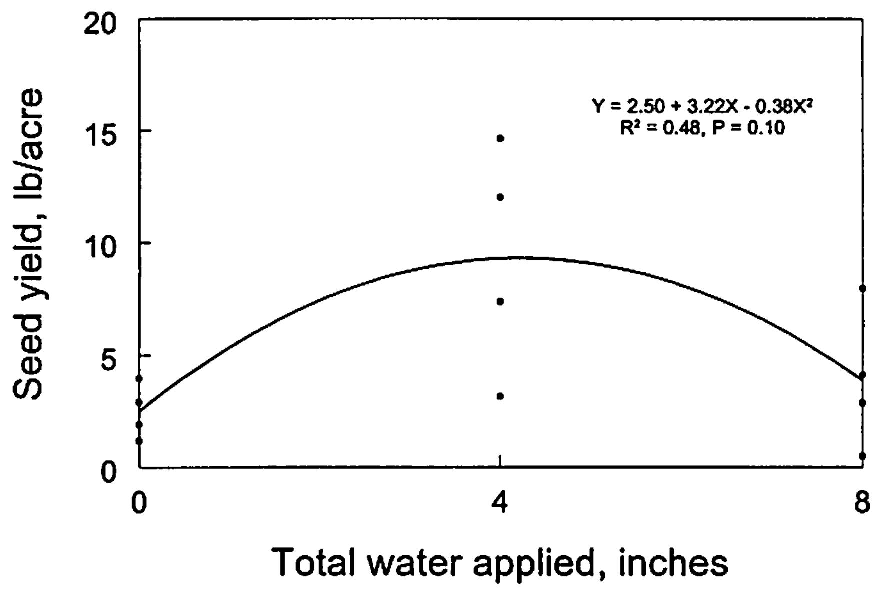

Figure 13. *Penstemon speciosus* seed yield response to irrigation water applied in 2007, Malheur Experiment Station, Oregon State University, Ontario, OR, 2008.

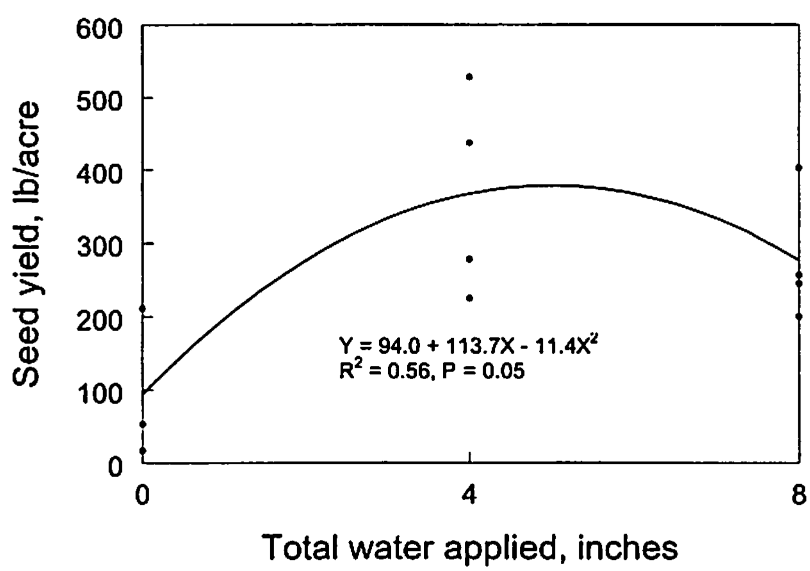

Figure 14. *Penstemon speciosus* seed yield response to irrigation water applied in 2008, Malheur Experiment Station, Oregon State University, Ontario, OR, 2008.

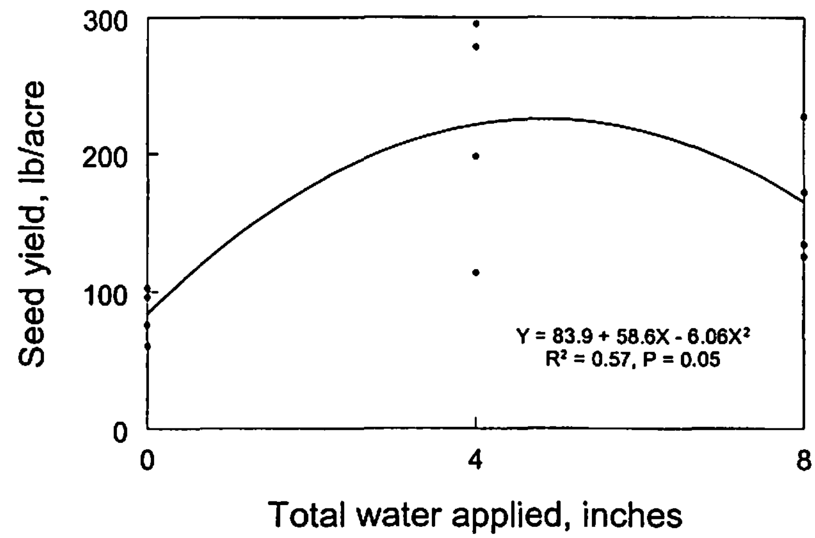

Figure 15. Average annual *Penstemon speciosus* seed yield response to irrigation water applied averaged over 3 years, Malheur Experiment Station, Oregon State University, Ontario, OR, 2008.

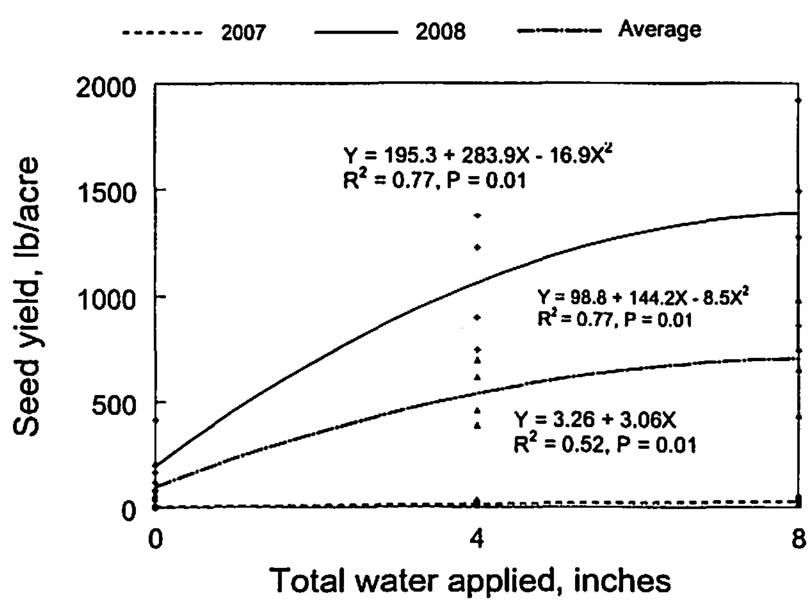

Figure 16. Annual and 2-year average *Lomatium triternatum* seed yield response to irrigation water applied, Malheur Experiment Station, Oregon State University, Ontario, OR, 2008.

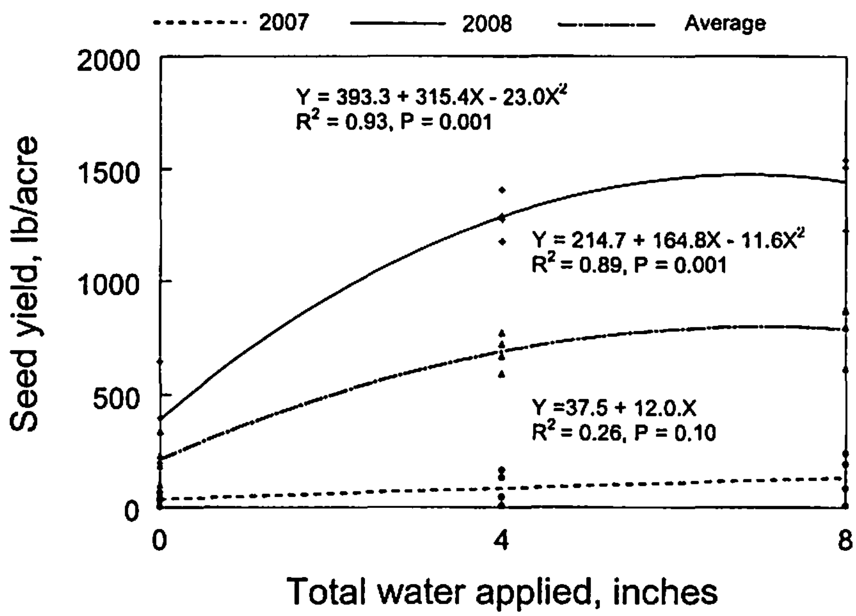

Figure 17. Annual and 2-year average *Lomatium grayi* seed yield response to irrigation water applied, Malheur Experiment Station, Oregon State University, Ontario, OR, 2008.