IRRIGATION REQUIREMENTS FOR SEED PRODUCTION OF FIVE NATIVE *PENSTEMON* SPECIES

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Summary

Penstemon is an important wildflower genus in the Great Basin of the United States. Seed of *Penstemon* species is desired for rangeland restoration activities, but little cultural practice information is known for seed production of native penstemons. The seed yield response of five *Penstemon* species to four biweekly irrigations applying either 0, 1, or 2 inches of water (a total of 0, 4, or 8 inches of water/season) was evaluated over multiple years. *Penstemon acuminatus* (sharpleaf penstemon) seed yields were maximized by 4 to 8 inches of water applied per season in warmer, drier years and did not respond to irrigation in cooler, wetter years. In 10 years of testing, *P. pachyphyllus* (thickleaf beardtongue) seed yields responded to irrigation only in years with lower than average precipitation (2013 and 2018), with 8 inches of water applied maximizing yields. In 10 years of testing, *P. cyaneus* (blue penstemon) responded to irrigation only in 2013, with 4 inches of water applied maximizing yield. In 10 years of testing, seed yields of *P. deustus* (scabland penstemon) responded to irrigation only in 2015, with highest yields resulting from 5.4 inches of water applied. From 2006 through 2020, *P. speciosus* (royal penstemon) showed a quadratic response to irrigation plus spring precipitation in 9 out of 15 years. *Penstemon speciosus* showed either no response or a negative response to irrigation in 3 years with higher than average spring precipitation and showed a linear positive response to irrigation in 2013, the year with the lowest precipitation. Averaged over the 15 years of testing, *P. speciosus* seed yields were maximized by 7.7 inches of water applied plus spring precipitation. Irrigation at the highest rate tested, 8 inches per year, resulted in significantly higher stand loss than irrigation at 0 or 4 inches per year for *P. speciosus, P. acuminatus,* and *P. cyaneus.*

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 variation in spring rainfall and soil moisture results in highly variable water stress at flowering, seed set, and seed development. Such stresses for other seed crops are known to compromise seed yield and quality.

Native wildflower plants are not well adapted to croplands; they often do not compete with crop weeds in cultivated fields, and this could 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 designed experiments to assure water availability for 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 five species of *Penstemon* native to the Intermountain West (Table 1).

Table 1. *Penstemon* species planted in drip-irrigation trials, Malheur Experiment Station, Oregon State University, Ontario, OR.

Species	Common names
Penstemon acuminatus	sharpleaf penstemon, sand-dune penstemon
Penstemon cyaneus	blue penstemon
Penstemon deustus	scabland penstemon, hotrock penstemon
Penstemon pachyphyllus	thickleaf beardtongue
Penstemon speciosus	royal penstemon, sagebrush penstemon

Materials and Methods

Penstemon acuminatus, *P. deustus*, and *P. speciosus*

Seed of *P. acuminatus, P. deustus,* and *P. speciosus* 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, 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 minutes 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 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, the seed was planted in 30-inch rows using a custom-made, small-plot grain drill with disc openers. All seed was planted at 20 to 30 seeds/ft of row. The seed was planted at 0.25-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 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. Seed emerged by late April. Starting June 24, the field was irrigated with the drip system for stand establishment. 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 were uneven. 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 on October 26, 2005, and fall and winter moisture was allowed to germinate the seed. In the spring of 2006, the plant stands of the replanted species were excellent, except for *P. deustus*. On November 11, 2006, the *P. deustus* plots were replanted again at 30 seeds/ft of row.

Stands of *P. speciosus* planted in 2006 regenerated by natural reseeding, but replanting was required in 2015 due to excessive die-off, especially in the plots with the highest irrigation rate. On November 2, 2015, seed of *P. speciosus* was planted on the soil surface at 30 seeds/ft of row. Stand of *P. speciosus* in the spring of 2016 was adequate after fall planting in 2015.

All plots of *P. deustus* were disked out in 2008 due to substantial stand loss after 2 years of seed production. Due to substantial stand loss, all plots of *P. acuminatus* were disked out in 2010.

Irrigations for each species were initiated and terminated on different dates (Table 2).

Weeds were controlled in the first year after fall planting by hand weeding. In subsequent years, weeds were controlled by yearly applications of pendimethalin (Prowl®, a soil-active herbicide), the grass herbicides sethoxydim (Poast®) and clethodim (Select Max® and Volunteer®), and hand weeding. All plots had Prowl at 1 lb ai/acre broadcast on the soil surface for weed control on November 17, 2006, November 9, 2007, April 15, 2008, March 18, 2009, December 4, 2009, November 17, 2010, November 9, 2011, October 27, 2016, and October 19, 2017. Prowl was not applied after 2011 to encourage natural reseeding. While natural reseeding might be advantageous for maintaining stands for irrigation research, it might be disadvantageous for seed production because of changes in the genetic composition of the stand over time. On March 18, 2009, Volunteer at 0.24 lb ai/acre was broadcast on all plots. On April 3, 2013, Select Max at 0.5 lb ai/acre was broadcast on all plots of *P. speciosus*. On March 2, 2016, Poast at 0.35 lb ai/acre was broadcast on all plots.

Penstemon acuminatus and *P. speciosus* were sprayed with Aza-Direct® at 0.0062 lb ai/acre on May 14 and 29, 2007, and Capture® 2EC at 0.1 lb ai/acre on May 20, 2008, for lygus bug control. On April 18, 2014, and April 20, 2015, Orthene® at 8 oz/acre was broadcast on all plots of *P. speciosus* for lygus bug control.

Fertilization was modest and was the same for all plots of all species. 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 each species. On April 29, 2014, 5 lb iron (Fe)/acre was applied through the drip tape to all plots of *P. speciosus*.

Penstemon cyaneus, *P. deustus*, and *P. pachyphyllus*

On November 25, 2009, seed of *P. cyaneus, P. deustus,* and *P. pachyphyllus* was planted in 30-inch rows using a custom-made, small-plot grain drill with disc openers. All seed was planted on the soil surface at 20 to 30 seeds/ft of row. After planting, sawdust was applied in a narrow band over the seed row at 0.26 oz/ft (558 lb/acre). Following planting and sawdust application, the beds were covered with row cover. The row cover (N-Sulate, DeWitt Co. Inc., Sikeston, MO) covered four rows (two beds) and was applied with a mechanical plastic mulch layer. The field was irrigated for 24 hours on December 2, 2009, due to very dry soil conditions. After the newly planted wildflowers had emerged, the row cover was removed in April of 2010. The irrigation treatments were not applied to these wildflowers in 2010.

Stands of *P. cyaneus* and *P. pachyphyllus* were not adequate for yield estimates. Gaps in the rows were replanted by hand on November 5, 2010. The replanted seed was covered with a thin layer of 50% sawdust and 50% hydroseeding mulch (Hydrostraw LLC, Manteno, IL) by volume. The mulch mixture was sprayed with water using a backpack sprayer.

A substantial amount of plant death occurred in the *P. deustus* plots during the winter and spring of 2011–2012. For *P. deustus*, only the undamaged parts in each plot were harvested in 2012. Seed of all species was harvested and cleaned manually. On October 26, 2012, dead *P. deustus* plants were removed and the empty row lengths were replanted by hand at 20 to 30 seeds/ft. After planting, sawdust was applied in a narrow band over the seed row. Following planting and sawdust application, the beds were covered with row cover. The replanted *P. deustus* did not flower in sufficient amounts for a seed harvest in 2013.

Stand of *P. deustus* was poor again at the end of 2015 due to die-off. On November 5, 2015, seed of *P. deustus* was planted on the soil surface at 30 seeds/ft of row. Following planting, the beds were covered with row cover. Stands of *P. cyaneus* and *P. pachyphyllus* are currently poor, but might regenerate from natural reseeding. While natural reseeding might be advantageous for maintaining stands for irrigation research, natural reseeding might be disadvantageous for seed production because of changes in the genetic composition of the stand over time.

Many areas of the wildflower seed production trials were suffering from severe iron deficiency early in the spring of 2012. On April 13, 2012, 50 lb nitrogen/acre, 10 lb P/acre, and 0.3 lb Fe/acre were applied to all plots as liquid fertilizer injected through the drip tape. On April 23, 2012, and April 29, 2014, 0.3 lb Fe/acre was applied to all plots as liquid fertilizer injected through the drip tape.

Weeds were controlled each year by hand weeding. In addition Prowl (pendimethalin) at 1 lb ai/acre was broadcast on all plots for weed control on October 27, 2016. On October 19, 2017, Prowl at 1 lb ai/acre was broadcast on all plots of *P. deustus* for weed control. On November 15, 2019, Prowl at 1 lb ai/acre, Outlook® (dimethenamid-P) at 0.98 lb ai/acre, and Poast (sethoxydim) at 0.38 lb ai/acre were applied to all species.

Irrigation for Seed Production

In April 2006, each planted strip of *P. acuminatus, P. deustus,* and *P. speciosus* 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 non-irrigated check, 1 inch of water applied per irrigation, and 2 inches of water applied per irrigation. Each treatment received four irrigations that were applied approximately every 2 weeks starting with bud formation and flowering (Table 2). 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 their different timings of flowering. *Penstemon deustus* and *P. speciosus* were irrigated together but separately from *P. acuminatus*. 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.

Penstemon cyaneus, P. deustus (second planting), and *P. pachyphyllus* were irrigated together starting in 2011, using the same procedures as previously described.

Flowering, Harvesting, and Seed Cleaning

Flowering dates for each species were recorded (Table 2). Each year, the middle two rows of each plot were harvested when seed of each species was mature (Table 2).

All species were harvested with a Wintersteiger small-plot combine. *Penstemon deustus* seedpods were too hard to be opened in the combine so the unthreshed seed was precleaned in a small Clipper seed cleaner and then seedpods were broken manually by rubbing the pods on a ribbed rubber mat. The seed was then cleaned again in the small Clipper seed cleaner. The other species were threshed in the combine, and the seed was further cleaned using a small Clipper seed cleaner. Seeds of *P. cyaneus, P. pachyphyllus,* and *P. speciosus* were harvested by hand when stands became too poor for combining.

Statistical Analysis

Seed yield means were compared by analysis of variance and by linear and quadratic regression. Seed yield (y) in response to irrigation or irrigation plus precipitation (x, inches/season) was estimated by the equation $y = a + b•x + c•x^2$, where a is the intercept, b is the linear parameter, and c is the quadratic parameter. For the quadratic equations, the amount of irrigation (x′) that resulted in maximum yield (y′) was calculated using the formula $x' = -b/2c$. For the linear regressions, the seed yield responses to irrigation were based on the actual greatest amount of water applied plus precipitation and the measured average seed yield.

For *P. speciosus,* seed yields for each year were regressed separately against 1) applied water; 2) applied water plus spring precipitation; 3) applied water plus winter and spring precipitation; and 4) applied water plus fall, winter, and spring precipitation. Winter and spring precipitation occurred in the same year that yield was determined; fall precipitation used in the calculations occurred the prior year. Adding seasonal precipitation to the irrigation response equation could potentially provide a closer estimate of the amount of water required for maximum seed yields for *P. speciosus*.

Regressions of seed yield each year were calculated on all the sequential seasonal amounts of precipitation and irrigation, but only some of the regressions are reported below. The period of precipitation plus applied water that had the lowest standard deviation for irrigation plus precipitation over the years was chosen as the most reliable independent variable for predicting seed yield. For species other than *P. speciosus*, there were few years where a yield response to irrigation existed, so yield responses only to water applied are reported.

Results and Discussion

Precipitation showed large year-to-year variation over the 15 years of irrigation trials (Table 3). The accumulated growing degree-days (50–86°F) from January through July in 2006, 2007, 2013–2016, and 2018 were higher than average (Table 3).

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 (Table 2). 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.

Seed Yields

Penstemon speciosus, **royal penstemon**

In 2006–2009, 2012, 2014, 2015, 2018, and 2020, seed yield of *P. speciosus* showed a quadratic response to irrigation rate plus spring precipitation (Tables 4 and 5). Seed yields were maximized by 7.7, 6.1, 6.4, 8.3, 6.5, 6.9, 8.2, 7.0, and 8.8 inches of water applied plus spring precipitation in 2006, 2007, 2008, 2009, 2012, 2014, 2015, 2018, and 2020, respectively. In 2011, 2017, and 2019, there was no difference in seed yield between treatments. In 2010, seed yields were highest with no irrigation and 4.3 inches of spring precipitation. The years 2010, 2011, 2017, and 2019 had higher than average spring precipitation (Table 3). In 2013, seed yield increased with increasing water application, up to 8.9 inches, the highest amount tested (includes 0.9 inches of spring precipitation). 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 non-irrigated plots. The replanting of *P. speciosus* in the fall of 2015 resulted in a good stand in 2016. The new stand of *P. speciosus* did not flower in 2016. In 2019, stands were observed to have deteriorated, especially in the plots with the highest irrigation amounts. A subjective evaluation showed 88, 73, and 43% stand for the non-irrigated, 4 inches/year, and 8 inches/year treatments, respectively, indicating the negative effect of higher amounts of irrigation on stand longevity (LSD 0.05 = 29).

Penstemon acuminatus, **sharpleaf penstemon**

There was no significant difference in seed yield between irrigation treatments for *P. acuminatus* in 2006 (Tables 4 and 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 4.1 inches of water applied in 2007. In 2008, seed yield showed a linear response to applied water. In 2009 seed yield showed a negative response to irrigation. The negative effects of irrigation in 2009 were exacerbated by root rot, which was more pronounced in the irrigated plots. 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. Following the 2005 planting, seed yields were substantial in 2006 and moderate in 2008. *Penstemon acuminatus* performed as a short-lived perennial. The trial area was disked out in 2010.

Penstemon cyaneus, **blue penstemon**

From 2011 to 2020, seed yields were responsive to irrigation only in 2013 (Tables 4 and 5). Seed yields showed a quadratic response to irrigation, with a maximum seed yield at 4 inches of water applied in 2013.

In 2019, stands of *P. cyaneus* were observed to be declining differentially by plot and irrigation criteria. A subjective evaluation showed 70, 78, and 58% stand for the non-irrigated, 4 inches/year, and 8 inches/year treatments, respectively, indicating the negative effect of higher amounts of irrigation on stand longevity (LSD 0.05 = 16).

Penstemon deustus, **scabland penstemon**

Seed yields did not respond to irrigation in any year except 2011 and 2015. In 2011, seed yields were highest with no irrigation (Tables 4 and 5). In 2015, seed yield showed a quadratic response to irrigation with a maximum seed yield at 5.4 inches of water applied.

Penstemon pachyphyllus, **thickleaf beardtongue**

From 2011 to 2020, seed yields responded to irrigation only in 2013 and 2018 (Tables 4 and 5). In 2013 and 2018, seed yields increased with increasing irrigation up to the highest level of 8 inches. The years 2013 and 2018 had lower than average spring precipitation (Table 3).

Conclusions

Subsurface drip irrigation was tested for native seed production because it has two potential strategic advantages: 1) low water use, and 2) the buried drip tape provides water to the plants at depth, precluding most irrigation-induced stimulation of weed seed germination on the soil surface and keeping water away from native plant tissues that are not adapted to a wet soil environment.

Due to the semi-arid environment, supplemental irrigation was required for successful flowering and seed set of the *Penstemon* species only in the drier years. The total irrigation requirements for these semi-arid land species were low and varied by species and year (Table 6). In 4 years of testing, *P. acuminatus* showed a quadratic response to irrigation in 2007 and 2008 and a negative response to irrigation in 2009. The years 2007 and 2008 had lower than average spring precipitation. From 2011 to 2020, *P. cyaneus* responded to irrigation only in 2013, and *P. pachyphyllus* responded to irrigation only in 2013 and 2018. The years 2013 and 2018 had lower than average fall, winter, and spring precipitation. From 2006 to 2020, *P. speciosus* showed a quadratic response to irrigation in 9 out of the 15 years. Similar to *P. pachyphyllus* and *P. cyaneus, P. speciosus* showed a positive linear response to irrigation in 2013. *Penstemon speciosus* showed either no response or a negative response to irrigation in 4 years with higher than average spring precipitation. In 10 years of testing, *P. deustus* responded to irrigation only in 2015.

Irrigation at the highest rate tested of 8 inches/year resulted in significantly higher stand loss than 4 inches/year or the non-irrigated treatments for *P. speciosus, P. acuminatus,* and *P. cyaneus.*

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Table 2. *Penstemon* flowering, irrigation, and seed harvest dates by species 2006–2020, Malheur Experiment Station, Oregon State University, Ontario, OR.

Species	Year	Flowering dates			Irrigation dates		
		Start	Peak	End	Start	End	Harvest
Penstemon acuminatus	2006	2-May	10-May	19-May	19-May	30-Jun	7-Jul
	2007	19-Apr		25-May	19-Apr	24-Jun	9-Jul
	2008	29-Apr		5-Jun	29-Apr	11-Jun	11-Jul
	2009	2-May		10-Jun	8-May	12-Jun	10-Jul
Penstemon cyaneus	2011	23-May	15-Jun	8-Jul	13-May	23-Jun	18-Jul
	2012	16-May	30-May	10-Jun	27-Apr	7-Jun	27-Jun
	2013	3-May	21-May	5-Jun	24-Apr	5-Jun	11-Jul
	2014	5-May	13-May	8-Jun	29-Apr	10-Jun	14-Jul
	2015	5-May		12-Jun	21-Apr	3-Jun	13-Jul
	2016	29-Apr		15-Jun	18-Apr	31-May	8-Jul
	2017	8-May	15-May	7-Jun	2-May	20-Jun	17-Jul
	2018	1-May	10-May	20-Jun	3-May	13-Jun	6-Jul
	2019	8-May	28-May	27-Jun	3-May	13-Jun	8-Jul
	2020	6-May	22-May	12-Jun	9-May	18-Jun	3-Jul
Penstemon deustus[a]	2006	10-May	19-May	30-May	19-May	30-Jun	4-Aug
	2007	5-May	25-May	25-Jun	19-Apr	24-Jun	
	2008	5-May		20-Jun	18-Apr	31-May	
	2011	23-May	20-Jun	14-Jul	13-May	23-Jun	16-Aug
	2012	16-May	30-May	4-Jul	27-Apr	7-Jun	7-Aug
	2013	3-May	18-May	15-Jun	24-Apr	5-Jun	
	2014	10-May	20-May	19-Jun	29-Apr	10-Jun	21-Jul
	2015	1-May		10-Jun	21-Apr	3-Jun	23-Jul
	2016		no flowering		18-Apr	31-May	
	2017	15-May	7-Jun	30-Jun	2-May	20-Jun	1-Aug
	2018	3-May		20-Jun	3-May	13-Jun	26-Jul
	2019	10-May	28-May	28-Jun	3-May	13-Jun	30-Jul
	2020	7-May	22-May	25-Jun	9-May	18-Jun	29-Jul
Penstemon pachyphyllus	2011	10-May	30-May	20-Jun	13-May	23-Jun	15-Jul
	2012	23-Apr	2-May	10-Jun	27-Apr	7-Jun	26-Jun
	2013	26-Apr		21-May	24-Apr	5-Jun	8-Jul
	2014	22-Apr	5-May	4-Jun	29-Apr	10-Jun	13-Jul
	2015	24-Apr	5-May	26-May	21-Apr	3-Jun	10-Jul
	2016	18-Apr		13-May	18-Apr	31-May	22-Jun
	2017	1-May	15-May	7-Jun	2-May	20-Jun	29-Jun
	2018	30-Apr	10-May	10-Jun	3-May	13-Jun	26-Jun
	2019	26-Apr		28-May	3-May	13-Jun	28-Jun
	2020	25-Apr	7-May	30-May	9-May	18-Jun	24-Jun
Penstemon speciosus[b]	2006	10-May	19-May	30-May	19-May	30-Jun	13-Jul
	2007	5-May	25-May	25-Jun	19-Apr	24-Jun	23-Jul
	2008	5-May		20-Jun	29-Apr	11-Jun	17-Jul
	2009	14-May		20-Jun	19-May	24-Jun	10-Jul
	2010	14-May		20-Jun	12-May	22-Jun	22-Jul
	2011	25-May	30-May	30-Jun	20-May	5-Jul	29-Jul
	2012	2-May	20-May	25-Jun	2-May	13-Jun	13-Jul
	2013	2-May	10-May	20-Jun	2-May	12-Jun	11-Jul
	2014	29-Apr	13-May	9-Jun	29-Apr	10-Jun	11-Jul
	2015	28-Apr	5-May	5-Jun	21-Apr	3-Jun	30-Jun
	2016		no flowering		3-May	13-Jun	6-Jul
	2017	8-May	15-May	7-Jun	2-May	20-Jun	17-Jul
	2018	2-May		13-Jun	3-May	13-Jun	6-Jul
	2019	8-May	26-May	28-Jun	3-May	13-Jun	9-Jul
	2020	5-May	22-May	18-Jun	7-May	3-Jun	6-Jul

[a]Second planting in the fall of 2009, third planting in the fall of 2015.
[b] partial die-off and natural reseeding in 2010 and 2011. Full replant in 2015.

Table 3. Early season precipitation and growing degree-days, Malheur Experiment Station, Oregon State University, Ontario, OR, 2006–2020.

	Precipitation (inch)			Growing degree-days (50–86°F)
Year	Spring	Spring + winter	Spring + winter + fall	Jan–July
2006	3.4	10.1	14.5	2064
2007	1.9	3.8	6.2	2203
2008	1.4	3.2	6.7	1799
2009	4.1	6.7	8.9	1908
2010	4.3	8.4	11.7	1642
2011	4.8	9.3	14.5	1533
2012	2.6	6.1	8.4	1979
2013	0.9	2.4	5.3	2064
2014	1.7	5.1	8.1	2112
2015	3.2	5.9	10.4	2327
2016	2.2	5.0	10.1	2138
2017	4.0	9.7	12.7	1962
2018	1.9	4.9	5.8	2075
2019	4.7	10.2	12.9	1912
2020	4.3	6.6	12.8	1991
15-year average:	3.0	6.5	9.9	27-year average: 1917

Table 4. *Penstemon* seed yield in response to irrigation rate (inches/season), 2006–2020, Malheur Experiment Station, Oregon State University, Ontario, OR.

Species	Year	0 inches	4 inches	8 inches	LSD (0.05)
		---- lb/acre ----			
Penstemon acuminatus	2006	538.4	611.1	544	NS[a]
	2007	19.3	50.1	19.1	25.5[b]
	2008	56.2	150.7	187.1	79
	2009	20.7	12.5	11.6	NS
	2010	-- Stand disked out --			
Penstemon cyaneus	2011	857.2	821.4	909.4	NS
	2012	343.3	474.6	581.1	NS
	2013	221.7	399.4	229.2	74.4
	2014	213.9	219.8	215.1	NS
	2015	148.4	122.5	216.8	NS
	2016	36.0	84.1	79.6	NS
	2017	117.7	196.6	173.1	NS
	2018	86.8	43.5	79.4	31.4[b]
	2019	85.4	89.9	74.9	NS
	2020	165.6	194.9	183.4	NS
	Average	227.6	284.0	274.2	NS
Penstemon deustus[c]	2006	1246.4	1200.8	1068.6	NS
	2007	120.3	187.7	148.3	NS
	2008	-- Stand disked out --			
	2011[c]	637.6	477.8	452.6	NS
	2012[c]	308.7	291.8	299.7	NS
	2013	--- no flowering ---			
	2014	356.4	504.8	463.2	NS
	2015[c]	20.0	76.9	67.0	43.7[b]
	2017	205.4	258.8	247.6	NS
	2018	110.7	85.3	94.7	NS
	2019	113.4	154.1	143.9	NS
	2020	81.7	122.3	93.8	NS
	Average	266.1	285.6	261.9	NS

Species	Year	0 inches	4 inches	8 inches	LSD (0.05)
		---- lb/acre ----			
Penstemon pachyphyllus	2011	569.9	337.6	482.2	NS
	2012	280.5	215	253.7	NS
	2013	159.4	196.8	249.7	83.6
	2014	291.7	238.6	282.1	NS
	2015	89.5	73.5	93.3	NS
	2016	142.7	186.3	169.7	NS
	2017	111.2	108.1	99.1	NS
	2018	152.5	133.7	221.0	59.5[b]
	2019	130.8	143.9	190.4	NS
	2020	174.0	222.1	194.6	NS
	Average	210.2	185.6	223.6	NS
Penstemon speciosus[a]	2006	163.5	346.2	213.6	134.3
	2007	2.5	9.3	5.3	4.7[b]
	2008	94	367	276.5	179.6
	2009	6.8	16.1	9.0	6.0[b]
	2010	147.2	74.3	69.7	NS
	2011	371.1	328.2	348.6	NS
	2012	103.8	141.1	99.1	NS
	2013	8.7	80.7	138.6	63.7
	2014	76.9	265.6	215.1	76.7
	2015[d]	105.4	207.3	173.7	50.3
	2016	--- no flowering ---			
	2017	88.6	117.1	82.3	NS
	2018	0.8	7.7	5.7	4.2
	2019	86.6	90.2	34.3	NS
	2020	86.9	253.5	151.8	103.8
	Average	96.5	160.2	128.9	30.5

[a]NS = not significant.
[b]LSD (0.10).
[c]Replanted in fall of 2009, fall of 2012, and fall of 2015.
[d]Replanted in fall of 2015.

Table 5. Regression analysis for *Penstemon* seed yield (y) in response to irrigation (x) (inches/season) using the equation $y = a + b \cdot x + c \cdot x^2$, 2006–2020, and 4- to 14-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. (Continues on next page.)

Penstemon acuminatus Year	Intercept	Linear	Quadratic	R^2	*P*	Maximum yield	Water applied for maximum yield
						lb/acre	inches/season
2006	538.4	35.6	-4.4	0.03	NS[a]		
2007	19.3	15.4	-1.9	0.44	0.10	50.5	4.1
2008	56.2	30.9	-1.8	0.63	0.05	188.8	8.6
2009	20.5	-1.1		0.28	0.10	11.4	0.0
Average	165.6	17.1	-1.8	0.1	NS		

Penstemon cyaneus Year	Intercept	Linear	Quadratic	R^2	*P*	Maximum yield	Water applied for maximum yield
						lb/acre	inches/season
2011	836.6	6.5		0.01	NS		
2012	347.4	29.7		0.21	NS		
2013	221.7	87.9	-10.9	0.63	0.05	398.9	4
2014	215.7	0.1		0.01	NS		
2015	128.4	8.5		0.09	NS		
2016	36.0	18.6	-1.6	0.29	NS		
2017	117.7	32.5	-3.2	0.19	NS		
2018	78.7	-0.9		0.02	NS		
2019	85.4	3.6	-0.6	0.08	NS		
2020	165.6	12.5	-1.3	0.08	NS		
Average	227.6	22.4	-2.1	0.36	NS		

Penstemon deustus Year	Intercept	Linear	Quadratic	R^2	*P*	Maximum yield	Water applied for maximum yield
						lb/acre	inches/season
2006	1260.9	-22.2		0.05	NS		
2007	120.3	30.2	-3.3	0.19	NS		
2011	615.2	-23.1		0.35	0.05	615.2	0
2012	304.6	-1.1		0.01	NS		
2014	356.4	60.8	-5.9	0.26	NS		
2015	20.0	22.6	-2.1	0.42	0.10	81.0	5.4
2017	205.4	21.4	-2.0	0.08	NS		
2018	104.9	-2.0		0.06	NS		
2019	113.4	16.5	-1.6	0.18	NS		
2020	81.7	18.8	-2.2	0.11	NS		
Average	266.1	10.3	-1.4	0.02	NS		

[a]NS = not significant. There was no statistically significant trend in seed yield in response to the amount of irrigation.

Table 5 (continued). Regression analysis for *Penstemon* seed yield in response to irrigation rate (inches/season), 2006–2020, and 4- to 14-year averages, Malheur Experiment Station, Oregon State University, Ontario, OR.

Penstemon pachyphyllus Year	Intercept	Linear	Quadratic	R^2	*P*	Maximum yield	Water applied for maximum yield
						lb/acre	inches/season
2011	507.1	-11		0.04	NS[a]		
2012	263.1	-3.3		0.01	NS		
2013	156.8	11.3		0.33	0.1	247.2	8.0
2014	275.6	-1.2		0.01	NS		
2015	83.6	0.5		0.01	NS		
2016	142.7	18.4	-1.9	0.07	NS		
2017	112.2	-1.5		0.02	NS		
2018	134.8	8.6		0.31	0.1	203.3	8.0
2019	125.3	7.5		0.23	NS		
2020	174.0	21.5	-2.4	0.06	NS		
Average	199.8	1.7		0.03	NS		

Penstemon speciosus Year	Intercept	Linear	Quadratic	R^2	*P*	Maximum yield	Water applied plus spring precipitation for maximum yield	Spring precipitation
						lb/acre	inches/season	inch
2006	-238.2	151.9	-9.9	0.66	0.05	347.2	7.7	3.4
2007	-5.1	4.7	-0.4	0.48	0.10	9.3	6.1	1.9
2008	-91.7	146.1	-11.4	0.56	0.05	378.4	6.4	1.4
2009	-19.5	8.6	-0.5	0.54	0.05	16.2	8.3	4.1
2010	177.8	-9.7		0.28	0.10	135.8	4.3	4.3
2011	374.0	-2.8		0.01	NS			4.8
2012	6.5	46.7	-3.6	0.54	0.05	158.8	6.5	2.6
2013	-2.8	16.2		0.77	0.001	141.0	8.9	0.9
2014	-78.8	102.9	-7.5	0.62	0.05	275.5	6.9	1.7
2015	-75.1	69.7	-4.2	0.64	0.05	211.6	8.2	3.2
2017	-2.4	30.8	-2.0	0.27	NS			4.0
2018	-5.6	3.9	-0.3	0.62	0.05	8.1	7.0	1.9
2019	6.3	25.9	-1.9	0.24	NS			4.7
2020	-394.1	147.5	-8.4	0.53	0.05	255.4	8.8	4.3
Average	-16.5	46.1	-3.0	0.60	0.05	161.6	7.7	3.1

[a]NS = not significant. There was no statistically significant trend in seed yield in response to the amount of irrigation.

Table 6. Amount of irrigation water for maximum *Penstemon* 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 for seed production	Year of first seed set	Approximate life span
	inches/season	from fall planting	years
P. acuminatus	0 in wetter years: 4 in warm, dry years	1	3
P. deustus	response to irrigation in 1 out of 10 years	2	3
P. cyaneus	no response in 9 out of 10 years, 4 inches in drier years	1	3
P. pachyphyllus	no response in 8 out of 10 years, 8 inches in drier years	1–2	3
P. speciosus	0 in cool, wet years; 6–8 in warm, dry years	1–2	3