

IRRIGATION REQUIREMENTS FOR *LOMATIUM* SEED PRODUCTION

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Summary

Lomatium species are important botanical components in the rangelands of the Intermountain West. Relatively little is known about the cultural practices necessary to produce *Lomatium* seed for use in rangeland restoration activities. The seed yield response to four biweekly irrigations applying either 0, 1, or 2 inches of water (total of 0, 4, or 8 inches/season) was evaluated for four *Lomatium* species over multiple years starting in 2007. In order to try to improve the accuracy of estimated irrigation water requirements, seed yield responses to irrigation plus precipitation during the previous spring; winter and spring; and fall, winter, and spring were also evaluated. On average, over 12 seed production seasons, *Lomatium dissectum* (fernleaf biscuitroot) seed yield was maximized by 8.2 to 9.8 inches of water applied plus spring precipitation depending on the seed source. On average, over 14 seed production seasons, *L. grayi* (Gray's biscuitroot) seed yield was maximized by 13.7 inches of water applied plus fall, winter, and spring precipitation. On average, over 14 seed production seasons, *L. triternatum* (nineleaf biscuitroot) seed yield was maximized by 10.9 inches of water applied plus spring precipitation. Over eight seed production seasons, *L. nudicaule* (barestem biscuitroot) seed yield responded to irrigation only in 2017. In seven seed production seasons, seed yield of *L. suksdorfii* (Suksdorf's desertparsley) responded to irrigation only in 2015.

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 production over years.

In native rangelands, the natural variation in spring rainfall and soil moisture results in highly unpredictable 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 and often are not competitive with crop weeds in cultivated fields, which could limit wildflower seed production. Supplemental water can be provided by sprinkler or furrow irrigation systems, but these irrigation systems risk further encouraging weeds. Sprinkler and furrow irrigation also can lead to the loss of plant stand and seed production due to fungal pathogens. Burying drip tapes at 12-inch depth and avoiding wetting the soil surface could help 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 *Lomatium* species (Table 1) from 2007 through 2020.

Subsurface drip irrigation systems were tested for native seed production because they have 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 environment.

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

Species	Common name	Accession	Origin	Collection year
<i>L. dissectum</i>	fernleaf biscuitroot	LODI 05	Mann Creek	2003
<i>L. dissectum</i>	fernleaf biscuitroot	LODI 38	Lucky Peak Nursery	2008
<i>L. dissectum</i>	fernleaf biscuitroot	LODI 41	Crowley Road	2009
<i>L. dissectum</i>	fernleaf biscuitroot	LODI Riggins	Riggins, ID	2008
<i>L. triternatum</i>	nineleaf biscuitroot, nineleaf desertparsley	LOTR 41	Hwy 395, OR	2006
<i>L. grayi</i>	Gray's biscuitroot, Gray's lomatium	LOGR 03	Weiser R. Road	2004
<i>L. nudicaule</i>	barestem biscuitroot, barestem lomatium			
<i>L. suksdorfii</i>	Suksdorf's desertparsley			

Materials and Methods

Plant Establishment

Seed of *L. dissectum*, *L. grayi*, and *L. triternatum* was received in late November 2004 from the Rocky Mountain Research Station (Boise, ID). The plan was to plant the seed in fall 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, we submitted the seed to cold stratification. The seed was soaked overnight in distilled water on January 26, 2005, after which the water was drained and the seed was 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, seed of *L. grayi* and *L. triternatum* started to sprout.

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

On March 3, 2005, seed of the three species (*L. dissectum*, *L. grayi*, and *L. triternatum*) 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 at 0.5-inch depth. The trial was irrigated from March 4 to April 29 with a minisprinkler system (R10 Turbo Rotator, Nelson Irrigation Corp., Walla Walla, WA) for even stand establishment. 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. *Lomatium triternatum* and *L. grayi* started emerging on March 29. Beginning on June 24, the field was irrigated with the drip irrigation 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 for *L. triternatum* and *L. grayi* were uneven; *L. 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 entire row lengths were replanted using the planter on October 26, 2005. In spring 2006, the plant stands were excellent.

On November 25, 2009, seed of *L. nudicaule*, *L. suksdorfii*, and three selections of *L. dissectum* (LODI 38, LODI 41, and seed from near Riggins, ID (LODI Riggins)) 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 two rows (two 30-inch 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.

Irrigation for Seed Production

In April 2006 (April 2010 for the species and selections planted in 2009), each planted strip of each species was divided into plots 30 ft long. Each plot contained four rows of each species. The experimental design for each species was a randomized complete block with four replicates. The three treatments were a nonirrigated check, 1 inch of water applied per irrigation, and 2 inches of water applied per irrigation. Each treatment received four irrigations applied approximately every 2 weeks starting with flowering. The length of time necessary to deliver 1 or 2 inches through the drip system was calculated. 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.

Irrigation dates are found in Table 2. Irrigations for each species were initiated and terminated on different dates each year.

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.

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 manually when seed of each species was mature (Table 2). Seed was cleaned manually.

Cultural Practices

Fertilization was modest and was the same for all plots of all species. On November 11, 2007, 100 lb nitrogen (N)/acre as urea was broadcast on the soil surface. Nitrogen was applied as URAN (urea ammonium nitrate) injected through the drip tape at 50 lb N/acre on April 9, 2009, May 3, 2011, and April 13, 2012. Nitrogen was applied as URAN at 20 lb N/acre on March 29, 2013, April 2, 2014, April 15, 2015, and March 31, 2016.

Phosphorus (P) was applied through the drip tape at 50 lb P/acre on October 27, 2006; 10 lb P/acre on April 9, 2009, and April 13, 2012; and 25 lb P/acre on March 29, 2013, April 2, 2014, April 15, 2015, and March 31, 2016.

Zinc (Zn) at 2 lb Zn/acre was injected through the drip tape on October 27, 2006.

Iron (Fe) as iron chelate was injected through the drip tape at 0.3 lb Fe/acre on April 13, 2012, March 29, 2013, April 2, 2014, April 15, 2015, March 31, 2016, April 4, 2017, and May 3, 2018.

The herbicides pendimethalin (Prowl[®]), dimethenamid-P (Outlook[®]), and sethoxydim (Poast[®]) have been used for weed control. Prowl at 1 lb ai/acre was broadcast on the soil surface on November 17, 2006, November 9, 2007, April 15, 2008, March 18, 2009, December 4, 2009, November 17, 2010, November 9, 2011, November 7, 2012, April 3, 2013, February 26, 2014, March 13, 2015, November 6, 2015, October 27, 2016, March 28, 2017, October 19, 2017, October 30, 2018, and November 15, 2019. Outlook at 0.98 lb ai/acre was broadcast along with Prowl on October 30, 2018, and November 15, 2019.

Poast at 0.38 lb ai/acre was broadcast on March 18, 2009, April 3, 2013, February 26, 2014, and March 28, 2017, for weed control. On November 6, 2015, Roundup[®] (glyphosate) at 24 oz/acre was broadcast for weed control. In addition to herbicides, hand weeding was used as necessary to control weeds.

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 $y = a + b \cdot x + c \cdot x^2$, 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 amounts of water applied plus precipitation and the measured average seed yield.

For each species, 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 the seasonal precipitation to the irrigation response equation could provide a closer estimate of the amount of water required for maximum seed yields of the *Lomatium* species. 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 with few years, where a yield response to irrigation existed, yield responses are reported as a function of water applied.

Results and Discussion

Spring precipitation in 2012 and 2015 was close to the average of 3.0 inches (Table 3). Spring precipitation in 2006, 2009–2011, 2017, 2019, and 2020 was higher than average, and spring precipitation in 2007, 2008, 2013, 2014, 2016, and 2018 was lower than average. The accumulated growing degree-days (50–86°F) from January through June in 2006, 2007, 2013–2016, and 2018 were higher than average (Table 3). The high accumulated growing degree-days in 2015 probably caused early harvest dates (Table 2).

In 2020, irrigations were delayed until May 7, at the end of flowering for *L. dissectum*, *L. grayi*, and *L. nudicaule*, due to repairs on the water supply system. Since two consecutive irrigations were applied on May 7, these were included in the amount of water applied in the regression analyses. Later irrigations were not considered in the analyses.

Flowering and Seed Set

Lomatium grayi and *L. triternatum* started flowering and producing seed in 2007 (second year after fall planting in 2005, Tables 2 and 4). *Lomatium dissectum* started flowering and producing seed in 2009 (fourth year after fall planting in 2005). *Lomatium nudicaule* started flowering and produced seed in 2012 (third year after fall planting in 2009), and *L. suksdorfii* started flowering and produced seed in 2013 (fourth year after fall planting in 2009).

Seed Yields

Lomatium dissectum, fernleaf biscuitroot

Lomatium dissectum had very little vegetative growth during 2006–2008 and produced very few flowers in 2008. All the *Lomatium* species tested were affected by *Alternaria* fungus, but the infection was greatest on the *L. dissectum* selection planted in this trial. This infection delayed *L. dissectum* plant development. In 2009, vegetative growth and flowering improved.

Seed yields of *L. dissectum* showed a quadratic response to irrigation rate plus spring precipitation in 2009–2011, 2013–2015, 2017, 2018, and 2019 (Tables 4 and 6). In 2012, seed yields of *L. dissectum* did not respond to irrigation. In 2016 and 2020, seed yield increased linearly with increasing irrigation rate plus spring precipitation. Averaged over the 12 years, seed yield showed a quadratic response to irrigation rate plus spring precipitation and was estimated to be maximized at 856 lb/acre/year by 9.8 inches of irrigation and spring precipitation.

Lomatium dissectum selection LODI Riggins

The Riggins selection of *L. dissectum* started flowering in 2013, but only in small amounts. Seed yields of this selection showed a quadratic response to irrigation rate plus spring precipitation in 2014, 2016, 2018, 2019, and 2020 (Tables 5 and 7). Seed yields were estimated to be maximized by 6.5, 7.5, 7.8, 9.9, and 6.5 inches of applied water and spring precipitation in 2014, 2016, 2018, 2019, and 2020, respectively. Seed was inadvertently not harvested in 2015. In 2017, seed yields showed a linear positive response to irrigation plus spring precipitation and was estimated to be maximized by 8 inches of applied water plus spring precipitation. On average,

seed yields were estimated to be maximized by 8.2 inches of applied water and spring precipitation.

***Lomatium dissectum* selection LODI 38**

Lomatium dissectum selection LODI 38 started flowering in 2013, but only in small amounts. In 7 years of testing, seed yields of LODI 38 responded to irrigation only in 2018 (Tables 5 and 7). In 2018, seed yields of LODI 38 showed a positive linear response to applied water plus spring precipitation, with seed yields maximized by 9.9 inches of applied water and spring precipitation. Averaged over 7 years, seed yields were not responsive to irrigation.

***Lomatium dissectum* selection LODI 41**

Seed yields of LODI 41 did not respond to irrigation in 2014 and 2016. In 2015, 2017, 2019, and 2020 seed yields of LODI 41 showed a quadratic response to irrigation rate (Tables 5 and 7). In 2018, seed yields of LODI 41 showed a positive linear response to applied water plus spring precipitation. Averaged over the 7 years, seed yields were estimated to be maximized by 8.3 inches of applied water and spring precipitation.

***Lomatium grayi*, Gray's biscuitroot**

Seed yields of *L. grayi* showed a quadratic response to irrigation rate plus fall, winter, and spring precipitation in 2008, 2012, 2014, 2015, and 2016 (Tables 4 and 6). In 2007, 2009, and 2013, seed yield showed a positive linear response to water applied plus precipitation. In 2010, 2011, 2017, 2019, and 2020, seed yields did not respond to irrigation. Precipitation was higher than average over the fall, winter, and spring in 2010, 2011, 2017, 2019, and 2020. On average, seed yields of *L. grayi* were maximized at 664 lb/acre by 13.7 inches of applied water and fall, winter, and spring precipitation.

Rodent damage was a complicating factor in 2010 that compromised seed yields. Extensive 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 the habitat attractiveness to voles, all of the *Lomatium* plants were mowed after becoming dormant in early fall of 2010 and in each subsequent year.

***Lomatium triternatum*, nineleaf biscuitroot**

Seed yields of *L. triternatum* showed a quadratic response to irrigation plus spring precipitation from 2008 through 2013 and in 2018 and 2019 (Tables 4 and 6). In 2007, 2014–2016, and 2020, seed yield showed a positive linear response to water applied plus spring precipitation. In 2017, seed yields did not respond to irrigation, probably due to heavy winter and spring precipitation. On average, seed yields of *L. triternatum* were maximized at 1,011 lb/acre by 10.9 inches of applied water and spring precipitation.

***Lomatium nudicaule*, barestem biscuitroot**

From 2012 through 2020, seed yields responded to irrigation only in 2017 and 2020 (Tables 4 and 8). In 2017, seed yields showed a quadratic response to irrigation rate. Seed yields in 2017 were maximized at 218 lb/acre with 9.9 inches of applied water. In 2020 seed yields were highest (67 lb/acre) with no irrigation.

***Lomatium suksdorfii*, Suksdorf's deserparsley**

Lomatium suksdorfii started flowering in 2013, but only in small amounts. In the 7 years that seed was harvested, seed yields of *L. suksdorfii* responded to irrigation only in 2015 (Tables 5 and 8). In 2015, seed yield increased linearly with increasing water applied up to the highest amount of water applied, 8 inches.

Conclusions

The *Lomatium* species were relatively slow to produce ample seed. *Lomatium grayi* and *L. triternatum* had reasonable seed yields starting in the second year, *L. dissectum* and *L. nudicaule* were productive in their fourth year, and *L. suksdorfii* was only moderately productive in the fifth year after planting. Delayed maturity affects the cost of seed production, but these species have proven to be strong perennials, especially when protected from rodent damage.

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 9). *Lomatium nudicaule* and *L. suksdorfii* did not respond to irrigation most years; natural rainfall was sufficient to maximize their seed production in the absence of weed competition. *Lomatium dissectum* required approximately 6 inches of irrigation. *Lomatium grayi* and *L. triternatum* responded quadratically to irrigation, with the optimum varying by year. Accounting for precipitation improved the accuracy in the estimates of irrigation necessary for optimal seed production for *L. grayi*, *L. triternatum*, and *L. dissectum*.

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Table 2. *Lomatium* flowering, irrigation, and seed harvest dates by species, 2006–2020, Malheur Experiment Station, Oregon State University, Ontario, OR. (Continues on next page.)

Species	Year	Flowering			Irrigation		Harvest
		Start	Peak	End	Start	End	
<i>Lomatium dissectum</i>	2006	No flowering			19-May	30-Jun	
	2007	No flowering			5-Apr	24-Jun	
	2008	Very little flowering			10-Apr	29-May	
	2009	10-Apr		7-May	20-Apr	28-May	16-Jun
	2010	25-Apr		20-May	15-Apr	28-May	21-Jun
	2011	8-Apr	25-Apr	10-May	21-Apr	7-Jun	20-Jun
	2012	9-Apr	16-Apr	16-May	13-Apr	24-May	4-Jun
	2013	10-Apr		25-Apr	4-Apr	16-May	4-Jun
	2014	28-Mar		21-Apr	7-Apr	20-May	2-Jun
	2015	1-Apr		24-Apr	1-Apr	13-May	26-May, 1-Jun ^a
	2016	25-Mar		24-Apr	31-Mar	9-May	26-May
	2017	7-Apr		8-May	19-Apr	6-Jun	6-Jun
	2018	1-Apr		1-May	18-Apr	30-May	31-May
	2019	4-Apr		26-Apr	12-Apr	30-May	3-Jun
2020	12-Apr		7-May	7-May	3-Jun	3-Jun	
<i>Lomatium grayi</i>	2006	No flowering			19-May	30-Jun	3-Jun
	2007	5-Apr		10-May	5-Apr	24-Jun	30-May, 29-Jun ^a
	2008	25-Mar		15-May	10-Apr	29-May	30-May, 19-Jun ^a
	2009	10-Mar		7-May	20-Apr	28-May	16-Jun
	2010	15-Mar		15-May	15-Apr	28-May	22-Jun
	2011	1-Apr	25-Apr	13-May	21-Apr	7-Jun	22-Jun
	2012	15-Mar	25-Apr	16-May	13-Apr	24-May	14-Jun
	2013	15-Mar		30-Apr	4-Apr	16-May	10-Jun
	2014	28-Mar		2-May	7-Apr	20-May	10-Jun
	2015	1-Mar		28-Apr	1-Apr	13-May	1-Jun
	2016	7-Mar		29-Apr	31-Mar	9-May	1-Jun
	2017	15-Mar		12-May	19-Apr	6-Jun	8-Jun
	2018	15-Mar		3-May	18-Apr	30-May	5-Jun
	2019	15-Mar	15-Apr	10-May	12-Apr	30-May	6-Jun
2020	15-Mar		7-May	7-May	3-Jun	4-Jun	

^a 0-inch irrigation treatment harvested on earlier dates, 4-inch and 8-inch irrigation treatments harvested on later dates.

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

Species	Year	Flowering			Irrigation		Harvest
		Start	Peak	End	Start	End	
<i>Lomatium triternatum</i>	2006	No flowering			19-May	30-Jun	
	2007	25-Apr		1-Jun	5-Apr	24-Jun	29-Jun, 16-Jul ^a
	2008	25-Apr		5-Jun	10-Apr	29-May	3-Jul
	2009	10-Apr	7-May	1-Jun	20-Apr	28-May	26-Jun
	2010	25-Apr		15-Jun	15-Apr	28-May	22-Jul
	2011	30-Apr	23-May	15-Jun	21-Apr	7-Jun	26-Jul
	2012	12-Apr	17-May	6-Jun	13-Apr	24-May	21-Jun
	2013	18-Apr		10-May	4-Apr	16-May	4-Jun
	2014	7-Apr	29-Apr	2-May	7-Apr	20-May	4-Jun
	2015	10-Apr	28-Apr	20-May	1-Apr	13-May	7-Jun, 15-Jun ^a
	2016	11-Apr	28-Apr	20-May	31-Mar	9-May	15-Jun
	2017	24-Apr	15-May	30-May	19-Apr	6-Jun	27-Jun
	2018	16-Apr	10-May	23-May	18-Apr	30-May	18-Jun
	2019	20-Apr	8-May	23-May	12-Apr	30-May	17-Jun
2020	18-Apr	7-May	26-May	7-May	3-Jun	15-Jun	
<i>Lomatium nudicaule</i>	2011	No flowering					
	2012	12-Apr	1-May	30-May	18-Apr	30-May	22-Jun
	2013	11-Apr		20-May	12-Apr	22-May	10-Jun
	2014	7-Apr		13-May	7-Apr	20-May	16-Jun
	2015	25-Mar		5-May	1-Apr	13-May	8-Jun
	2016	5-Apr		5-May	11-Apr	23-May	6-Jun
	2017	12-Apr		15-May	19-Apr	6-Jun	19-Jun
	2018	9-Apr	30-Apr	11-May	18-Apr	30-May	11-Jun
	2019	5-Apr	26-Apr	15-May	12-Apr	30-May	12-Jun
	2020	6-Apr		7-May	7-May	3-Jun	18-Jun
<i>Lomatium suksdorfii</i>	2013	18-Apr		23-May			
	2014	15-Apr		20-May	7-Apr	20-May	30-Jun
	2015	3-Apr	27-Apr	10-May	1-Apr	13-May	23-Jun
	2016	5-Apr	27-Apr	31-May	11-Apr	23-May	28-Jun
	2017	17-Apr		2-Jun	19-Apr	6-Jun	19-Jun
	2018	16-Apr	10-May	31-May	18-Apr	30-May	2-Jul
	2019	20-Apr		28-May	12-Apr	30-May	8-Jul
2020	5-Apr		12-May	7-May	3-Jun	6-Jul	

^a 0-inch irrigation treatment harvested on earlier dates, 4-inch and 8-inch irrigation treatments harvested on later dates.

Table 3. Precipitation and growing degree-days at the Malheur Experiment Station, Oregon State University, Ontario, OR, 2006–2020.

Year	Precipitation (inch)			Growing degree-days (50–86°F) Jan–July
	Spring	Spring + winter	Spring + winter + fall	
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. Seed yield response to irrigation (inches/season) for four *Lomatium* species, 2006–2020, Malheur Experiment Station, Oregon State University, Ontario, OR.

Species	Year	Irrigation rate			LSD (0.05) ^a
		0 inches	4 inches	8 inches	
<i>Lomatium dissectum</i>		----- lb/acre -----			
	2006	---- no flowering ----			
	2007	---- no flowering ----			
	2008	- very little flowering -			
	2009	50.6	320.5	327.8	196.4 ^b
	2010	265.8	543.8	499.6	199.6
	2011	567.5	1342.8	1113.8	180.9
	2012	388.1	460.3	444.4	NS
	2013	527.8	959.8	1166.7	282.4
	2014	353.4	978.9	1368.3	353.9
	2015	591.2	1094.7	1376.0	348.7
	2016	1039.4	1612.7	1745.4	564.2
	2017	488.2	713.1	674.4	220.5 ^b
	2018	79.2	237.9	280.3	148.0
	2019	554.9	880.2	850.1	209.8 ^b
	2020	54.8	140.0	207.7	68.3
	12-year average	413.4	787.7	836.3	126.5

Species	Year	Irrigation rate			LSD (0.05) ^a
		0 inches	4 inches	8 inches	
<i>Lomatium nudicaule</i>		----- lb/acre -----			
	2010	---- no flowering ----			
	2011	---- no flowering ----			
	2012	53.8	123.8	61.1	NS
	2013	357.6	499.1	544.0	NS
	2014	701.3	655.6	590.9	NS
	2015	430.6	406.1	309.3	NS
	2016	363.0	403.7	332.5	NS
	2017	53.7	159.7	212.0	49.7
	2018	17.1	41.3	28.7	NS
	2019	335.4	389.1	318.0	NS
	2020	67.4	49.1	34.6	20.8 ^b
	9-year average	264.4	303.1	270.1	NS

Species	Year	Irrigation rate			LSD (0.05) ^a
		0 inches	4 inches	8 inches	
<i>Lomatium grayi</i>		----- lb/acre -----			
	2006	---- no flowering ----			
	2007	36.1	88.3	131.9	77.7 ^b
	2008	393.3	1287	1444.9	141.0
	2009	359.9	579.8	686.5	208.4
	2010	1035.7	1143.5	704.8	NS
	2011	570.3	572.7	347.6	NS
	2012	231.9	404.4	377.3	107.4
	2013	596.7	933.4	1036.3	NS
	2014	533.1	1418.1	1241.3	672.0
	2015	186.4	576.7	297.6	213.9
	2016	483.7	644.2	322.9	218.7
	2017	333.5	259.5	246.3	NS
	2019	647.4	562.7	453.6	NS
	2020	13.5	54.1	42.7	NS
	12-year average	421.2	655.7	564.1	152.6

Species	Year	Irrigation rate			LSD (0.05) ^a
		0 inches	4 inches	8 inches	
<i>Lomatium triternatum</i>		----- lb/acre -----			
	2006	---- no flowering ----			
	2007	2.3	17.5	26.7	16.9 ^b
	2008	195.3	1060.9	1386.9	410.0
	2009	181.6	780.1	676.1	177.0
	2010	1637.2	2829.6	3194.6	309.4
	2011	1982.9	2624.5	2028.1	502.3 ^b
	2012	238.7	603	733.2	323.9
	2013	153.7	734.4	1050.9	425.0
	2014	240.6	897.1	1496.7	157.0
	2015	403.2	440.8	954.9	446.6
	2016	395.0	475.7	638.4	175.7
	2017	932.8	948.9	1266.2	216.8
	2018	2.0	41.4	46.2	30.4
	2019	448.1	812.8	669.1	280.0
	2020	42.4	108.8	159.1	48.0
	14-year average	489.7	884.0	1010.8	104.9

^aNS = not significant

^bLSD (0.10)

Table 5. Seed yield response to irrigation amount (inches/season) for two *Lomatium* species 2014–2020, Malheur Experiment Station, Oregon State University, Ontario, OR.

Species	Year	Irrigation rate			LSD (0.05) ^a
		0 inches	4 inches	8 inches	
		----- lb/acre -----			
<i>Lomatium dissectum</i> LODI Riggins	2014	276.8	497.7	398.4	163.0
	2016	299.1	679.5	592.4	247.4
	2017	315.1	405.1	440.0	87.4
	2018	61.8	142.8	141.8	51.3
	2019	230.9	531.4	460.3	153.8
	2020	133.5	321.7	177.6	123.9
	6-year average	219.5	42.7	368.4	102.6
<i>Lomatium dissectum</i> LODI 38	2014	281.9	356.4	227.1	NS
	2015	865.1	820.9	774.6	NS
	2016	474.8	634.5	620.0	70.3
	2017	398.8	575.0	553.2	NS
	2018	220.1	280.0	358.2	NS
	2019	467.5	457.4	431.2	NS
	2020	367.3	630.1	410.2	NS
	7-year average	469.2	536.3	440.4	NS
<i>Lomatium dissectum</i> LODI 41	2014	222.2	262.4	149.8	NS
	2015	152.2	561.9	407.4	181.4
	2016	238.1	297.7	302.0	NS
	2017	214.9	363.0	377.5	71.0
	2018	53.7	71.4	97.6	NS
	2019	165.5	341.2	347.0	127.7
	2020	85.0	163.0	119.1	55.1 ^b
	7-year average	161.7	294.4	257.2	85.6
<i>Lomatium suksdorfii</i>	2014	162.6	180.0	139.8	NS
	2015	829.6	1103.9	1832.0	750.2
	2016	692.6	898.8	467.5	NS
	2017	1315.5	1736.6	1315.5	NS
	2018	346.7	788.3	546.8	NS
	2019	915.7	952.5	1122.9	NS
	2020	526.8	810.8	488.5	NS
	7-year average	589.9	924.4	859.3	NS

^aNS = not significant

Table 6. Regression analysis for seed yield (y) response to irrigation (x) (inches/season) for *Lomatium dissectum*, *L. grayi*, and *L. triternatum* using the equation $y = a + bx + cx^2$, 2006–2020, and 12- 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.

<i>Lomatium dissectum</i>								
Year	Intercept	Linear	Quadratic	R^2	P	Maximum yield lb/acre	Water applied plus spring precip. for maximum yield inches/season	Spring precipitation inch
2009	-922.0	307.9	-16.9	0.60	0.05	478	9.1	4.1
2010	-178.3	128.3	-5.9	0.51	0.05	514	10.8	4.3
2011	-1669.6	618.7	-31.4	0.86	0.001	1380	9.9	4.8
2012	293.9	43.4	-2.8	0.07	NS			2.6
2013	407.0	148.1	-7.0	0.68	0.01	1186	10.5	0.9
2014	9.7	211.4	-7.4	0.83	0.001	1524	14.3	1.7
2015	24.5	198.4	-6.9	0.78	0.01	1441	14.3	3.2
2016	916.9	88.2		0.42	0.05	1623	10.2	2.2
2017	134.7	139.9	-8.2	0.40	0.10	730	8.5	4.0
2018	-36.2	68.0	-3.6	0.67	0.01	281	9.3	1.9
2019	-279.2	229.9	-11.1	0.66	0.05	911	10.4	4.7
2020	-107.5	38.2		0.77	0.001	198	8.3	4.3
Average	-125.0	199.9	-10.2	0.90	0.001	856	9.8	3.2
<i>Lomatium grayi</i>								
Year	Intercept	Linear	Quadratic	R^2	P	Maximum yield lb/acre	Water applied plus spring, winter, and fall precip. for max. yield inches/season	Spring, winter, fall precipitation inch
2007	-36.6	12.0		0.26	0.10	59	14.2	6.19
2008	-2721.1	621.3	-23.0	0.93	0.001	1475	13.5	6.65
2009	17.8	40.8		0.38	0.05	344	16.8	8.8
2010	-2431.4	495.9	-17.1	0.22	NS			11.7
2011	-1335.1	234.7	-7.1	0.07	NS			14.5
2012	-778.8	172.8	-6.2	0.66	0.01	418	13.8	8.4
2013	344.3	55.0		0.25	0.10	1075	13.3	5.3
2014	-4502.3	890.8	-33.2	0.64	0.05	1477	13.4	8.1
2015	-3980.4	617.7	-20.9	0.71	0.01	579	14.8	10.4
2016	-2046.2	403.1	-15.1	0.66	0.01	651	13.4	9.1
2017	461.9	-10.9		0.22	NS			12.7
2019	754.6	1.5	-0.8	0.2	NS			12.9
2020	-781.5	147.6	-6.5	0.23	NS			8.8
Average	-1239.9	278.6	-10.2	0.49	0.05	664	13.7	9.8
<i>Lomatium triternatum</i>								
Year	Intercept	Linear	Quadratic	R^2	P	Maximum yield lb/acre	Water applied plus spring precip. for maximum yield inches/season	Spring precipitation inch
2007	-2.6	3.1		0.52	0.01	28	9.9	1.92
2008	-245.1	332.1	-16.9	0.77	0.01	1390	9.8	1.43
2009	-1148.3	416.1	-22.0	0.83	0.001	824	9.5	4.1
2010	-586.2	625.4	-25.9	0.83	0.001	3196	12.1	4.3
2011	-400.3	684.1	-38.7	0.45	0.10	2623	8.8	4.8
2012	-123.6	158.4	-7.3	0.52	0.05	734	10.8	2.6
2013	-3.8	192.2	-8.3	0.68	0.01	1115	11.6	0.9
2014	-22.7	157.4		0.97	0.001	1509	9.7	1.7
2015	101.8	69.0		0.51	0.01	875	11.2	3.2
2016	313.9	30.4		0.29	0.10	624	10.2	2.2
2017	717.1	41.7		0.20	NS	1217	12.0	4.0
2018	-28.7	18.3	-1.1	0.52	0.05	48	8.4	1.9
2019	-627.0	303.7	-15.9	0.44	0.10	823	9.6	4.7
2020	-18.0	14.6		0.45	0.05	103	8.3	4.3
Average	18.5	182.1	-8.4	0.80	0.001	1011	10.9	3.2

Table 7. Regression analysis for seed yield response to irrigation rate (inches/season), 2012–2020, for three selections of *Lomatium dissectum* planted in 2009. 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.

<i>Lomatium dissectum</i> LODI Riggins						Water applied plus spring precipitation for maximum yield	Spring precipitation	
Year	Intercept	Linear	Quadratic	R^2	P	Maximum yield lb/acre	inches/season	inch
2014	82.1	129.9	-10.0	0.57	0.05	503	6.5	1.7
2016	-113.8	218.4	-14.6	0.63	0.05	703	7.5	2.2
2017	262.3	15.6		0.37	0.05	387	8.0	4.0
2018	-4.9	40.1	-2.6	0.71	0.01	153	7.8	1.9
2019	-595.0	230.6	-11.6	0.75	0.01	551	9.9	4.7
2020	-1406.7	535.9	-41.5	0.58	0.05	322	6.5	4.3
Average	-136.8	139.9	-8.5	0.78	0.01	440	8.2	3.2
<i>Lomatium dissectum</i> LODI 38								
2014	186.6	66.1	-6.4	0.11	NS			1.7
2015	901.8	-11.3		0.01	NS			3.2
2016	311.0	85.9	-5.4	0.32	NS			2.2
2017	28.2	117.9	-6.2	0.38	NS			4.0
2018	184.5	17.3		0.33	0.10	355	9.9	1.9
2019	334.0	50.4	-3.4	0.07	NS			4.7
2020	-1848.0	773.5	-60.3	0.39	NS			4.3
Average	250.2	76.5	-5.1	0.14	NS			3.2
<i>Lomatium dissectum</i> LODI 41								
2014	222.2	29.1	-4.8	0.13	NS			1.7
2015	-587.4	286.5	-17.6	0.67	0.01	576	8.1	3.2
2016	181.3	29.4	-1.7	0.18	NS			2.2
2017	-64.2	86.9	-4.2	0.70	0.01	388	10.4	4.0
2018	41.9	5.5		0.34	0.05	86	8.0	1.9
2019	-256.8	115.0	-5.3	0.56	0.05	367	10.8	4.7
2020	-499.3	201.0	-15.2	0.51	0.05	164	6.6	4.3
Average	-62.3	87.8	-5.3	0.58	0.05	301	8.3	3.2

Table 8. Regression analysis for seed yield response to irrigation rate (inches/season), 2012–2020, for *Lomatium nudicaule* and *L. suksdorfii* planted in 2009. 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.

<i>Lomatium nudicaule</i>						Maximum yield lb/acre	Water applied for maximum yield inches/season
Year	Intercept	Linear	Quadratic	R ²	P		
2012	53.8	34.1	-4.1	0.18	NS		
2013	357.6	47.5	-3.0	0.11	NS		
2014	704.5	-13.8		0.08	NS		
2015	430.6	2.9	-2.3	0.15	NS		
2016	363.0	24.1	-3.5	0.07	NS		
2017	53.7	33.2	-1.7	0.75	0.01	218	9.9
2018	17.1	10.6	-1.1	0.26	NS		
2019	335.4	29.0	-3.9	0.29	NS		
2020	66.7	-4.1		0.49	0.05	67	0
Average	264.4	18.6	-2.2	0.09	NS		

<i>Lomatium suksdorfii</i>						Maximum yield lb/acre	Water applied for maximum yield inches/season
Year	Intercept	Linear	Quadratic	R ²	P		
2014	162.6	11.5	-1.8	0.01	NS		
2015	753.9	125.3		0.43	0.05	1756	8.0
2016	692.6	131.2	-19.9	0.17	NS		
2017	750.7	422.4	-44.0	0.39	NS		
2018	346.7	195.8	-21.3	0.35	NS		
2019	889.0	25.9		0.06	NS		
2020	526.8	146.8	-19.0	0.13	NS		
Average	589.9	133.6	-12.5	0.27	NS		

Table 9. Amount of irrigation water plus precipitation for maximum *Lomatium* 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 plus precipitation inches	Critical precipitation period	Years to first seed set from fall planting	Life span years
<i>Lomatium dissectum</i>	2.8–9.5 ^a	spring	4	14+
<i>Lomatium grayi</i>	13.7	fall, winter, and spring	2	14+
<i>Lomatium nudicaule</i>	no response in 8 out of 9 years, 10 inches in 2017	undetermined	3	9+
<i>Lomatium suksdorfii</i>	no response in 6 out of 7 years, 8 inches irrigation in 2015	undetermined	5	9+
<i>Lomatium triternatum</i>	10.9	spring	2	14+

^aThe amount of recommended irrigation plus precipitation varied with the *L. dissectum* seed source.