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Cultivation and Irrigation of Fernleaf Biscuitroot *(Lomatium dissectum)* for Seed Production

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***Abstract*. Native grass, forb, and shrub seed is needed to restore rangelands of the U.S. Intermountain West. Fernleaf biscuitroot [*Lomatium dissectum* (Nutt.) Mathias & Constance] is a desirable component of rangelands. Commercial seed production is necessary to provide the quantity and quality of seed needed for rangeland restoration and reclamation efforts. Fernleaf biscuitroot has been used for hundreds if not thousands of years in the western United States as a source of food and medicine. Knowledge about fernleaf biscuitroot is confined to ethnobotanical reports, evaluation of some of its chemical constituents, and its role in rangelands. Products derived from fernleaf biscuitroot are sourced from wild plant populations. Little is known about fernleaf biscuitroot cultivation or its seed production. Variations in spring rainfall and soil moisture result in highly unpredictable water stress at flowering, seed set, and seed development of fernleaf biscuitroot. Water stress is known to compromise seed yield and quality for other seed crops. Irrigation trials were conducted at the Oregon State University Malheur Experiment Station at Ontario, OR, a location within the natural environmental range of fernleaf biscuitroot. It was anticipated that supplemental irrigation would be required to produce a seed crop in all years. Fernleaf biscuitroot was established through mechanical planting and cultivation on 26 Oct. 2005 in a randomized complete block design with four replicates; plot size was 9.1 m × 3.04 m wide. Irrigation treatments were 0 mm, 100 mm, and 200 mm/year applied in four equal treatments 2 weeks apart, timed to begin with flowering and continue through seed formation. First flowering occurred in the third year after planting. Seed production increased from the fourth through the sixth year. Optimal irrigation for seed production was calculated as 140 mm/year.**

Fernleaf biscuitroot or desert parsley [*Lomatium dissectum* (Nutt.) Mathias & Constance] is a long-lived forb (non-woody perennial wildflower) with yellow, purple, or green/brown flowers native to the western United States. The shoot develops from the crown of a large taproot in early spring using the natural moisture from snow melt and spring rain. Fernleaf biscuitroot can start flowering before the last frosts, but floral development may suffer from hard freezes. Flowers are in compound umbels atop stalks that range from 60 to 150 cm (2 to 5 ft) in height. The highly dissected leaves have a fern-like appearance and are often over 40 cm (15 in) in length (Thompson, 1998). Plants initiate growth in early spring and complete vegetative growth, flowering, and seed set by early to midsummer. After seed set, the leaves die back during midsummer. Plants are dormant during summer and do not resume growth with fall rains.

L. dissectum is self-fertile and protogynous and bee pollination is necessary for fernleaf biscuitroot seed production. *Halictus* sweat bees and *Apis* honeybees have been observed in production stands of fernleaf biscuitroot in Ontario, OR. In nature, there are other bees that specialize in pollinating fernleaf biscuitroot (Jim Cane, USDA-ARS Pollinating Insects–Biology, Management, and Systematics Research Unit, personal communication).

L. dissectum grows at elevations from sea level to 2500 m in western North America from southern California to British Columbia to the Rocky Mountains, mostly on rocky soils and in meadows (Meilleur et al., 1990; Soltis et al., 1997). Highly fertile, well-drained, and rocky soils are preferred environments where *L. dissectum* grows into large clumps 1.0 to 1.2 m (3 to 4 ft) wide. It can grow in a range of precipitation regimes, including semiarid conditions. Three varieties, *L. dissectum* var. *dissectum*, *L. dissectum* var. *eatonii*, and *L. dissectum* var. *multifidum*, have been recognized indicating a considerable range of variation in the species; however, the varieties intergrade and there is disagreement as to whether varietal separation is warranted (Cronquist et al., 1997; Soltis et al., 1997).

Current State of Knowledge

Lomatium dissectum was used by Native American populations as food, medicine, and a piscicide. Specific uses described in historic, ethnobotanical records cannot be verifiably linked to *L. dissectum* as a result of the morphological similarities, especially in leaf morphology, among some *Lomatium* spp. and revisions of taxonomic classifications after the ethnobotanical studies (Ebeling, 1986; Jones, 1941; Meilleur et al., 1990). More than half of the *Lomatium* spp. are relatively rare with geographically restricted ranges (Soltis et al., 1997) making proper identification by a generally trained ethnobotanist less likely and perpetuating possible cases of folk underdifferentiation, the use of one folk name for two closely associated Linnaean species (Hunn and Brown, 2011). Of the 70 to 80 *Lomatium* species from western North America, only 20 occur in the ethnobotanical literature (Moerman, 2012).

Recent pharmacological research has demonstrated antiviral and antibacterial effects of *L. dissectum*. In laboratory studies, root extracts have inhibited rotavirus (a cause of severe childhood diarrhea), *Mycobacterium tuberculosis* (one cause of tuberculosis), and *Mycobacterium avium* (McCutcheon et al., 1995, 1997). *Lomatium dissectum* has shown no activity against a variety of other viruses and bacteria: bovine coronavirus (BCV, Coronaviridae), bovine herpesvirus type 1 (BHVl, Herpesviridae), bovine parainfluenza virus type 3 (BP13, Paramyxoviridae), bovine respiratory syncytial virus (BRSV, Paramyxoviriaize), vaccinia virus (Poxviridae), and

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vesicular stomatitis virus (VSV, Rhabdoviridae), *Mycobacterium aurum*, and *Mycobacterium smegmatis* (McCutcheon et al., 1995, 1997; Newton et al., 2002). *L. dissectum* also showed no antifungal activity in a screening against nine fungi (McCutcheon et al., 1994). McCutcheon and colleagues' studies (1994, 1995, and 1997) did not seek to isolate the specific active components in the roots. VanWagenen and Cardellina (1986) isolated two tetronic acids from *L. dissectum* as the principal antimicrobial metabolites based on the CH_2Cl_2-soluble extract from one whole plant. Four water-soluble constituents of *L. dissectum* that may inhibit bacterial and fungal growth have also been isolated, a flavonoid glycoside and three coumarin glycosides (VanWagenen et al., 1988). Links have yet to be drawn between the active components of the plant and the specific viruses or bacteria they act against.

Essential oils have been extracted and described from *L. dissectum*. The aromaticity was found to be primarily in the roots as opposed to the fruits and foliage. Based on the content of longifolene and ester in root oils, it may be possible to distinguish between *L. dissectum* var. *dissectum*, containing higher percentages of ester, and *L. dissectum* var. *multifidum*, containing more longifolene (Bairamian et al., 2004). The higher percentages of essential oils in *L. dissectum* roots is not a characteristic of the genus; the percentages are low in other studied *Lomatium* species, specifically *L. dasycarpum, L. lucidum*, *L. macrocarpum*, and *L. utriculatum* (Asuming et al., 2005). Neither studies of the essential oils nor pharmacological components of *L. dissectum* have discovered why its root extract can function as a piscicide (Bairamian et al., 2004; Meilleur et al., 1990). The geographic distribution of *L. dissectum* chemical properties is unknown.

On modern rangelands, *L. dissectum* serves as the host to *Depressaria leptotaeniae* moth larvae that feed on umbel sheaths and umbels (Clarke, 1953; Thompson, 1983). *Depressaria betina* larvae have also been found on the plants. *Depressaria* spp. have high degrees of host specificity. *Lomatium dissectum* is also a preferred food of grazing animals and some birds, its roots are eaten by rodents, and its seeds are a desirable food for some insects and mammals (Thompson, 1985, 1998). Natural plant populations of *L. dissectum* are also attacked by *Puccinia* spp. rust and insect pests including *Phytomyza* spp. leaf miner and *Contarinia* spp. gall flies (Thompson, 1998). We have observed aphids on native plant stands, but the species of aphids was not identified.

Germination of *L. dissectum* occurs after a vernalization period of three to four months with soil temperatures below 4.5 °C (Scholten et al., 2009). The authors are unaware of any prior research into the production of *L. dissectum* leaves, roots, or other plant parts. Production of native forb seed crops depends on establishing best management practices for plant establishment, weed control, pest control, irrigation, and plant pollination. The focus of this article is on irrigation criteria for growing *Lomatium dissectum* for seed production. Irrigation directly affects seed yield. This research also included successful practices for plant establishment and weed control.

Methods

An irrigation trial for forb species including *Lomatium dissectum*, *L. grayi*, and *L. triternatum* was initiated in 2005 at the Malheur Experiment Station of Oregon State University, Ontario, OR. *Lomatium dissectum* seed came from wild collections made by the U.S. Forest Service near the Mann Creek Reservoir, Washington County, ID (lat. 44.401° N, long. –116.898° W, 850 m) in 2002 and 2004.

The field, a Nyssa silt loam (coarse-silty, mixed, mesic, Xeric Haplodurid), was bedded into 76-cm (30 in) rows. Drip tape (T-Tape TSX 515-16-340) was buried at 30 cm (1 ft) depth and spaced 1.52 m (5 ft) apart beneath alternating interrow spaces. The flow rate for the drip tape was 4.16 L/min/100 m (0.34 gal/min/100 ft) at 55 kPa (8 PSI) with emitters spaced 41 cm (16 in) apart, resulting in a water application rate of 1.7 mm/h (0.066 in/h). Water was filtered through sand media filters and application duration was controlled automatically.

Initially all *Lomatium* species were vernalized in the same manner. In 2005, seed was vernalized at 1 °C for 5.5 weeks until *L. grayi* and *L. triternatum* began to germinate. Seed was planted on 3 Mar. 2005 using a custom-made plot grain drill with disk openers at 1.25 cm depth with 65–100 seeds/m of row. Unlike the other two *Lomatium* species, *L. dissectum* did not emerge and the entire rows were replanted from the same seed lot at 65 seeds/m using the planter on 26 Oct. 2005 so that natural, winter vernalization could occur. In the spring of 2006, the plant stand was excellent.

In Apr. 2006, the *L. dissectum* strip was divided into four plots 9.1 m long. Each plot contained four 0.76-cm rows. The experimental design was randomized complete blocks with four replicates. The three irrigation treatments were control (0 mm/year), 100 mm/year (4 in/year), and 200 mm/year (8 in/year). The 100-mm and 200-mm irrigation treatments received four irrigations, ≈2 weeks apart, starting during forb flowering. Each irrigation was scheduled to deliver 25 mm (100-mm treatment) or 50 mm (200-mm treatment) through the drip system. The amount of water applied was measured by a water meter and recorded after each irrigation (Table 1). In 2007, irrigation treatments were inadvertently continued after the fourth irrigation doubling the planned irrigation amounts.

In Mar. 2007, the drip irrigation system was modified to allow separate irrigation of the forb species as a result of differing onset dates of flowering. The three *Lomatium* spp. were irrigated together. Flowering dates for *Lomatium dissectum* were recorded and are reported in conjunction with the irrigation dates in Table 2. Seed was harvested and cleaned by hand. Seed quality was not determined.

Soil volumetric water content was measured several times each season by a neutron probe. The neutron probe was calibrated by taking soil samples and probe readings at 20 cm, 50 cm, and 80 cm 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 analysis of a soil sample taken on 22 Nov. 2005 showed a pH of 8.3, 1.09% organic matter, 12 ppm P_2O_5, 438 ppm potassium, 27 ppm SO_4-S, 4370 ppm calcium, 456 ppm magnesium, 81 ppm sodium, 1.6 ppm zinc, 0.6 ppm copper, 4 ppm manganese, 3 ppm iron, and 0.6 ppm boron. Fertilization of the irrigation trial over the six years was minimal. On 27 Oct. 2006, 56 $kg·ha^{-1}$ phosphorus (P) and 2.2 $kg·ha^{-1}$ zinc were injected through the drip tape. On 11 Nov. 2006, 112 $kg·ha^{-1}$ nitrogen (N) as urea was broadcast. On 9 Apr. 2009, 56 $kg·ha^{-1}$ N and 11 $kg·ha^{-1}$

Table 1. Water applied to the 100-mm and 200-mm irrigation treatments of *Lomatium dissectum* from 2006 to 2011 at Ontario, OR.

	Actual water applied (mm)					
Target irrigation rates	2006	2007	2008	2009	2010	2011
100 mm	124	233[z]	137	104	103	102
200 mm	221	448[z]	218	204	202	202

[z]Irrigation in error.

Table 2. *Lomatium dissectum* flowering, irrigation, and seed harvest dates at Ontario, OR.

	Flowering		Irrigation		
Yr	Start	End	Start	End	Harvest
2006	No flowering		19 May	30 June	None
2007	No flowering		5 April	24 June	None
2008	Very little flowering		10 Apr.	29 May	None
2009	10 Apr.	7 May	20 Apr.	28 May	16 June
2010	25 Apr.	20 May	15 Apr.	28 May	21 June
2011	8 Apr.	10 May	21 Apr.	7 June	20 June

P were applied through the drip irrigation system. On 3 May 2011, 56 kg·ha^{-1} N was applied through the drip irrigation system. Precipitation from October through June was 407, 158, 157, 225, 303, and 374 mm for 2006 through 2011, respectively.

During the first two years (2005 and 2006), weeds were controlled primarily with cultivation and hand rouging. Herbicides were screened for their effectiveness and plant tolerance in other trials (Shock et al., 2010), but these products are not yet registered for use. In the irrigation trial, Prowl® (pendimethalin) at 1.1 kg a.i./ha was broadcast on the soil surface for weed control on 17 Nov. 2006, 9 Nov. 2007, 15 Apr. 2008, 18 Mar. 2009, 4 Dec. 2009, and 17 Nov. 2010. Volunteer® (clethodim) was broadcast at 0.57 L·ha^{-1} on 18 Mar. 2009. Hand rouging of weeds continued.

Seed yield was determined by manual once-over harvest of all mature seed stalks in the middle 7.5 m of the two center rows. Seed was cleaned from stalks and chaff and weighed. Seed yield means were compared by protected analysis of variance and nonlinear regression of seed yield against applied water.

Results and Discussion

Lomatium dissectum seed planted in the fall of 2005 germinated in the spring of 2006 after natural vernalization during the winter. The failure of *L. dissectum* to germinate in the spring of 2005 after 5.5 weeks vernalization is consistent with the findings of Scholten et al. (2009) who determined that 12 weeks of vernalization were necessary for emergence. Planting seed at 1.25 cm depth provided adequate emergence without supplemental irrigation. Subsequently, improved seedling establishment of native rangeland plants has been shown with fall seed planting under row cover (Shock et al., 2011). *Lomatium dissectum* vegetative growth was slow over the first three years (2006–08) and plants produced a few flowers in 2008. In 2009, vegetative growth and flowering for *L. dissectum* were greater and seed was harvested. *L. dissectum*, *L. grayi*, and *L. triternatum* were affected by *Alternaria* spp. fungi, but the infection was greatest and persistent on the *L. dissectum*. This infection likely delayed *L. dissectum* plant development and seed production. The resistance of *L. dissectum* to *Alternaria* spp. appears to vary by the selection chosen. The irrigation trial was planted using seed from a single *L. dissectum* seed collection site; other selections of *L. dissectum* used in different trials in Ontario, OR, have been observed to suffer from less *Alternaria* infection.

Lomatium dissectum produced seed in its fourth year of growth. Although changes in biomass were not tracked quantitatively, the plants have grown larger since their first seed set. The increase in plant size between 2009 and 2011 is consistent with the increased seed production across treatments (Table 3).

Plant irrigation needs for survival and some seed production are met by the natural precipitation in Ontario, OR, which lies within the native range of the species (Table 4); however, the addition of supplemental irrigation significantly influenced seed yield. In both 2010 and 2011, seed yield showed a quadratic response to irrigation rate (Fig. 1). In 2010, seed yield was estimated to be maximized by 161 mm of applied water. In 2011, the optimum was at 127 mm. Averaged over the three years, seed yield showed a quadratic response to irrigation rate and was estimated to be maximized by 140 mm of applied water [Fig. 1 and Eq. (4)]. The total of 140 mm may actually underestimate typical annual irrigation needs because both 2010 and 2011 were unusually wet before *L. dissectum* growth (Table 4).

Letting annual seed yield be Y in kg·ha^{-1} and applied irrigation to be X in millimeters, the data in Figure 1 fits the following equations:

$$Y_{2009} = 80.3 + 1.55 * X, \quad R^2 = 0.30,\ P(0.10) \qquad [1]$$

$$Y_{2010} = 297 + 3.44 * X - 0.0107 * X^2, \quad R^2 = 0.51,\ P(0.05) \qquad [2]$$

$$Y_{2011} = 635 + 14.3 * X - 0.0562 * X^2, \quad R^2 = 0.86,\ P(0.001) \qquad [3]$$

$$Y_{2009-2011} = 330 + 6.91 * X - 0.0247 * X^2, \quad R^2 = 0.72,\ P(0.01). \qquad [4]$$

Because substantial seed yields of *L. dissectum* were achieved under cultivation, it is reasonable to assume that other plant parts could also be grown for medicinal or pharmacological use.

Seed yield in 2011 was substantially higher at all irrigation levels. The relatively high yield without any irrigation in 2011 may have been the result of greater plant

Table 3. *Lomatium dissectum* seed production by year and irrigation treatment at Ontario, OR.

Yr	0 mm	100 mm	200 mm	LSD (0.05)
	(kg/ha)			
2006	No flowering			
2007	No flowering			
2008	Very little flowering			
2009	56.7	282.8	367.1	NS
2010	297.8	535.2	559.6	NS
2011	635.6	1503.9	1247.5	202.6
3-year average	330	774	724.7	219.2

LSD = least significant difference; NS = non-significant.

Table 4. Natural precipitation in Ontario, OR, over the course of the irrigation trial before and during *Lomatium dissectum* growth and seed production.

	Precipitation (mm)			Growing degree-days (10 to 30 °C)
Yr	October to June	January to June	April to June	January to June
2006	407	229	79	622
2007	158	79	48	671
2008	157	74	30	520
2009	225	147	99	571
2010	303	211	109	433
2011	374	211	98	373
21-year average	248	147	69	569

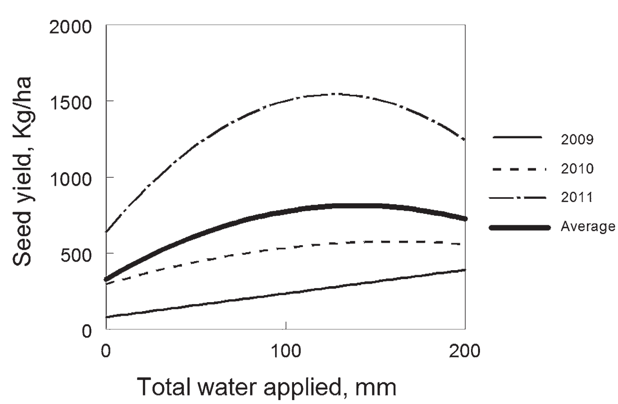

Fig. 1. *Lomatium dissectum* seed yield at Ontario, OR responded linearly to irrigation in 2009 and in a quadratic fashion in 2010 and 2011. The seed yield response averaged over the three years was also quadratic.

Table 5. Soil moisture averaged over 0.20-, 0.50-, and 0.80-m depths as determined by neutron probe in plots where *Lomatium dissectum* was grown with variable irrigation, 2009–2011, Ontario, OR.

			Annual irrigation (mm)		
			0	100	200
Yr	Calendar day	Day of the yr	Percent volumetric water content		
2009					
	24 Apr	114	19.62	22.45	29.26
	7 May	127	21.89	22.63	28.46
	20 May	140	19.19	22.84	30.93
	1 June	152	18.42	20.76	29.56
2010					
	13 Apr.	103	20.20	21.40	26.09
	4 May	124	19.00	23.98	27.00
	12 May	132	18.20	21.15	27.65
	26 May	146	18.67	19.67	27.21
	18 June	169	18.55	21.74	29.17
2011					
	31 Mar.	90	25.59	27.57	30.26
	22 Apr.	112	21.49	24.86	30.27
	17 May	137	19.10	22.99	27.13
	3 June	154	18.69	22.12	28.56

development and substantially wetter soil at the beginning of the 2011 growing season (Table 5).

Conclusions

Lomatium dissectum was successfully established with mechanical fall planting after a spring planting failed. Drip irrigation was an effective irrigation system. Seed production was delayed until the fourth year and continued to increase through the sixth crop year. Considering seed yield over the fourth through sixth years, the optimal irrigation amount at Ontario, OR, was calculated to be 140 mm/year.

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