

Irrigation Requirements for Seed Production of Three Leguminous Wildflowers of the U.S. Intermountain West

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Abstract. Increasing the supply of native wildflower seed is essential for restoring burned and degraded wildlands in the Intermountain West. Limitations to wildland seed collection necessitate development of effective cultural practices to improve reliability of seed production in agricultural fields. Irrigation trials were conducted over multiple years for three perennial species in the Fabaceae family [*Dalea ornata* (Douglas ex Hook.) Eaton & J. Wright, *Dalea searlsiae* (A. Gray) Barneby, and *Astragalus filipes* Torr. ex A. Gray]. Each of the three species was grown at the Oregon State University Malheur Experiment Station, Ontario, OR and received 0, 100, or 200 mm·year⁻¹ of drip irrigation in four equal biweekly increments during bud formation and flowering. Seed yield responses to irrigation were evaluated by linear and quadratic regression 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. In general, seed yields responded quadratically to irrigation. Adding fall, winter, and spring precipitation to applied water improved the accuracy of estimated water requirements for maximum seed production of *D. ornata* and *D. searlsiae*. For *D. ornata*, the highest yields averaged 396 kg·ha⁻¹ and ranged from 146 to 545 kg·ha⁻¹. Averaged over 6 years, seed yield of *D. ornata* was highest with applied water plus fall, winter, and spring precipitation totaling 393 mm. For *D. searlsiae*, the highest yields averaged 260 kg·ha⁻¹ and ranged from 51 to 424 kg·ha⁻¹. Averaged over 6 years, seed yield of *D. searlsiae* was highest with applied water plus fall, winter, and spring precipitation totaling 412 mm. Seed yields of *A. filipes* ranged from 7 to 110 kg·ha⁻¹ depending on year and averaged 40 kg·ha⁻¹ over 6 years. Seed yields of *A. filipes* did not respond to irrigation in any of the 5 years of testing.

Restoration of lands in the Intermountain West following wildfire or disturbances resulting from mining, energy development, or other human activities requires increased

supplies of high-quality native seeds appropriate for local site conditions (Oldfield and Olwell, 2015). By “Intermountain” West, we are referring to the “Great Basin” in the western United States between the west coast mountain ranges and the Rocky Mountains. Recent emphasis on inclusion of native wildflowers in seed mixes derives from the need to restore and maintain diverse and resilient native plant communities that provide habitat for wildlife and contribute to the conservation of native pollinator populations (Olwell and Riibe, 2016). Species capable of surviving and recovering rapidly following wildfire are especially valuable additions to seed mixes. Native wildflowers are highly diverse and represent a range of plant families. Adding priority wildflower species to the list of materials available for ecological restoration necessitates development of cultural practices for seed increase in agricultural settings as adequate seed supplies of most species

cannot be obtained through wildland collections (Shaw and Jensen, 2014). Economical commercial production of these species requires development of cultural practices specific to each species (Shock et al., 2015).

Legumes (Fabaceae) are valuable in the Great Basin ecosystem, because they can provide biologically fixed nitrogen to associated species and can enhance forage quality of rangelands. The three species in this study [*D. ornata* (Douglas ex Hook.) Eaton & J. Wright, *D. searlsiae* (A. Gray) Barneby, and *A. filipes* Torr. ex A. Gray] are long-lived perennials native to the western United States. These three species are important components of rangeland ecosystems of the intermountain West and are nontoxic to herbivores (Bhattarai et al., 2008, 2010). *Dalea ornata* and *A. filipes* occur in the northern Intermountain area and *D. searlsiae* is found in southwestern Intermountain area.

These species are dormant in the winter. Shoots of these plants grow from the crown of a taproot in early spring using the natural moisture from snow melt and spring rain. Vegetative growth, flowering, and seed set are complete by late spring to early summer. Some species of the genus *Astragalus* are eaten by sage-grouse chicks (Drut et al., 1994) and by bighorn sheep in northwestern Mexico (Tarango, et al., 2002). Plants of the genus *Dalea* are likely preferred by sage-grouse (Stiver et al., 2015). *Astragalus* and *Dalea* are recommended to provide habitat for pollinators (Cane and Love, 2016). The three species included in this research and likely other members of these genera are tolerant of burning and provide nectar for recovering bee populations by the first or second year after fire (B. Love and J.H. Cane, personal communication).

Commercial seed production of *Dalea* spp. and *Astragalus* spp. is needed for use in rangeland restoration plantings within their native ranges in the Intermountain West, but these species are rarely cultivated, and cultural practices for seed production are largely unknown. A major limitation to economically viable commercial production of *Dalea* spp. and *A. filipes* seed is achieving stable and consistent seed production from year to year. In native rangelands, natural variation in spring rainfall and soil moisture results in highly unpredictable water stress at flowering, seed set, and seed development, and water stress is known to compromise seed yield and quality for many plant species.

Native wildflowers are not well adapted to row crop production practices. Supplemental water can be provided by sprinkler or furrow irrigation systems, but these irrigation systems risk encouraging weeds and fungal pathogens. Subsurface drip irrigation can reduce wetting of the soil surface and could reduce weed and disease pressure.

The trials reported here tested the effects of three low rates of subsurface drip irrigation on the seed yield of *D. ornata*, *D. searlsiae*, and *A. filipes*. The optimum amount of irrigation for each species was evaluated based not only on the amount of irrigation but also on the amount of seasonal precipitation each year.

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Materials and Methods

Irrigation trials for *D. ornata*, *D. searlsiae*, and *A. filipes* were started in 2009 at the Malheur Experiment Station of Oregon State University, Ontario, OR at 43°58'42.3"N, 117°1'26.8"W at 689 m elevation. Annual precipitation averaged 249 mm during the study, ranging from 179 to 292 mm. The Nyssa silt loam (coarse-silty, mixed, mesic, and Xeric Haplodurid) was bedded into 76-cm rows and four rows were planted to each species. Most of the field lacked topsoil because of land leveling in the 1950s. The analysis of a soil sample taken on 22 Nov. 2005 indicated a pH of 8.3, 1.09% organic matter, 12 ppm phosphorus (P), 438 ppm potassium, 27 ppm SO₄-S, 4370 ppm calcium, 456 ppm magnesium, 81 ppm sodium, 1.6 ppm zinc (Zn), 0.6 ppm copper, 4 ppm manganese, 3 ppm iron (Fe), and 0.6 ppm boron.

Drip tape (T-Tape TSX 515-16-340) was buried at 30-cm depth and spaced 1.52 m apart beneath alternating interrow spaces. The flow rate for the drip tape was 4.16 L·min⁻¹ per 100 m of tape at 55 kPa with emitters spaced 41 cm apart, resulting in a water application rate of 1.7 mm·h⁻¹. Water was filtered through sand media filters. Application durations were controlled automatically as described in the following paragraphs.

Seed of each species came from pooled wild collections made by USDA Agricultural Research Service employees. Seeds of *D. ornata*, *D. searlsiae*, and *A. filipes* were planted on 25 Nov. 2009 in four rows spaced 76 cm apart using a custom-made small-plot grain drill with disk openers. Rows of seeds were 38 cm to each side of the buried drip tapes. Seed was planted on the soil surface with 65–100 seeds/m of row. After planting, sawdust was applied in a narrow band over the seed row at 24 g·m⁻¹ of row. Following planting and sawdust application, the beds were covered with rowcover (N-sulate; DeWitt Co., Inc., Sikeston, MO). Each rowcover extended across two rows and was applied with a mechanical plastic mulch layer. The field was irrigated for 24 h on 2 Dec. 2009 because of very dry soil conditions. After the newly planted wildflowers emerged, the rowcover was removed in Apr. 2010. The variable irrigation treatments were not applied to these legumes until 2011.

In Apr. 2011, each legume strip was divided into twelve 9.1-m-long plots. Each plot contained four rows spaced 76 cm apart. The irrigation experimental design for each species had a randomized complete block design with four replications.

The three irrigation treatments were 0 mm·year⁻¹ (control), 100 mm·year⁻¹, and 200 mm·year⁻¹ of additional water. The 100 and 200-mm irrigation treatments received four irrigations, 2 weeks apart, starting at the beginning of flowering. Each irrigation supplied 25 mm (100-mm treatment) or 50 mm (200-mm treatment) of water. The drip irrigation system was designed to allow separate irrigation of the species because of different timings of flowering and seed formation. The

irrigation treatments of the two *Dalea* spp. were applied together. The *A. filipes* was irrigated separately to correspond to its flowering and seed set dates. Flowering dates for each species were recorded and are reported in conjunction with the irrigation dates in Table 1.

Weeds were controlled primarily with cultivation and hand weeding. Harvested seed pods of *D. ornata*, *D. searlsiae*, and *A. filipes* were extensively damaged from feeding by seed beetles in 2013 (Cane et al., 2013). Damage was observed in 2014, but to a lesser degree than in 2013. Control measures were started in 2015 for *D. ornata* and *D. searlsiae*. Adult weevils were observed on flowers in mid-May 2015. On 21 May 2015, Capture[®] 2EC (bifenthrin) at 0.05 kg a.i./ha and Rimon[®] (novaluron) at 0.04 kg a.i./ha were broadcast sprayed in the evening to minimize harm to pollinators. On 28 May 2015, Rimon[®] at 0.04 kg a.i./ha was again broadcast sprayed in the evening to minimize harm to pollinators. Seed beetles were not observed during flowering in 2016.

Seed yield was determined by a manual once-over harvest of all seed stalks in the middle 7.5 m of the two center rows of the four-row plots. The seed was cleaned from stalks and chaff and weighed. Seed yield responses to irrigation were evaluated by linear and quadratic regression. Seed yield for each species each year was 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 calendar year that the yield was determined; fall precipitation occurred the previous year. Seed yield (*y*, kg·ha⁻¹) in response to irrigation or irrigation plus precipitation (*x*, mm/season) was estimated by the equation $y = a + b \times x + c \times x^2$. For the quadratic equations, the amount of irrigation (*x'*) that resulted in maximum yield (*y'*) was calculated using the formula $x' = -b \times (2c)^{-1}$, where *a* is the intercept, *b* is the linear parameter, and *c* is the quadratic parameter and the maximum yield was considered the “highest” yield. For the linear regressions, the highest seed yield for a species in each year was based on the highest measured average seed yield.

Adding the seasonal precipitation to the irrigation response equation would have the potential to provide a closer estimate of the amount of irrigation water required for maximum seed yield for each species each year. Regressions of seed yield for each species each year were calculated on all the sequential seasonal amounts of precipitation and irrigation, but only the regressions that improved the estimated water requirements are reported in the following paragraphs. For each species, 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. To compare yield responses over years, regressions were also made on the relative seed yields compared with irrigation plus precipitation. Relative seed yield for each plot was calculated

Table 1. Flowering, irrigation, and seed harvest dates for three wildflower species grown at the Oregon State University Malheur Experiment Station, Ontario, OR, 2011–16.

Species	Yr	Flowering dates			Irrigation dates		Harvest date
		Start	Peak	End	Start	End	
<i>Dalea searlsiae</i>	2011	8 June	20 June	20 July	27 May	6 July	21 July
	2012	23 May	10 June	30 June	11 May	21 June	10 July
	2013	13 May		15 June	8 May	19 June	29 June
	2014	15 May	4 June	24 June	6 May	17 June	1 July
	2015	13 May	26 May	16 June	5 May	17 June	22 June
	2016	11 May	28 May	10 June	3 May	14 June	16 June
<i>Dalea ornata</i>	2011	8 June	20 June	20 July	27 May	6 July	22 July
	2012	23 May	10 June	30 June	11 May	21 June	11 July
	2013	13 May	21 May	15 June	8 May	19 June	28 June
	2014	15 May	4 June	24 June	6 May	17 June	1 July
	2015	5 May	26 May	22 June	5 May	17 June	25 June
	2016	3 May	26 May	10 June	3 May	14 June	13 June
<i>Astragalus filipes</i>	2011	20 May	26 May	30 June	13 May	23 June	18 July
	2012	28 Apr	23 May	19 June	11 May	21 June	5 July
	2013	3 May	10 May	25 May	8 May	19 June	28 June
	2014	5 May	13 May	28 May	29 Apr.	10 June	24 June
	2015	17 Apr.	13 May	1 June	21 Apr.	3 June	16 June

Table 2. Precipitation and growing degree-days at the Malheur Experiment Station, Ontario, OR, 2011–16.

Yr	Precipitation (mm)			Growing degree-days (10–30 °C)
	Spring	Winter + spring	Fall + winter + spring	January to June
2011	121	235	367	476
2012	66	156	213	682
2013	22	60	135	733
2014	44	130	205	741
2015	82	151	265	895
2016	56	128	255	810
72-year average	67	147	230	23-year average: 665

as the percentage of the yield of the highest yielding treatment for each species for each year. Regressions were also made relating seed yield to growing degree-days.

Results

Both *Dalea* species and *A. filipes* began flowering and producing seed in the second

year after fall planting (Table 1). Both precipitation and growing degree-days showed large year-to-year variation (Table 2). Large year-to-year variations in seed yields also occurred for all three species (Table 3). For the *Dalea* species, seed yields in 2013 were substantially lower than the other years, possibly because of damage from seed-feeding beetles (Cane et al., 2013). Although

there were tremendous variations in seed yields over species and years, general tendencies emerged for the mean seed yields for each species and irrigation treatment.

Dalea ornata, blue mountain prairie clover. Seed yields of *D. ornata* exhibited a quadratic response to irrigation amount each year from 2012 to 2016 (Table 4; Fig. 1A–C). In 2011, seed yields of *D. ornata*

Table 3. Average seed yields of three legume species over multiple years in response to 0, 100, and 200 mm of irrigation during flowering and seed set, Oregon State University Malheur Experiment Station, Ontario, OR.

Species	Yr	0 mm	100 mm	200 mm	Least significant difference (0.05)
		----- (kg·ha ⁻¹) -----			
<i>Dalea searlsiae</i>	2011	294.2	258.9	219.9	56.1
	2012	196.6	323.5	339.4	104.8
	2013	16.6	35.5	49.7	6.8
	2014	67.2	203.2	260.1	81.6
	2015	247.8	370.4	385.5	76.5
	2016	166.5	267.5	249.0	62.7
	Average	164.8	243.1	250.6	34.2
<i>Dalea ornata</i>	2011	506.1	460.1	393.9	NS
	2012	162.5	408.9	483.2	212.0
	2013	32.0	117.2	146.0	43.5
	2014	133.7	473.6	533.5	161.4
	2015	238.4	444.3	299.3	122.8
	2016	275.9	344.9	349.9	NS
	Average	225.6	365.3	371.8	81.3
<i>Astragalus filipes</i>	2011	97.4	110.2	82.9	NS
	2012	25.4	14.1	18.0	NS
	2013	9.5	11.0	6.8	NS
	2014	63.4	88.8	80.5	NS
	2015	19.9	14.0	13.0	NS
	2016	43.2	39.5	40.3	NS
	Average	43.2	39.5	40.3	NS

Table 4. Regression analysis for *Dalea ornata* seed yield (y , kg·ha⁻¹) in response to irrigation (x , mm/season) using the equation $y = a + b \times x + c \times x^2$ in 2011–16, and 6-year average. Irrigation amounts were 0, 100, and 200 mm. For the quadratic equations, the amount of irrigation that resulted in maximum yield was calculated using the formula $x = -b / (2c)^{-1}$, where b is the linear parameter and c is the quadratic parameter, Oregon State University Malheur Experiment Station, Ontario, OR.

Water applied vs. yield								
Yr	Intercept	Linear	Quadratic	R ²	P	Highest yield (kg·ha ⁻¹)	Water applied for highest yield (mm/season)	
2011	509.5	-0.561		0.11	NS	509.5	0.0	
2012	162.5	3.325	-0.00861	0.65	0.01	483.6	193.2	
2013	32.1	1.132	-0.00281	0.88	0.001	146.0	201.4	
2014	133.8	4.800	-0.01401	0.87	0.001	545.0	171.3	
2015	243.4	3.612	-0.01603	0.64	0.05	446.8	112.7	
2016	275.9	2.860	-0.01245	0.55	0.10	440.2	114.9	
Average	215.6	2.405	-0.00801	0.79	0.001	396.1	150.1	
Water applied plus fall, winter, and spring precipitation vs. yield								
Yr	Intercept	Linear	Quadratic	R ²	P	Highest yield (kg·ha ⁻¹)	Water applied plus fall, winter, and spring precipitation for highest yield (mm/season)	Precipitation, fall, winter, and spring (mm)
2011	712.2	-0.552		0.11	NS	509.5	367.0	367.0
2012	-913.5	6.826	-0.00834	0.65	0.01	483.6	409.3	213.1
2013	-167.3	1.847	-0.00272	0.88	0.001	146.0	339.2	134.6
2014	-1410.0	10.301	-0.01357	0.87	0.001	545.0	379.6	205.5
2015	-1788.7	11.785	-0.01553	0.64	0.05	446.8	379.4	264.9
2016	-1228.5	8.972	-0.01206	0.55	0.10	440.2	372.0	255.3
Average	-800.1	6.094	-0.00776	0.79	0.001	396.1	392.6	240.1
Water applied plus fall, winter, and spring precipitation vs. relative yield								
Yr	Intercept	Linear	Quadratic	R ²	P	Water applied plus fall, winter, and spring precipitation for highest relative yield (mm/season)		
2011	140.7	-0.109		0.11	NS	367.0		
2012	-189.1	1.413	-0.00173	0.65	0.01	409.3		
2013	-114.6	1.265	-0.00186	0.88	0.001	339.2		
2014	-264.3	1.931	-0.00254	0.87	0.001	379.6		
2015	-462.3	3.046	-0.00401	0.64	0.05	379.4		
2016	-280.9	2.051	-0.00276	0.55	0.10	372.0		
Average	-212.7	1.620	-0.00206	0.79	0.001	392.6		

did not respond to irrigation. The year 2011 had the highest fall, winter, and spring precipitation and the lowest number of growing degree-days among the 6 years of testing (Table 2). Of the three periods of precipitation evaluated, adding fall, winter, and spring precipitation to applied water resulted in the least variation in the water requirement for maximum seed production of *D. ornata*. The standard deviation of the estimated optimal amount of water decreased with the duration of the period of precipitation considered: 78.8, 57.1, 45.6, and 36.1 mm for irrigation alone, irrigation plus spring precipitation, irrigation plus winter and spring precipitation, and irrigation plus fall through spring precipitation, respectively. The amount of water applied plus fall, winter, and spring precipitation for maximum seed yield, calculated from the regression equations, ranged from 367 mm yielding 509 kg·ha⁻¹ in 2011 to 409 mm yielding 484 kg·ha⁻¹ in 2012. The highest yields averaged 396 kg·ha⁻¹ and ranged from 146 to 545 kg·ha⁻¹. Averaged over 6 years, relative seed yield was highest with applied water plus fall, winter, and spring precipitation totaling 393 mm (Table 4; Fig. 1C). Fall, winter, and spring precipitation provided a substantial amount of the water needed for maximum seed yield, from 40% in 2013 to 100% in 2011.

Dalea searlsiae, Searls' prairie clover. Seed yields of *D. searlsiae* exhibited a quadratic response to irrigation amount in 2012, 2014, 2015, and 2016 (Table 5; Fig. 1DF). In 2011, seed yields of *D. searlsiae* had a negative linear response to irrigation plus fall, winter, and spring precipitation. The year 2011 had the highest fall, winter, and spring precipitation and the lowest fewest growing degree-days, over the 6 years of testing (Table 2). In 2013, seed yields of *D. searlsiae* showed a linear positive response to irrigation plus fall, winter, and spring precipitation. The year 2013 had the lowest fall, winter, and spring precipitation over the 6 years of testing. Of the three periods of precipitation evaluated, adding fall, winter, and spring precipitation to applied water resulted in the lowest variation in the optimal water requirement for maximum seed production of *D. searlsiae*. The standard deviation of the estimated optimal amount of water decreased with the duration of the period of precipitation considered: 75.1, 48.7, 43.7, and 22.7 mm for irrigation alone, irrigation plus spring precipitation, irrigation plus winter and spring precipitation, and irrigation plus fall through spring precipitation, respectively. The amount of water applied plus fall, winter, and spring precipitation for maximum seed yield, calculated from the regression equations, ranged from 367 mm yielding 295 kg·ha⁻¹ in 2011 to 432 mm yielding 262 kg·ha⁻¹ in 2014. The highest yields averaged 260 kg·ha⁻¹ and ranged from 51 to 424 kg·ha⁻¹. Averaged over 6 years, relative seed yield was highest with applied water plus fall, winter, and spring precipitation totaling 412 mm (Table 5; Fig. 1F). Fall, winter, and spring precipitation provided from 40% in 2013

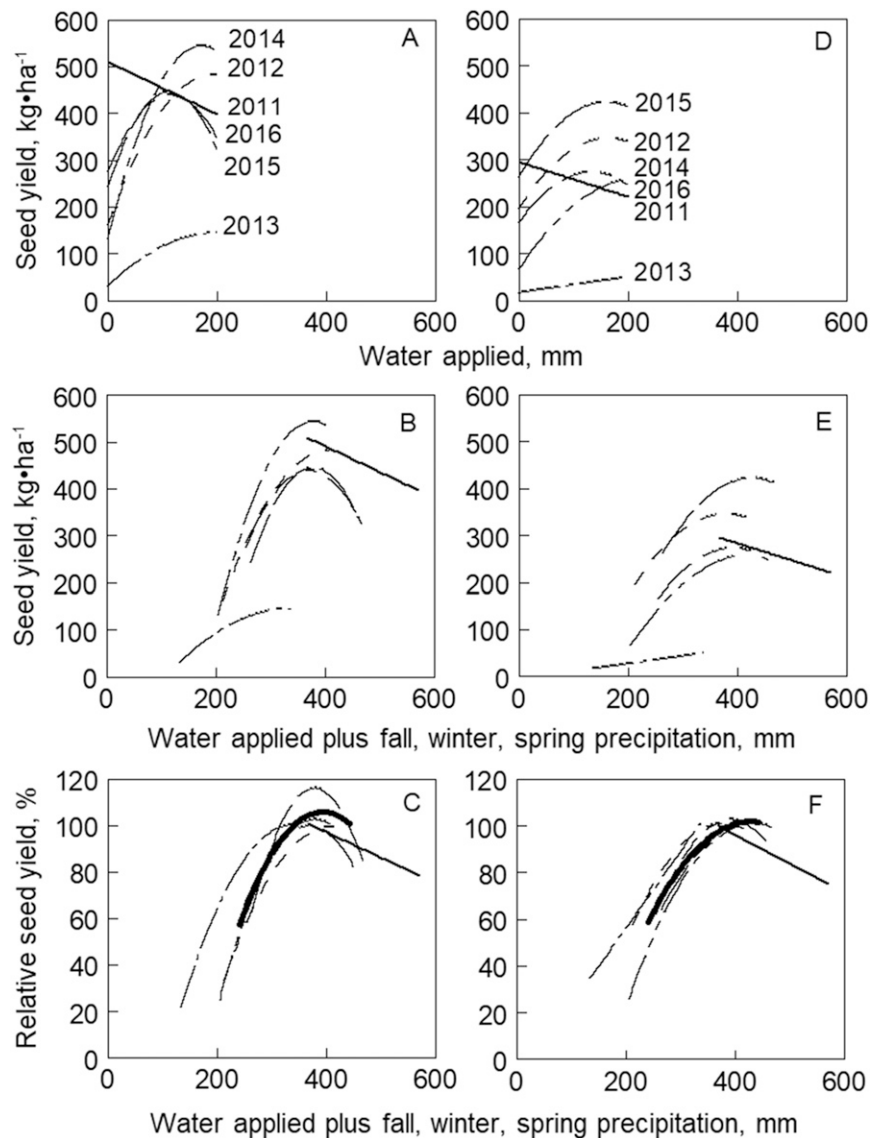


Fig. 1. Seed yield response of *Dalea ornata* and *Dalea searlsiae* to irrigation in 2011–16, Oregon State University Malheur Experiment Station, Ontario, OR. The seed yield response of *D. ornata* to applied water (A), water applied plus fall, winter, and spring precipitation (B) are compared with the seed yield response of *D. searlsiae* to applied water (D), water applied plus fall, winter, and spring precipitation (E). The relative seed yield response of *D. ornata* to water applied plus fall, winter, and spring precipitation (C) is compared with the relative seed yield response of *Dalea searlsiae* to water applied plus fall, winter, and spring precipitation (F).

to 100% in 2011 of the water needed for maximum seed yield for *D. searlsiae* as it did for *D. ornata*.

Astragalus filipes, basalt milkvetch. Seed yields ranged from 7 to 110 kg·ha⁻¹ depending on the year (Table 3). Seed yields averaged 40 kg·ha⁻¹ over 5 years. Seed yields of *A. filipes* did not respond to irrigation in any of the 5 years of testing (Tables 3 and 6).

Discussion

Seasonal precipitation varied greatly among years, as did the amount of water required for maximum seed production of *D. ornata* and *D. searlsiae*. The irrigation requirements for the *Dalea* species in this study are consistent with the results for *Lomatium dissectum* (Nutt.) Mathias & Constance,

Lomatium triternatum (Pursh) J.M. Coult. & Rose, and *Lomatium grayi* (J.M. Coult. & Rose) J.M. Coult. & Rose (Shock et al., 2012, 2016) and *Eriogonum umbellatum* Torr., and *Eriogonum heracleoides* Nutt. (Shock et al., 2017) grown at the same site in that the water requirements for seed production were low and the responses to applied irrigation were quadratic. The regression analyses showed large differences in the optimum amount of water for maximum seed yield among years. When precipitation was added to the amount of water applied, the variability in the optimum amount of water decreased for *D. ornata* and *D. searlsiae* like the seed yield responses over multiple years described for *L. grayi* and *E. umbellatum*, which had highest yields with irrigation plus precipitation

Table 5. Regression analysis for *Dalea searlsiae* seed yield (y , kg·ha⁻¹) in response to irrigation (x , mm/season) using the equation $y = a + b \times x + c \times x^2$ in 2011–16, and 6-year averages. Irrigation amounts were 0, 100, and 200 mm. For the quadratic equations, the amount of irrigation that resulted in maximum yield was calculated using the formula $x = -b/2c$, where b is the linear parameter and c is the quadratic parameter, Oregon State University Malheur Experiment Station, Ontario, OR.

Water applied vs. yield							
Yr	Intercept	Linear	Quadratic	R ²	P	Highest yield (kg·ha ⁻¹)	Water applied for highest yield (mm/season)
2011	294.8	-0.372		0.49	0.05	294.8	0.0
2012	196.6	1.825	-0.00555	0.62	0.05	346.5	164.3
2013	17.4	0.166		0.54	0.01	51.0	203.0
2014	67.2	1.754	-0.00395	0.79	0.001	262.1	222.2
2015	264.5	1.982	-0.00617	0.56	0.05	423.6	160.6
2016	166.5	1.607	-0.00597	0.56	0.05	274.6	134.5
Average	167.8	1.088	-0.00322	0.63	0.05	259.7	169.0

Water applied plus fall, winter, and spring precipitation vs. yield								
Yr	Intercept	Linear	Quadratic	R ²	P	Highest yield (kg·ha ⁻¹)	Water applied plus fall, winter, and spring precipitation for highest yield (mm/season)	Precipitation, fall, winter, and spring (mm)
2011	429.2	-0.366		0.49	0.05	294.8	367.0	367.0
2012	-430.6	4.089	-0.00538	0.62	0.05	346.5	380.0	213.1
2013	-4.6	0.163		0.54	0.01	50.5	337.6	134.6
2014	-448.9	3.297	-0.00382	0.79	0.001	262.1	431.3	205.5
2015	-671.8	5.118	-0.00598	0.56	0.05	423.6	428.1	264.9
2016	-614.1	4.535	-0.00579	0.56	0.05	274.6	391.9	255.3
Average	-268.8	2.567	-0.00312	0.63	0.05	259.7	411.8	240.1

Water applied plus fall, winter, and spring precipitation vs. relative yield							
Yr	Intercept	Linear	Quadratic	R ²	P	Highest yield (kg·ha ⁻¹)	Water applied plus fall, winter, and spring precipitation for highest relative yield (mm/season)
2011	145.9	-0.124		0.49	0.05		367.0
2012	-126.9	1.205	-0.00159	0.62	0.05		380.0
2013	-9.3	0.328		0.54	0.01		337.6
2014	-172.6	1.268	-0.00147	0.79	0.001		431.3
2015	-149.7	1.165	-0.00135	0.56	0.05		428.1
2016	-229.6	1.695	-0.00216	0.56	0.05		391.9
Average	-120.2	1.037	-0.00121	0.63	0.05		411.8

Table 6. Regression analysis for *Astragalus filipes* seed yield (y , kg·ha⁻¹) in response to irrigation (x , mm/season) using the equation $y = a + b \times x + c \times x^2$ in 2011–15, and 5-year averages. Irrigation amounts were 0, 100, and 200 mm. For the quadratic equations, the amount of irrigation that resulted in maximum yield was calculated using the formula $x = -b/2c$, where b is the linear parameter and c is the quadratic parameter, Oregon State University Malheur Experiment Station, Ontario, OR.

Yr	Intercept	Linear	Quadratic	R ²	P	Highest yield (kg·ha ⁻¹)	Water applied for highest yield (mm/season)
2011	105.3	-0.081		0.01	NS	105.3	0.0
2012	24.7	-0.041		0.04	NS	24.7	0.0
2013	11.7	-0.015		0.03	NS	11.7	0.0
2014	71.1	0.472	-0.00188	0.08	NS	100.7	125.4
2015	21.4	-0.039		0.16	NS	21.4	0.0
Average	47.2	-0.016		0.01	NS	47.2	0.0

totaling 358 and 209 mm, respectively (Shock et al., 2016, 2017). *Lomatium dissectum* and *L. triternatum* seed yields were best estimated by a quadratic response to irrigation plus spring precipitation with highest yields at 243 and 255 mm, respectively. *Eriogonum heracleoides* seed yields were best estimated by a quadratic response to irrigation with no correction for precipitation and with highest yields at 126 mm.

Seed yields of *A. filipes* did not respond to irrigation and were substantially lower than seed yields of the *Dalea* species. The lack of seed yield response of *A. filipes* to irrigation was similar to the response of *Lomatium nudicaule* (Pursh) J.M. Coult. & Rose (Shock et al., 2016). Seed harvest of *A. filipes* poses a greater challenge than for the *Dalea* spp. For all three species, a range of seed maturity is present simultaneously among and within plants, and mature seed detaches rapidly from the plant. The variability in seed maturity requires that a single once-over

harvest is a compromise between immature, mature, and dehiscing seed. *Dalea* flowers are arranged in a spike-like cluster of small flowers that bloom from the base to the tip of the cluster. The *Dalea* floral spikes are initiated over a short period of ≈ 2 weeks, making a single once-over harvest more feasible. For *A. filipes*, flowers are initiated individually over a long period, making a single once-over harvest less successful and seed yields lower.

Bhattarai et al. (2008) reported *A. filipes* seed yields under irrigation in Utah in the range of 0–24 kg·ha⁻¹. Seed yields in the present study were slightly higher. Bhattarai et al. (2008) also reported that application of imidacloprid insecticide as a soil drench in early June significantly increased seed yields compared with untreated plants. The low seed yields of *A. filipes* in the present study might also be partially related to the lack of seed beetle control. For the *Dalea* spp., the importance of seed beetle control in the present study is unknown. Seed beetle

infestations were present in 2013, 2014, and 2015. Seed beetle control was only applied in 2015, but seed yields were only reduced in 2013 compared with other years. It can be difficult to reduce seed damage by controlling ovipositing adults with nonsystemic, short-duration insecticides.

Other studies that examined responses of xerophytic plants to irrigation found similar results within the ranges of irrigation amounts in our study. In Tucson, AZ, with annual precipitation of 293 mm, native grass and native woody plant establishment from seed was optimum with 187–210 mm of irrigation plus precipitation (Roundy et al., 2001). In the Chihuahuan Desert in New Mexico, with annual precipitation of 211 mm, only 6 of 15 species increased vegetative growth in response to 338 mm of annual irrigation (Gutierrez and Whitford, 1987).

There are few published studies examining seed production of native plants in response to irrigation in arid regions. In a west-central Texas area that receives 530 mm of annual

precipitation, Petersen and Ueckert (2005) found that seed production of *Atriplex canescens* (Pursh) Nutt. (fourwing saltbush) did not respond to either 400 mm of irrigation in 1 year or 200 mm of irrigation the next year. In the Owens Valley, CA, with an annual precipitation of 113 mm, *Sarcobatus vermiculatus* (Hook.) Torr. (greasewood) seed yields were significantly higher when irrigated (Breen and Richards, 2008). These studies were not designed to determine optimum amounts of irrigation for seed yield.

In this study, both *Dalea* species tested responded to irrigation with increased seed yields. The amount of irrigation plus precipitation needed for maximum *Dalea* seed yields (300–400 mm·year⁻¹) was lower than that of irrigation plus precipitation requirements for row crops in the Treasure Valley of Oregon. Treasure Valley crop evapotranspiration ranges from 500 to 800 mm·year⁻¹ during the spring and summer depending on the crop and year (AgriMet, 2017; Feibert and Shock, 2017). Although *Dalea* species are perennials, they complete their cycle from sprouting to seed harvest by early July; thus, their irrigation requirements would be expected to be lower than those of annual crops. However, the irrigation requirements for *Dalea* are low even when compared with an early season crop such as winter wheat (*Triticum aestivum* L.), which has an average estimated crop evapotranspiration of 633 mm in the Treasure Valley (Feibert and Shock, 2017).

Studies of cultural practices for native plants are essential to increase seed production and availability of plant material used in restoration of ecosystems in the Intermountain West. Two germplasms of *D. ornata* have been released, Majestic and Spectrum. One select germplasm of *A. filipes* has been released, NBR-1. As restoration needs increase, the economic opportunities for native plant seed growers will also increase. Developing in-depth

knowledge on seed production practices will support the native seed industry in the future.

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