IRRIGATION REQUIREMENTS FOR SEED PRODUCTION OF SEVERAL NATIVE WILDFLOWER SPECIES

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Introduction

Commercial seed production of native wildflowers is necessary to provide the quantity of seed needed for restoration of Intermountain West rangelands. Native wildflower plants may not be well adapted to croplands. Native plants are often not competitive with crop weeds in cultivated fields, and this poor competitiveness with weeds 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 tape at a 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 effects of three low rates of irrigation on seed yield of 14 native wildflower species (Table 1).

Table 1. Wildflower species planted in the fall of 2012 at the Malheur Experiment Station, Oregon State University, Ontario, OR.

Species	Common name	Longevity	Row spacing (inches)
Achillea millefolium	common yarrow	perennial	30
Chaenactis douglasii	Douglas' dustymaiden	perennial	30
Crepis intermedia[a]	limestone hawksbeard	perennial	30
Cymopterus bipinnatus[b]	Hayden's cymopterus	perennial	30
Enceliopsis nudicaulis	nakedstem sunray	perennial	30
Heliomeris multiflora	showy goldeneye	perennial	30
Ipomopsis aggregata	scarlet gilia	biennial	15
Ligusticum canbyi	Canby's licorice-root	perennial	30
Ligusticum porteri	Porter's licorice-root	perennial	30
Machaeranthera canescens	hoary tansyaster	perennial	30
Nicotiana attenuata	coyote tobacco	perennial	30
Phacelia linearis[c]	threadleaf phacelia	annual	15
Phacelia hastata	silverleaf phacelia	perennial	15
Thelypodium milleflorum	manyflower thelypody	biennial	30

[a]Planted in the fall of 2011.
[b]Recently classified as *Cymopterus nivalis* S. Watson "snowline springparsley." Planted in the fall of 2009.
[c]Planted in the fall of 2013.

Materials and Methods

Plant Establishment

Each wildflower species was planted on 60-inch beds in rows 450 ft long on Nyssa silt loam at the Malheur Experiment Station, Ontario, Oregon. The soil had a pH of 8.3 and 1.1% organic matter. In October 2012, drip tape (T-Tape TSX 515-16-340) was buried at 12-inch depth in the center of each bed to irrigate the rows in the plot. 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 October 30, 2012, seed of 11 species (Table 1) was planted in either 15-inch or 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 of row (558 lb/acre). Following planting and sawdust application, the beds were covered with row cover (N-Sulate, DeWitt Co., Inc., Sikeston, MO). The row cover` covered two rows (two 30-inch beds) and was applied with a mechanical plastic mulch layer. *Cymopterus bipinnatus* was planted on November 25, 2009, *Crepis intermedia* was planted on November 28, 2011, and *Phacelia linearis* was planted on October 31, 2013, as previously described using similar methods.

Weeds were controlled by hand weeding as necessary.

Starting in March following fall planting, the row cover was removed. Immediately following the removal of the row cover, bird netting was placed over the seedlings on no. 9 galvanized wire hoops to prevent bird feeding on young seedlings and new shoots. During seedling emergence, wild bird seed was placed several hundred feet from the trial to attract quail away from the trials. Bird netting was removed in early May. Bird netting was applied and removed each spring.

On April 13, 2012, 50 lb nitrogen/acre, 10 lb phosphorus/acre, and 0.3 lb iron (Fe)/acre was applied to all plots of *Cymopterus bipinnatus* and *C. intermedia* as liquid fertilizer injected through the drip tape.

Cultural Practices in 2013

On July 26, all plots of *Machaeranthera canescens* were sprayed with Capture® at 19 oz/acre (bifenthrin at 0.3 lb ai/acre) for aphid control. On October 31, seed of *Phacelia linearis* was planted as previously described.

Due to poor stand, seed of *Chaenactis douglasii* was replanted on November 1, as previously described. Stand of *Nicotiana attenuata* was extremely poor, but seed was unavailable for replanting.

Cultural Practices in 2014

The stand of *Chaenactis douglasii,* which was replanted in the fall of 2013, was poor and did not allow evaluation of irrigation responses.

On November 11, *Phacelia linearis, Nicotiana attenuata,* and *Thelypodium milleflorum* were replanted as previously described. Lengths of row with missing stand in plots of *Chaenactis douglasii* were replanted by hand; row cover was not applied to the replanting.

Cultural Practices in 2015

On November 2, *Nicotiana attenuata* and *Enceliopsis nudicaulis* were replanted as previously described. Before planting, the ground was not tilled, only cultipacked. On November 5, *Phacelia linearis, Chaenactis douglasii*, *Achillea millefolium*, and *Ipomopsis aggregata* were replanted as previously described.

Cultural Practices in 2016

On November 22, *Nicotiana attenuata, Phacelia linearis,* and *Thelypodium milleflorum* were replanted as previously described.

Cultural Practices in 2017

On October 19, Prowl® H_2O at 2 pt/acre was broadcast on all plots of *Enceliopsis nudicaulis*, *Crepis intermedia*, and *Thelypodium milleflorum* for weed control. On November 8, *Ipomopsis aggregata* was replanted. On November 14, *Nicotiana attenuata* was replanted.

Cultural Practices in 2018

Liquid fertilizer containing 0.3 lb Fe/acre was injected using a brief pulse of water through the drip irrigation system to all plots of *Crepis intermedia*, *Thelypodium milleflorum*, and *Cymopterus bipinnatus* on May 3. On October 26, Prowl H_2O (pendimethalin) at 2 pt/acre and Outlook® (dimethenamid-P) at 21 oz/acre were broadcast on all plots of *Crepis intermedia*, *Ipomopsis aggregata, Heliomeris multiflora, Phacelia hastata,* and *Achillea millefolium* for weed control. On November 14, *Phacelia linearis, Nicotiana attenuata, Cymopterus bipinnatus*, *Enceliopsis nudicaule*, and *Thelypodium milleflorum* were replanted.

Cultural Practices in 2019

On November 5, *Phacelia linearis, Nicotiana attenuata,* and *Machaeranthera canescens* were replanted. On November 15, Prowl H_2O (pendimethalin) at 2 pt/acre, Outlook (dimethenamid-P) at 21 oz/acre, and Shadow® (clethodim) at 5 oz/acre were broadcast on all plots of *Crepis intermedia*, *Heliomeris multiflora, Phacelia hastata, Thelypodium milleflorum, Chaenactis douglasii,* and *Enceliopsis nudicaule* for weed control.

Irrigation for Seed Production

In March 2010 for *Cymopterus bipinnatus,* and March 2013 for the other species, the planted strip of each wildflower species was divided into twelve 30-ft-long plots. 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 non-irrigated check, 1 inch of water per irrigation, and 2 inches of water per irrigation. Each treatment received four irrigations that were applied approximately every 2 weeks starting at bud formation and flowering. 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.

The drip irrigation system was designed to allow separate irrigation of each species due to different timings of flowering and seed formation. All species were irrigated separately except the two *Phacelia* spp. and the two *Ligusticum* spp. Flowering, irrigation, and harvest dates were recorded (Table 2) except for *Nicotiana attenuata*, which did not germinate in 2014, and the *Ligusticum* spp., which did not flower.

Harvest

All species were harvested manually in 2013. Due to a long flowering duration, seed of *Enceliopsis nudicaulis*, *Chaenactis douglasii,* and *Crepis intermedia* required multiple harvests. Seed of *E. nudicaulis* was harvested manually once a week. Seed of *C. douglasii* and *C. intermedia* was harvested weekly with a leaf blower in vacuum mode. In 2016, the duration of flowering for *C. intermedia* was much shorter and uniform in timing between irrigation treatments. In 2016, 2017, and 2018, seed of *C. intermedia* was harvested by mowing and bagging just prior to the seed heads opening. In 2016, a seed sample from each plot of *C. intermedia* was cleaned manually to determine the proportion of pure seed. A sample of light yellow (immature) seed and dark brown (mature) seed of *C. intermedia* was analyzed for viability (tetrazolium). In 2016, seed of *C. douglasii* was harvested manually once a week.

Machaeranthera canescens seed was harvested by cutting and windrowing the plants. After drying for 2 days the *M. canescens* plants were beaten on plastic tubs to separate the seed heads from the stalks.

Phacelia hastata was harvested with a small-plot combine in 2014 and 2015. In 2016 and 2017, *P. hastata* was harvested manually due to the low stature of the plants.

Heliomeris multiflora was harvested with a small-plot combine in 2015 and 2016. The duration of flowering for *H. multiflora* tends to increase with increasing irrigation. In 2013 and 2014, the duration of flowering in the wetter plots of *H. multiflora* was much longer than in the drier plots, making a single mechanical harvest unfeasible. In 2015, the duration of flowering in the wetter plots of *H. multiflora* was shorter, enabling mechanical harvest. In 2016, plots of the driest treatment were harvested manually before the other plots, which were harvested mechanically on July 8. All plots of *H. multiflora* were harvested with a small-plot combine in 2017.

Seed of all species was cleaned manually.

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 greatest amount of water applied plus precipitation and the measured average seed yield.

Results and Discussion

Precipitation in the spring in 2013 was lower and in 2017, 2019, and 2020 was higher than the 8-year average (Table 3). In 2018, precipitation in the fall, winter, and spring was lower than average. Precipitation in the other years was close to the average. The accumulation of growing degree-days (50–86°F) was higher than the 27-year average in 2013–2016, 2018, and 2020 (Table 3). In 2017 and 2019, the accumulation of growing degree-days was close to the 27-year average.

Chaenactis douglasii. Stands of *C. douglasii* were poor in 2013 and 2014 and did not permit evaluation of irrigation responses. Replanting in the fall of 2013, 2014, and 2015 was necessary to establish an adequate stand of *C. douglasii*, allowing evaluations of irrigation responses from 2015 through 2019. Replanting was necessary again on November 14, 2018. *Chaenactis douglasii* seed yields did not respond to irrigation in 2015–2017 or 2019 (Tables 4 and 5). In 2018, a relatively dry year (Table 3), seed yield showed a quadratic response to irrigation with maximum seed yields of 80 lb/acre at 5.5 inches of water applied. Highest seed yields averaged 225 lb/acre over the 5 years. Stand deteriorated from 2019 to 2020, preventing evaluations of irrigation responses in 2020.

Crepis intermedia. *Crepis intermedia* flowered and produced seed for the first time in 2015, the third year after fall planting in 2011. The uniform and short flowering of *C. intermedia* in 2016 allowed the seed from all plots to be harvested once. A single mechanical harvest is more efficient, but some of the seed could be immature because harvest needed to occur just before seed heads opened. In 2016, 77% of the seed harvested was mature and had a viability of 57%. The other 23% of the harvested seed was immature and had a viability of 5%. This suggests that a single harvest as conducted in this trial resulted in adequate seed quality. *Crepis intermedia* seed yields increased with increasing irrigation rate up to the highest rate of 8 inches in 2015 (Tables 4 and 5). In 2016, 2017, 2019, and 2020 seed yields of *C. intermedia* did not respond to irrigation. In 2018, seed yield showed a quadratic response to irrigation with maximum seed yields of 151 lb/acre at 4 inches of water applied. Seed yields increased each year from 2015 to 2017, with the highest seed yield of 302 lb/acre in 2017. Seed yields have been relatively stable.

Machaeranthera canescens. *Machaeranthera canescens* seed yields showed a quadratic response to irrigation in 2013, with a maximum seed yield at 2.4 inches of water applied (Table 5). In 2014, 2015, and 2018, and averaged over the 3 years, seed yields of *M. canescens* did not respond to irrigation. Highest seed yields averaged 700 lb/acre over the 4 years. Partial die-off of *M. canescens* over the winter of 2015–2016 resulted in stands too uneven for an irrigation trial in 2016 and 2017. Natural reseeding occurred over the winter of 2016–2017, but the young plants did not flower in 2017. Partial die-off of *M. canescens* over the winter of 2018–2019 resulted in stands too uneven to measure irrigation treatment responses in 2019. The replanting in the fall of 2019 did not result in adequate stand for irrigation treatments in 2020.

Nicotiana attenuata. Stand establishment has been difficult with only two fall plantings (2015 and 2018) out of seven resulting in adequate stand for the irrigation trial. Seed yields of *N. attenuata* showed a quadratic response to irrigation in 2016 and 2019, with a maximum seed yield of 180 lb/acre at 4.6 and 4.1 inches of water applied, respectively (Table 5). The replanting in the fall of 2019 did not result in adequate stand for irrigation treatments in 2020.

Thelypodium milleflorum. In 4 years of testing, seed yield of *T. milleflorum* responded to irrigation only in 2020 (Tables 4 and 5). Seed yields of *A. millefolium* showed a negative response to irrigation in 2020, with maximum seed yield of 197 lb/acre with no water applied (Tables 4 and 5). Averaged over the 4 years, seed yields were estimated to be highest with 2.3 inches of total applied irrigation water, yielding 150 lb/acre of seed.

Achillea millefolium. Flowering and seed production in 2016, the first year after fall planting, was minimal. Seed yields of *A. millefolium* showed a quadratic response to irrigation in 2017, 2018, and 2019, with maximum seed yields of 235 lb/acre, 68 lb/acre, and 121 lb/acre at 10.3, 6.5, and 10.9 inches of water applied plus spring precipitation in 2017, 2018, and 2019, respectively (Table 6). Over the winter of 2018–2019, stand loss occurred in the non-irrigated plots. In late August 2019, the stand was 40, 96, and 97% for the non-irrigated, 4 inches/year, and 8 inches/year treatments, respectively (LSD 0.05 = 15.3). The stand was terminated in the spring of 2020 to make way for burial of underground irrigation pipe.

Cymopterus bipinnatus. *Cymopterus bipinnatus* did not flower in either 2010 or 2011 and flowered very little in 2012. In 2013 and 2014, seed yields showed a positive linear response to water applied plus spring precipitation with (Tables 4 and 6). Seed yields were maximized by 8.9 and 9.7 inches of water applied plus spring precipitation in 2013 and 2014, respectively. In 2015, 2016, and 2018, seed yields showed a quadratic response to irrigation, with maximum seed yields at 7.4, 6.7, and 6.7 inches of water applied in 2015, 2016, and 2018, respectively. In 2017, seed yields were highest with no irrigation. Averaged over the 6 years, seed yields were estimated to be highest with 7.9 inches of total applied irrigation water plus spring precipitation, yielding 1012 lb/acre of seed. Stand die-off was evaluated subjectively in 2018. Stand was 50, 25, and 25% 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 = 21). Replanting in the fall of 2018 was not successful in establishing adequate stand in 2019.

Enceliopsis nudicaulis. *Enceliopsis nudicaulis* seed yield was very low and did not respond to irrigation in 2013. In 2014 and 2016, seed yield showed a quadratic response to irrigation with a maximum seed yield at 7.2 and 8 inches of water applied plus spring precipitation, respectively (Tables 4 and 6). Extensive die-off of *E. nudicaulis* occurred over the winter of 2014–2015 and was more severe in the plots receiving the highest amount of irrigation. In 2015, 2017, 2019, and 2020, years with higher than average spring precipitation, seed yields of *E. nudicaulis* were highest without irrigation. Seed yields did not respond to irrigation in 2018. The replanting done in the fall of 2015 was successful, but stands continue to decline, especially in the irrigated plots.

Heliomeris multiflora. *Heliomeris multiflora* seed yield increased with increasing irrigation rate plus spring precipitation in 2013–2015 and in 2019. *Heliomeris multiflora* seed yield did not respond to irrigation in 2016 and 2017 (Tables 4 and 6). In 2018 and 2020, seed yields showed a quadratic response to irrigation, with maximum seed yield at 5.6 and 10.3 inches of water applied plus spring precipitation, respectively. Highest seed yields averaged 106 lb/acre over the 8 years.

Ipomopsis aggregata. *Ipomopsis aggregata* flowered very little in 2013, then flowered and set seed in 2014. The stand of *I. aggregata* died over the winter of 2014–2015, which indicated a biennial growth habit. *Ipomopsis aggregata* was replanted in the fall in 2015 and 2017, with seed harvests occurring in 2017 and 2019.

Ipomopsis aggregata seed yields were highest with 8 inches of water applied in 2014 (Tables 4 and 6). In 2017 and 2019, seed yields showed a quadratic response to water applied plus spring precipitation, with seed yields maximized by 7.5 and 9 inches in 2017 and 2019, respectively. Averaged over the 3 years, seed yields were maximized at 270 lb/acre by 7.1 inches of water applied plus spring precipitation.

Phacelia hastata. Irrigation responses for *P. hastata* were evaluated for two sets of plots: the 6-year-old stand planted in 2012 and a new stand originating in 2015 from volunteer seed (Tables 4 and 6). *Phacelia hastata* (planted in the fall of 2012) seed yields showed a quadratic response to irrigation plus spring precipitation, with a maximum seed yield at 6.3, 9.3, and 7.1

inches of water applied in 2013, 2014, and 2018, respectively. In 2015, seed yield of *P. hastata* did not respond to irrigation, possibly due to loss of stand in this weak perennial. The stand of *P. hastata* planted in the fall of 2012 was extremely poor in 2016, and seed was not harvested. The stand regenerated from natural reseeding in 2017, but seed was not produced.

Seed yields of *P. hastata* (planted in the fall of 2014) increased with increasing water applied plus spring precipitation in 2015. In 2016 and 2018, seed yields of *P. hastata* showed a quadratic response to irrigation, with a maximum seed yield at 6.2 and 8.7 inches of water applied in 2016 and 2018, respectively. In 2017, 2019, and 2020, seed yields of *P. hastata* did not respond to irrigation.

Averaged over years, seed yields of *P. hastata* showed a quadratic response to irrigation plus spring precipitation with a maximum seed yield of 162 lb/acre and 68 lb/acre at 8.1 and 8.3 inches of water applied plus spring precipitation for the 2012 and 2014 stands, respectively. The two stands of *P. hastata* showed a pattern of increased seed yields in the second year, a decline in the third year, and an increase in the fourth year. Seed yields were very low in 2019, which could have been caused by the unusually high precipitation that occurred in May after *P. hastata* started flowering. After *P. hastata* started flowering on May 8, a total of 2.3 inches of rain fell by the end of May. The average rainfall for May is 1.1 inches.

Phacelia linearis. Seed yields of *P. linearis* showed a quadratic response to irrigation plus spring precipitation in 2013, with a maximum seed yield at 7 inches of water applied plus spring precipitation (Tables 4 and 6). In 2014, 2019, and 2020, seed yields of *P. linearis* did not respond to irrigation. Highest seed yields averaged 183 lb/acre over the 4 years. Averaged over the 4 years, seed yields of *P. linearis* showed a quadratic response to irrigation, with a maximum seed yield at 9.6 inches of water applied plus spring precipitation.

The replanting of *P. linearis* in the fall of 2014 and 2015 did not result in adequate stands. *Phacelia linearis* was replanted in the fall of 2016 in a different location in the field, but the stand in the springs of both 2017 and 2018 was extremely poor. *Phacelia linearis* was replanted in November of 2018. The stand of *P. linearis* in the spring of 2019 and 2020 was good.

***Ligusticum* spp.** Stands of *Ligusticum porteri* and *L. canbyi* were poor and uneven and did not permit evaluation of irrigation responses. Very few of the seedlings were adapted to the local environment.

Acknowledgements

The work reported here was funded by the U.S. Forest Service Great Basin Native Plant Project, U.S. Bureau of Land Management, Oregon State University, and the Malheur County Education Service District and supported by Formula Grant nos. 2020-31100-06041 and 2020-31200-06041 from the USDA National Institute of Food and Agriculture and similar grants from previous years.

Table 2. Native wildflower flowering, irrigation, and seed harvest dates by species, Malheur Experiment Station, Oregon State University, Ontario, OR, 2013–2020. (Table 2 continues on the next page.)

	Flowering dates			Irrigation dates		
Year	Start	Peak	End	Start	End	Harvest
Achillea millefolium						
2017	26-Apr	7-Jun	12-Jul	2-May	20-Jun	26-Jul
2018	30-Apr	13-Jun	30-Jun	16-May	27-Jun	3-Aug
2019	3-May	15-Jun	15-Jul	3-May	13-Jun	6-Aug
***Chaenactis douglasii,* Douglas' dustymaiden**						
2013	23-May	30-Jun	15-Jul	22-May	3-Jul	2-Jul, 22-Jul
2014	20-May		15-Jul	13-May	24-Jun	poor stand
2015	5-May		10-Jul	5-May	17-Jun	weekly, 6-8 to 7-15
2016	23-May		22-Jul	23-May	8-Jul	weekly, 6-17 to 7-7
2017	25-May	7-Jun	19-Jul	9-May	20-Jun	weekly, 6-16 to 7-6
2018	10-May	13-Jun	10-Jul	16-May	27-Jun	weekly, 6-13 to 7-15
2019	15-May	3-Jun	15-Jul	13-May	27-Jun	weekly, 6-6 to 7-16
2020	18-May		10-Jul	9-May	18-Jun	
***Crepis intermedia,* limestone hawksbeard**						
2015	28-Apr	5-May	1-Jun	21-Apr	3-Jun	weekly, 6-1 to 7-2
2016	29-Apr		25-May	27-Apr	7-Jun	26-May
2017	15-May		7-Jun	9-May	20-Jun	8-Jun
2018	3-May		25-May	3-May	13-Jun	31-May
2019	10-May		31-May	3-May	13-Jun	31-May
2020	10-May	20-May	28-May	7-May	3-Jun	1-Jun
***Cymopterus bipinnatus,* Hayden's cymopterus**						
2013	5-Apr		15-May	12-Apr	22-May	10-Jun
2014	7-Apr		29-Apr	7-Apr	20-May	16-Jun
2015	25-Mar		24-Apr	1-Apr	13-May	8-Jun
2016	15-Mar		25-Apr	31-Mar	9-May	7-Jun
2017	27-Mar		1-May	19-Apr	6-Jun	16-Jun
2018	15-Mar		3-May	18-Apr	30-May	5-Jun
2019	15-Mar		10-May			partial winter die-off
***Enceliopsis nudicaulis,* nakedstem sunray**						
2013	30-Jun		15-Sep	3-Jul	14-Aug	weekly, 8-Aug to 30-Aug
2014	5-May	1-Jul	30-Jul	6-May	17-Jun	weekly, 14-Jul to 30-Aug
2015	28-Apr	13-May	5-Aug	29-Apr	10-Jun	weekly, 2-Jun to 15-Aug
2016	20-Apr		30-Jul	3-May	14-Jun	weekly, 27-Apr to 29-Jul
2017	11-May	7-Jun	20-Aug	23-May	6-Jul	weekly, 4-Jun to 15-Aug
2018	30-Apr	26-Jun	30-Jul	16-May	27-Jun	weekly, 27-Apr to 27-Jul
2019	10-May	30-May	16-Jul	3-May	13-Jun	weekly, 3-Jun to 15-Aug
2020	7-May	22-May	10-Jul	9-May	18-Jun	weekly, 1-Jun to 15-Aug
***Heliomeris multiflora,* showy goldeneye**						
2013	15-Jul		30-Aug	5-Jun	17-Jun	8-Aug, 15-Aug, 28-Aug
2014	20-May	20-Jun	30-Aug	13-May	24-Jun	weekly, 15-Jul to 15-Aug
2015	5-May	26-May	10-Jul	5-May	17-Jun	13-Jul
2016	5-May	15-Jun	30-Sep	9-May	22-Jun	8-Jul
2017	12-May	7-Jun	30-Jul	9-May	20-Jun	17-Jul
2018	12-May	13-Jun	20-Jul	16-May	27-Jun	1-Aug
2019	14-May	15-Jun	16-Jul	13-May	27-Jun	15-Jul
2020	20-May	15-Jun	18-Jul	9-May	18-Jun	3-Jul non irrigated, 15-Jul irrigated

Table 2 (continued). Native wildflower flowering, irrigation, and seed harvest dates by species, Malheur Experiment Station, Oregon State University, Ontario, OR, 2013-2020.

	Flowering dates			Irrigation dates		
Year	Start	Peak	End	Start	End	Harvest
***Ipomopsis aggregata,* scarlet gilia**						
2013	31-Jul	very little flowering		31-Jul	11-Sep	
2014	22-Apr	13-May	30-Jul	23-Apr	3-Jun	20-Jun
2015	winter die-off					
2016	no flowering			7-Jun	22-Jul	
2017	1-May	15-May	27-Jun	2-May	20-Jun	23-Jun
2018	no flowering			16-May	27-Jun	
2019	26-Apr	13-May	10-Aug	3-May	13-Jun	14-Jun
***Machaeranthera canescens,* hoary tansyaster**						
2013	13-Aug		1-Oct	17-Jul	28-Aug	2-Oct
2014	20-Aug	17-Sep	5-Oct	22-Jul	2-Sep	6-Oct
2015	10-Aug	17-Sep	1-Oct	11-Aug	22-Sep	6-Oct, 15-Oct
2016	17-Aug	20-Sep	10-Oct			partial winter die-off
2017	29-Aug		20-Oct			
2018	20-Aug		22-Oct	23-Aug	20-Sep	22-Oct
2019						partial winter die-off
***Nicotiana attenuata*, coyote tobacco**						
2016	16-May		31-Jul	16-May	22-Jun	weekly, 21-Jun to 29-Jul
2017	1-May		15-Aug			
2019	5-Jun	27-Jun	20-Jul	13-Jun	27-Jun	weekly, 25-Jun to 15-Aug
***Phacelia hastata,* silverleaf phacelia**						
2013	17-May		30-Jul	22-May	3-Jul	30-Jul (0 in), 7-Aug, 19-Aug (8 in)
2014	5-May		10-Jul	29-Apr	10-Jun	14-Jul
2015 (1st year)	28-Apr	26-May	7-Aug	20-May	30-Jun	6-Aug
2015 (3rd year)	28-Apr	26-May	7-Aug	29-Apr	10-Jun	7-Jul (0 in), 21-Jul (4, 8 in)
2016	28-Apr		17-Jun	27-Apr	7-Jun	23-Jun
2017	8-May	7-Jun		2-May	20-Jun	25-Jul
2018	6-May		20-Jun	16-May	27-Jun	27-Jun
2019	8-May	3-Jun	30-Jun	3-May	13-Jun	27-Jun
2020	9-May	30-May	21-Jun	7-May	3-Jun	1-Jul
***Phacelia linearis,* threadleaf phacelia**						
2013	3-May	16-May	15-Jun	2-May	12-Jun	2-Jul
2014	5-May	4-Jun	1-Jul	1-May	10-Jun	7-Jul
2015	winter die-off					
2019	8-May		30-Jun	3-May	13-Jun	19-Jun
2020	5-May	15-May	22-Jun	7-May	18-Jun	15-Jun
***Thelypodium milleflorum,* manyflower thelypody**						
2013	No flowering					
2014	22-Apr	5-May	10-Jun	23-Apr	3-Jun	2-Jul
2015	No flowering					
2016	11-Apr	6-May	8-Jun	11-Apr	23-May	21-Jun
2017	No flowering					
2018	27-Apr	10-May	10-Jun	3-May	13-Jun	18-Jun
2019	No flowering					
2020	20-May		10-Jun	7-May	3-Jun	24-Jun

Table 3. Precipitation and growing degree-days at the Malheur Experiment Station, Oregon State University, Ontario, OR, 2013–2020.

	Precipitation (inch)			Growing degree-days (50–86°F)
Year	Spring	Spring + winter	Spring + winter + fall	Jan–July
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
8-year average:	2.9	6.2	9.8	27-year average: 1917

Table 4. Native wildflower seed yield (lb/acre) in response to season-long irrigation rate (inches), Malheur Experiment Station, Oregon State University, Ontario, OR, 2013–2020. (Table 4 continues on the next page.)

		Irrigation amount			
Species	Year	0 inches	4 inches	8 inches	LSD (0.05)[a]
Achillea millefolium	2017	59.2	213.3	220.4	99.8
	2018	7.3	45.1	57.1	NS
	2019	47.5	125.0	100.6	39.5
	Average	29.3	101.8	95.9	37.9
Chaenactis douglasii	2015	132.1	137.6	183.3	NS
	2016	29.1	16.0	27.2	NS
	2017	707.1	711.1	627.3	NS
	2018	7.1	74.7	65.9	33.0
	2019	120.6	118.2	126.5	NS
	Average	198.9	208.3	200.3	NS
Crepis intermedia	2015	68.6	55.5	166.3	63.2
	2016	83.6	87.0	77.8	NS
	2017	301.5	268.1	287.1	NS
	2018	98.3	151.0	100.2	16.1
	2019	186.8	195.4	209.8	NS
	2020	83.3	181.3	115.8	NS
	Average	147.7	151.4	167.7	NS
Cymopterus bipinnatus	2013	194.2	168.41	623.68	NS
	2014	1236.2	1934.0	2768.5	844.7
	2015	312.3	749.0	374.9	252.9
	2016	1501.4	2253.5	1799.0	578.6 [b]
	2017	298.1	230.4	102.6	NS
	2018	87.0	149.5	122.5	16.6
	Average	618.8	979.6	939.6	201.2
Enceliopsis nudicaulis	2013	2.3	6.8	5.9	NS
	2014	1.5	34.6	29.1	20.7
	2015	15.7	3.2	4.4	7.3
	2016	10.5	47.6	45.9	34.9
	2017	105.0	43.2	25.0	59.6
	2018	20.2	20.5	20.1	NS
	2019	105.4	35.7	20.6	58.9
	2020	47.5	79.6	38.4	NS
	Average	37.7	31.8	23.2	NS

[a]NS = not significant.
[b]LSD (0.10).

Table 4 (continued). Native wildflower seed yield (lb/acre) in response to season-long irrigation rate (inches), Malheur Experiment Station, Oregon State University, Ontario, OR, 2013–2020.

		Irrigation amount			
Species	Year	0 inches	4 inches	8 inches	LSD (0.05)[a]
Heliomeris multiflora	2013	28.7	57.6	96.9	NS
	2014	154.6	200.9	271.7	107.3[b]
	2015	81.7	115.6	188.2	58.2
	2016	92.3	89.2	98.0	NS
	2017	87.8	75.9	89.9	NS
	2018	44.5	73.9	34.3	23.4
	2019	53.2	119.6	164.4	71.1
	2020	27.5	87.6	87.9	26.1
	Average	72.5	102.4	128.9	20.3
Ipomopsis aggregata	2014	47.1	60.9	63.6	9.0
	2017	241.0	315.8	188.8	74.5
	2019	164.1	327.2	207.2	69.9
	Average	168.1	269.7	158.2	68.9
Machaeranthera canescens	2013	206.1	215	124.3	73.6
	2014	946.1	1210.2	1026.3	NS
	2015	304.1	402.6	459.1	NS
	2018	330.3	426.3	380.6	NS
	Average	586.1	701.6	634.3	NS
Nicotiana attenuata	2016	49.4	151.0	95.8	81.4
	2019	48.9	180.7	72.6	91.9
	Average	49.1	165.9	84.2	69.8
Phacelia hastata (planted fall 2012)	2013	35.3	102.7	91.2	35.7
	2014	87.7	305.7	366.4	130.3
	2015	78.8	79.3	65.0	NS
	2018	32.8	108.6	89.6	59.4
	Average	58.6	149.1	153.0	37.0
Phacelia hastata (planted fall 2014)	2015	0.0	21.4	50.4	13.7
	2016	82.5	125.2	83.1	26.8
	2017	20.3	23.2	23.2	NS
	2018	57.1	128.5	140.2	68.3
	2019	11.6	14.8	16.0	NS
	2020	51.0	73.6	25.3	NS
	Average	37.1	66.8	56.4	22.0
Phacelia linearis	2013	121.4	306.2	314.2	96
	2014	131.9	172.9	127.2	NS
	2019	94.4	134.9	120.5	NS
	2020	55	103.62	65.94	NS
	Average	100.7	179.4	157	42.5
Thelypodium milleflorum	2014	200.5	246.2	205.6	NS
	2016	121.9	110.0	63.3	NS
	2018	61.4	61.4	64.1	NS
	2020	193.8	137.4	60.6	68.9
	Average	142.7	145.5	103.5	NS

[a]NS = not significant.
[b]LSD (0.10).

Table 5. Regression analysis for native wildflower seed yield (y) in response to irrigation (x) (inches/season) using the equation $y = a + b \cdot x + c \cdot x^2$. 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, 2013–2020.

Year	Intercept	Linear	Quadratic	R^2	P^a	Maximum yield	Water applied for maximum yield
						lb/acre	inches/season
Chaenactis douglasii							
2015	125.4	6.4		0.08	NS		
2016	25.1	-0.2		0.01	NS		
2017	707.1	12.0	-2.7	0.09	NS		
2018	7.1	26.5	-2.4	0.95	0.01	80.3	5.5
2019	119.2	0.7		0.01	NS		
Average	197.7	3.3	-0.2	0.05	NS		
Crepis intermedia							
2015	49.0	11.4		0.31	0.10	140.2	8.0
2016	83.6	2.4	-0.4	0.07	NS		
2017	292.8	-1.8		0.01	NS		
2018	98.3	26.1	-3.2	0.41	0.10	151.0	4.0
2019	185.8	2.9		0.05	NS		
2020	83.3	45.0	-5.1	0.27	NS		
Average	145.6	2.5		0.20	NS		
Machaeranthera canescens							
2013	206.1	14.7	-3.1	0.54	0.05	223.5	2.4
2014	946.1	122	-14	0.13	NS		
2015	311.1	19.4		0.02	NS		
2018	330.3	41.7	-4.4	0.03	NS		
Average	586.1	51.7	-5.7	0.09	NS		
Nicotiana attenuata							
2016	49.4	45.0	-4.9	0.50	0.05	152.7	4.6
2019	48.9	86.9	-10.5	0.61	0.05	228.9	4.1
Average	49.1	58.6	-6.8	0.54	0.05	175.9	4.3
Thelypodium milleflorum							
2014	200.5	22.2	-2.7	0.12	NS		
2016	126.2	-7.3		0.32	NS		
2018	61.0	0.3		0.01	NS		
2020	197.2	-16.6		0.57	0.05	197.2	0.0
Average	142.7	6.3	-1.4	0.46	0.10	149.8	2.3

[a]Not significant. There was no statistically significant trend in seed yield in response to amount of irrigation.

Table 6. Regression analysis for native wildflower seed yield (y) in response to irrigation plus spring precipitation (x) (inches/season) using the equation $y = a + bx + cx^2$. For the quadratic equations, the amount of irrigation plus spring precipitation 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, 2013–2020. (Continues on next page.)

Year	Intercept	Linear	Quadratic	R^2	P^a	Maximum yield	Water applied plus spring precipitation for maximum yield	Spring precipitation
						lb/acre	inches/season	inch
Achillea millefolium								
2017	-230.5	90.4	-4.4	0.75	0.01	234.9	10.3	4.0
2018	-52.4	36.9	-2.8	0.62	0.05	67.9	6.5	1.9
2019	-105.9	41.7	-1.9	0.64	0.05	120.5	10.9	4.7
Average	-87.3	40.6	-2.1	0.78	0.01	107.3	9.6	3.5
Cymopterus bipinnatus								
2013	109.5	48.22		0.42	0.10	536.2	8.9	0.9
2014	884.8	190.6		0.41	0.05	2739.7	9.7	1.7
2015	-628.2	373.7	-25.3	0.46	0.10	749.6	7.4	3.2
2016	563.3	506.3	-37.7	0.43	0.10	2262.7	6.7	2.2
2017	405.2	-24.4		0.38	0.10	405.2	0.0	4.0
2018	26.3	37.4	-2.8	0.60	0.05	151.3	6.7	1.9
Average	227.4	198.2	-12.5	0.56	0.05	1011.7	7.9	2.3
Enceliopsis nudicaulis								
2013	0.7	2.1	-0.2	0.26	NS			0.9
2014	-24.8	17.3	-1.2	0.60	0.05	37.1	7.2	1.7
2015	18.0	-1.4		0.29	0.10	18.0	3.2	3.2
2016	-26.9	19.5	-1.2	0.57	0.05	51.6	8.0	2.2
2017	138.8	-10.0		0.44	0.05	138.8	4.0	4.0
2018	19.9	0.2	-0.02	0.01	NS			1.9
2019	146.1	-10.6		0.42	0.05	146.1	4.7	4.7
2020	168.6	-11.9		0.49	0.05	168.6	4.3	4.3
Average	42.9	-1.9		0.20	NS			2.9
Heliomeris multiflora								
2013	19.7	8.5		0.38	0.05	87.9	8.0	0.9
2014	125.2	14.6		0.27	0.10	242.3	8.0	1.7
2015	32.4	13.3		0.48	0.05	138.9	8.0	3.2
2016	89.1	0.7		0.01	NS			2.2
2017	82.5	0.3		0.01	NS			4.0
2018	6.6	24.1	-2.2	0.72	0.01	74.1	5.6	1.9
2019	-6.7	13.8		0.66	0.01	103.3	8.0	4.7
2020	-104.7	38.7	-1.9	0.84	0.001	95.3	10.3	4.3
Average	49.2	7.1		0.67	0.01	105.6	8.0	2.9

[a]Not significant. There was no statistically significant trend in seed yield in response to amount of irrigation.

Table 6 (continued). Regression analysis for native wildflower seed yield (y) in response to irrigation plus spring precipitation (x) (inches/season) using the equation $y = a + bx + cx^2$. For the quadratic equations, the amount of irrigation plus spring precipitation 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, 2013–2020.

Year	Intercept	Linear	Quadratic	R^2	P^a	Maximum yield	Water applied plus spring precipitation for maximum yield	Spring precipitation
						lb/acre	inches/season	inch
Ipomopsis aggregata								
2014	45.0	2.1		0.23	NS			1.7
2017	-32.7	94.0	-6.3	0.52	0.05	317.5	7.5	4.0
2019	-387.8	159.2	-8.8	0.85	0.01	328.0	9.0	4.7
Average	-61.6	93.9	-6.7	0.42	0.10	269.7	7.1	3.5
***Phacelia hastata* (planted fall 2012)**								
2013	10.8	30.9	-2.5	0.66	0.01	107.7	6.3	0.9
2014	-55.4	91.2	-4.9	0.76	0.01	367.4	9.3	1.7
2015	67.6	5.0	-0.5	0.04	NS			3.2
2018	-36.1	42.0	-3.0	0.49	0.05	112.9	7.1	1.9
Average	-15.6	43.8	-2.7	0.84	0.001	162.0	8.1	1.9
***Phacelia hastata* (planted fall 2014)**								
2015	-21.5	6.3		0.88	0.001	49.0	11.2	3.2
2016	22.2	33.0	-2.6	0.72	0.01	125.2	6.2	2.2
2017	14.6	1.8	-0.1	0.04	NS			4.0
2018	2.6	32.4	-1.9	0.57	0.05	143.0	8.7	1.9
2019	5.6	1.6	-0.1	0.05	NS			4.7
2020	-53.0	33.6	-2.2	0.31	NS			4.3
Average	-19.5	21.0	-1.3	0.74	0.01	68.0	8.3	3.4
Phacelia linearis								
2013	59.4	77.7	-5.53	0.69	0.01	332.2	7.0	0.9
2014	131.9	21.1	-2.7	0.11	NS			1.7
2019	94.4	17	-1.72	0.2	NS			4.7
2020	-94.6	46.3	-2.7	0.27	NS			4.3
Average	-109.2	60.8	-3.2	0.75	0.01	183.4	9.6	2.9

[a]Not significant. There was no statistically significant trend in seed yield in response to amount of irrigation.