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Evaluation of Cool Season Cover Crops in the Great Basin

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ABSTRACT

Cool season annual cover crops provide multiple benefits to agricultural production. These include weed suppression, reducing soil erosion, nutrient scavenging, increased water quality, nitrogen production, increased organic matter, biofumigation, bio-tillage, and other soil health improvements. The success and effectiveness of these benefits depends not only on the cover crop species selected, but also the best adapted cultivar that meets the planting objective. The purpose of this study was to evaluate 60 commercially available cultivars of eight common annual cool season species for their adaptation to the Great Basin cold desert in central Nevada. Oats (*Avena sativa* L. and *Avena strigosa* Schreb.), cereal rye (*Secale cereal* L.), Austrian winter pea (*Pisum sativum* L.), daikon radish (*Raphanus sativus* L.), crimson clover (*Trifolium incarnatum* L.), red clover (*Trifolium pretense* L.), balansa clover (*Trifolium michelianum* Savi), and hairy vetch (*Vicia villosa* Roth and *V. villosa* Roth ssp. *varia* (Host) Corb) were evaluated for field emergence, winter hardiness, plant height, days after planting to 50% bloom, and end of season cover at the Fallon, NV Plant Materials Center in 2016-2017 (non-irrigated; non-fertilized; planted 10-19-16) and 2017-2018 (irrigated; fertilized; planted 9-21-17). All species expressed significant cultivar specific response to one or more variables. Oats, cereal rye, and daikon radish exhibited excellent emergence for both years. 'Cosaque' black seeded oats exhibited excellent winter hardiness while 'Soil Saver' black oats completely winterkilled both years. Cereal rye exhibited excellent winter hardiness for both years, except for 'FL401' which winterkilled in 2018 (21% winter survival). Daikon radishes exhibited poor winter survival (ranging 0 – 42%). Clover emergence was poor for balansa clover, moderate to excellent for red clover, and poor to excellent for crimson clover. Winter hardiness was poor for all three clovers in 2017, but significantly improved in 2018. Austrian winter pea had moderate to excellent emergence, with highly variable winter hardiness that was significantly better in 2017 than 2018. Hairy vetch exhibited poor to good emergence and ranged in winter survival from 60-100%. Of these cover crops tested, only cereal rye exhibited excellent weed suppression capabilities. Additional information is needed on biomass production of best performing cultivars to maximize their use as a cover crop.

INTRODUCTION

Cover crops are a useful tool for agricultural production. They provide cover, reduce soil erosion, reduce weed pressure, provide food for beneficial microbes, break up pest cycles, and increase organic matter (Reeves 1994, Idowu and Grover 2014, Clark 2012, Marcillo and Miguez 2017). Individual cover crop species may have additional benefits. Legumes, such as hairy vetch and clovers, produce nitrogen, reducing nitrogen inputs required for subsequent crops (Hargrove 1986, Smith et al. 1987; Singh et al. 2004), while grains such as cereal rye scavenge nitrogen, which reduces leaching losses and reduces water pollution (Meisinger et al. 1991). Large tap rooted species such as daikon radishes and turnips may organically till the soil, reducing compaction while minimizing soil disturbance (Williams and Weil 2004). Some glucosinolate-containing cover crops, such as daikon radishes, can be used as biofumigants to kill specific pests (Budahn et al. 2009, Kankam et al. 2015, Morris et al. 2019). Mixes of these cover crop strategies may increase the overall utility of the cover crop planting. However, multiple benefits are not achieved unless the best adapted cultivar(s) are planted that meet the planting objectives and end-

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user's expectations. The purpose of this study is to evaluate growth characteristics of several varieties of common cool season annual cover crops to determine their adaptation in the cold desert of the Great Basin.

MATERIALS AND METHODS

The study was conducted at the USDA-Natural Resources Conservation Service (NRCS) Great Basin Plant Materials Center (NVPMC), Fallon, NV, in 2016-2017 (Y1) and 2017-2018 (Y2). This facility is in a cold desert of the Great Basin at an elevation of 3,960 ft; USDA plant hardiness zone 7A (USDA-ARS 2012). The fields are dominated by Sagouspe loamy sand soils. Pre-planting field preparations for Y1 and Y2 included tilling, with Y1 receiving an herbicide treatment of Roundup Powermax at one quart per acre on 18 October. Eight species, totaling 60 cultivars, of annual cool season cover crops were planted a pure live seed (PLS) planting rate from NRCS standards and specifications for cover crop establishment (Table 1). Legumes were inoculated with appropriate rhizobia before seeding. Plots were drill seeded in 6-ft x 10-ft plots with a Kincaid cone seeder (Kincaid Equipment, Haven KS) with 8" rows. Y1 was planted on 19 October 2016 and was non-irrigated. Y2 was planted on 21 September 2017 in an adjacent field to avoid contamination from the previous year. Y2 was fertilized with 40 lb/ac of 40N:30P:60K and was flood irrigated with 3.54 inches on 15 September prior to planting, and after planting on 24 September, 20 October, and 26 April. Both studies were planted in a randomized complete block design with four replications and a triticale (x*Triticosecale* Wittm. Ex A. Camus [*Secale* x *Triticum*]) buffer planted along the perimeter of the planting.

Data collected included emergence, winter hardiness, days after planting (DAP) to 50% flowering, height at 50% flowering, and end of season cover (summer cover). Emergence was estimated every seven days for the first four weeks using the following rating scale: 0 = poor (<25% germination), 1 = moderate (30-60%), 2 = good (65–85%), 3 = excellent (90-100%). Winter survival was evaluated from a 3-ft section of an interior row. Individual plants were counted in that section prior to December, and again after spring green-up. Before and after counts were then divided to calculate the percent winter survival. DAP to 50% flowering was recorded when 50% of the plants started to flower. Height at 50% flowering was calculated by averaging the height of three random plants in a plot. Summer cover was evaluated by visually estimating the percent of the plot covered by the cover crop. The percent cover rating was the same as for emergence. Rainfall and daily temperatures were recorded by a Bureau of Reclamation AgriMet Weather station located on site.

Statistic 10 (Analytic Software, Tallahassee, FL) was used to determine mean and standard deviation for field emergence, percent winter hardiness, DAP to 50% bloom, and plant height. These values were used to determine variation among cultivars within a species. A two sample T-test was used to test if Y1 and Y2 were equal for the four emergence dates and for percent winter hardiness.

In Y1, a resident deer herd utilized the cereal rye in the study. Utilization data was collected in a five point rating scale based on the percent of the plot with visible bites: 0=no utilization (0-5%), 1=low (6-25%), 2=medium (26-50%), 3=high (51-75%), 4=very high (>76%). End of season biomass data was collected by clipping two 2.7 ft^2 square frames per plot. Clipped biomass was air-dried prior to yield determination. An analysis of variance procedure was used to assess differences in biomass production among cereal rye cultivars and statistically significant means were separated at $P<0.05$ according to Tukey's honest significant difference test. No assessment of deer damage in Y2 was conducted due to minimal deer damage.

Table 1. Species, cultivars and seeding rates of annual cool seasons planted in 2016 and 2017 at the USDA NRCS Fallon, NV Plant Materials Center.

Common name	Species	Cultivar	PLS lb/acre	% PLS	Seeding rate lb/acre
Austrian winter pea	*Pisum sativum*	Arvica 4010	70	95	74
Austrian winter pea	*Pisum sativum*	Dunn	70	85	82
Austrian winter pea	*Pisum sativum*	Frost Master	70	85	82
Austrian winter pea	*Pisum sativum*	Lynx	70	98	71
Austrian winter pea	*Pisum sativum*	Maxum	70	92	76
Austrian winter pea	*Pisum sativum*	Survivor 15	70	80	88
Austrian winter pea	*Pisum sativum*	Whistler	70	90	78
Austrian winter pea	*Pisum sativum*	Windham	70	80	88
Balansa clover	*Trifolium michelianum*	Fixation	5	47	11
Balansa clover	*Trifolium michelianum*	Frontier	5	58	9
Black oats	*Avena sativa*	Cosaque	60	83	72
Black seeded oats	*Avena strigosa*	Soil Saver	60	98	61
Cereal Rye	*Secale cereale*	Aroostook	100	90	111
Cereal Rye	*Secale cereale*	Bates	100	88	113
Cereal Rye	*Secale cereale*	Brasetto	100	92	109
Cereal Rye	*Secale cereale*	Elbon	100	88	114
Cereal Rye	*Secale cereale*	FL 401	100	80	126
Cereal Rye	*Secale cereale*	Guardian	100	93	108
Cereal Rye	*Secale cereale*	Hazlet	100	84	119
Cereal Rye	*Secale cereale*	Maton	100	90	111
Cereal Rye	*Secale cereale*	Maton II	100	91	110
Cereal Rye	*Secale cereale*	Merced	100	84	119
Cereal Rye	*Secale cereale*	Oklon	100	90	112
Cereal Rye	*Secale cereale*	Rymin	100	83	120
Cereal Rye	*Secale cereale*	Wheeler	100	82	122
Cereal Rye	*Secale cereale*	WinterGrazer 70	100	78	128
Cereal Rye	*Secale cereale*	Wren's Abruzzi	100	84	119
Crimson clover	*Trifolium incarnatum*	AU Robin	18	56	32
Crimson clover	*Trifolium incarnatum*	AU Sunrise	18	42	43
Crimson clover	*Trifolium incarnatum*	AU Sunup	18	91	20
Crimson clover	*Trifolium incarnatum*	Contea	18	60	30
Crimson clover	*Trifolium incarnatum*	Dixie	18	53	34
Crimson clover	*Trifolium incarnatum*	KY Pride	18	98	18
Hairy vetch	*Vicia villosa*	CCS Groff	18	90	20
Hairy vetch	*Vicia villosa*	Purple Bounty	18	78	23
Hairy vetch	*Vicia villosa*	Purple Prosperity	18	90	20
Hairy vetch	*Vicia villosa*	Villana	18	89	20
Woollypod vetch	*Vicia villosa* subsp. *varia*	Lana	18	98	18
Daikon radish	*Raphanus sativus*	Big Dog	9	93	10
Daikon radish	*Raphanus sativus*	Concorde	9	88	10

Table 1 (cont.). Species, cultivars and seeding rates of annual, cool seasons planted in 2016 and 2017 at the USDA NRCS Fallon, NV Plant Materials Center.

Common name	Species	Cultivar	PLS lb/acre	% PLS	Seeding rate lb/acre
Daikon radish	*Raphanus sativus*	Eco-till	9	88	10
Daikon radish	*Raphanus sativus*	Graza	9	93	10
Daikon radish	*Raphanus sativus*	Groundhog	9	85	11
Daikon radish	*Raphanus sativus*	Lunch	9	93	10
Daikon radish	*Raphanus sativus*	Nitro	9	98	9
Daikon radish	*Raphanus sativus*	Sodbuster Blend	9	94	10
Daikon radish	*Raphanus sativus*	Tillage	9	90	10
Red clover	*Trifolium pratense*	Cinnamon Plus	9	59	15
Red clover	*Trifolium pratense*	Cyclone II	9	60	15
Red clover	*Trifolium pratense*	Dynamite	9	59	15
Red clover	*Trifolium pratense*	Freedom	9	59	15
Red clover	*Trifolium pratense*	Kenland	9	80	11
Red clover	*Trifolium pratense*	Mammoth	9	88	10
Red clover	*Trifolium pratense*	Starfire	9	59	15
Red clover	*Trifolium pratense*	Wildcat	9	59	15

RESULTS AND DISCUSSION

The two years, 2016-2017 (Y1) and 2017-2018 (Y2), were very different in both temperature, total precipitation, precipitation distribution, and irrigation. Y1 had the coldest lowest temperature (-7.77°F) and fewer days after planting before nightly freezing temperatures, but was warmer on average than Y2, especially in December and February (Fig. 1). Despite Y1 being planted a month later in the year than Y2, Y1 accumulated more growing degree days (GDD) than Y2 in the first 30 days after planting (Fig. 2; base 40°F). Y1 also had earlier and more rapid accumulation of GDD after January than Y2 (Fig. 3). Y1 had above average rainfall (5.22 inches) while Y2 had below average rainfall (3.26 inches). However, distribution of that rainfall was not uniform, with Y1 receiving below average (0.5 inches), and Y2 receiving above average (2.18 inches), rainfall during spring green-up in March, April, and May (Fig. 4). Y2 was also irrigated twice in September, once in October, and once in late April. The two different irrigation regimes was due to irrigation availability. Irrigation in Fallon was shut off in August 2016 and was not available for Y1. Water availability increased in 2017, allowing for irrigation in Y2.

Summer cover data reflects end of season crop performance, after the plant is subjected to freezing winter temperatures, limited moisture at green-up, and weed competition. Y1 was collected on May 11th with the results listed in each crop's corresponding table. Y2 was not added to the cover crop tables due to poor performance for all cultivars tested, except for cereal rye (excellent). The poor performance was influenced by annual mustard (*Descurainia* spp.), a cool season weed that had 100% cover on all impacted cover crops in Y2 (Fig. 5).

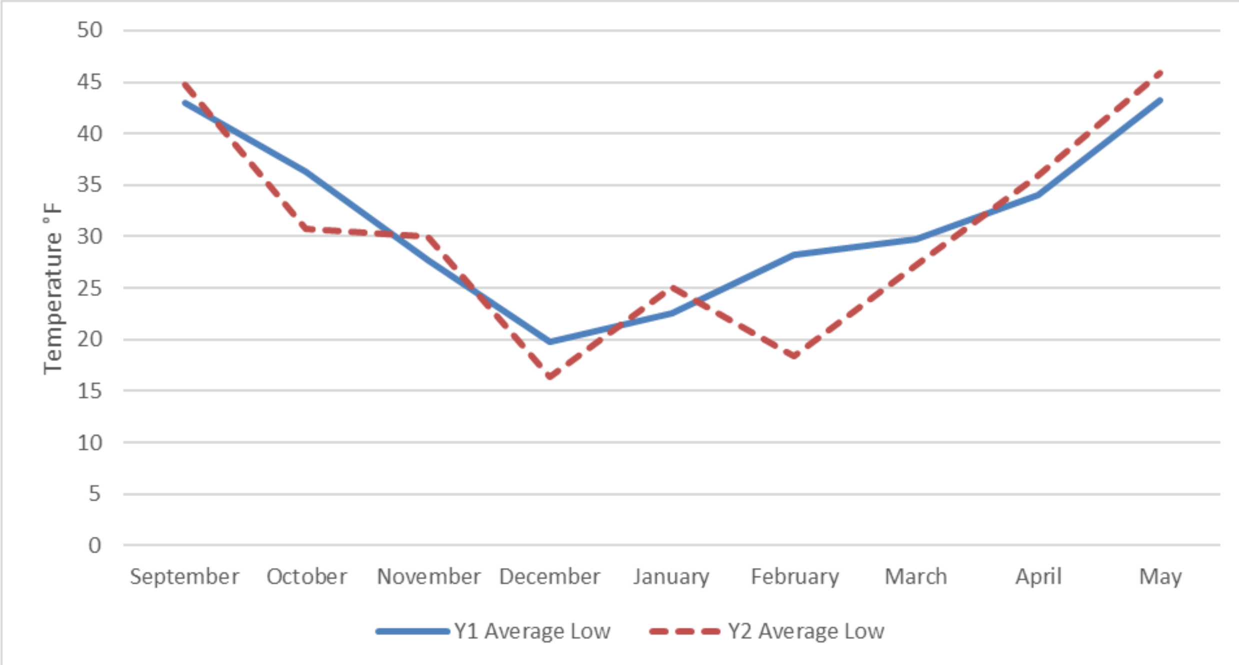

Figure 1: Monthly average low temperatures in Y1 and Y2, Fallon, NV.

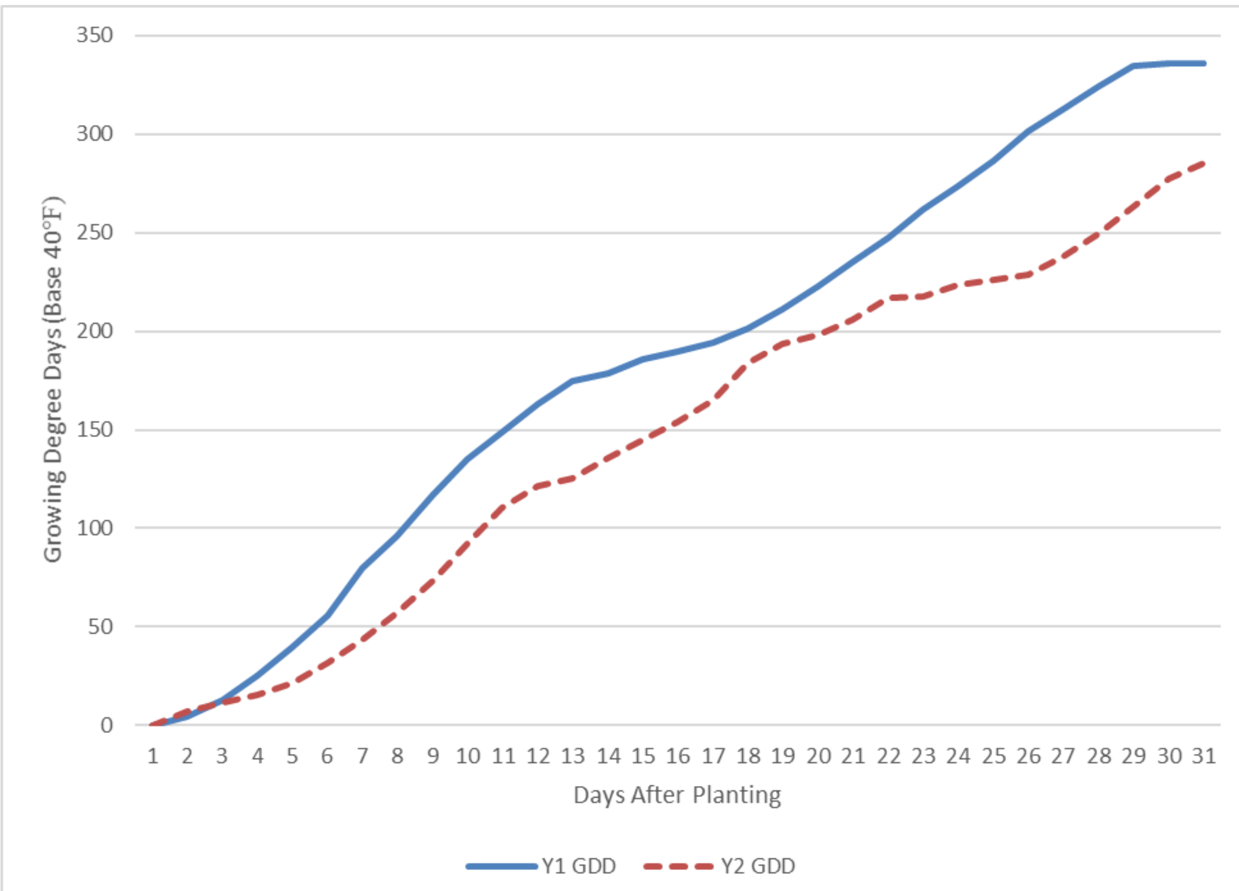

Figure 2: Cumulative growing degree days for the first thirty days after planting.

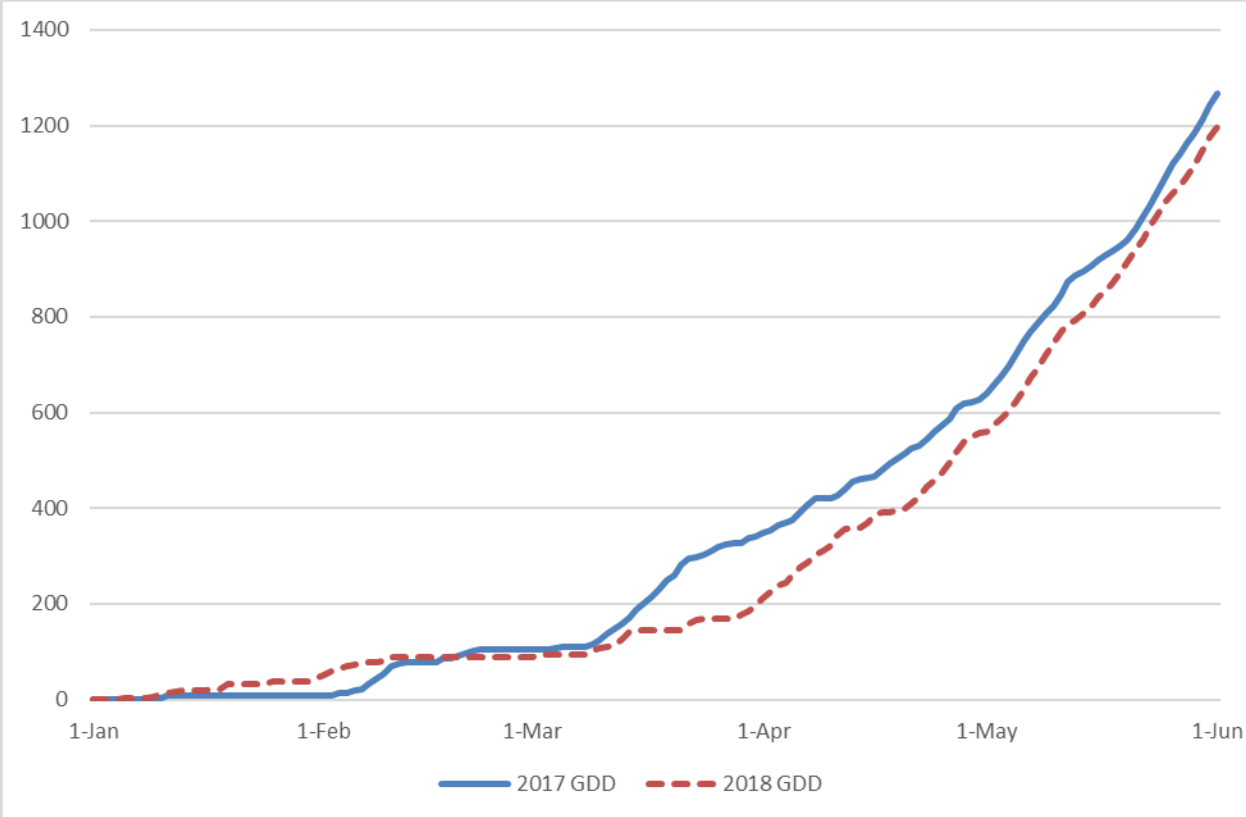

Figure 3: Cumulative GDD from January through June for Y1 and Y2.

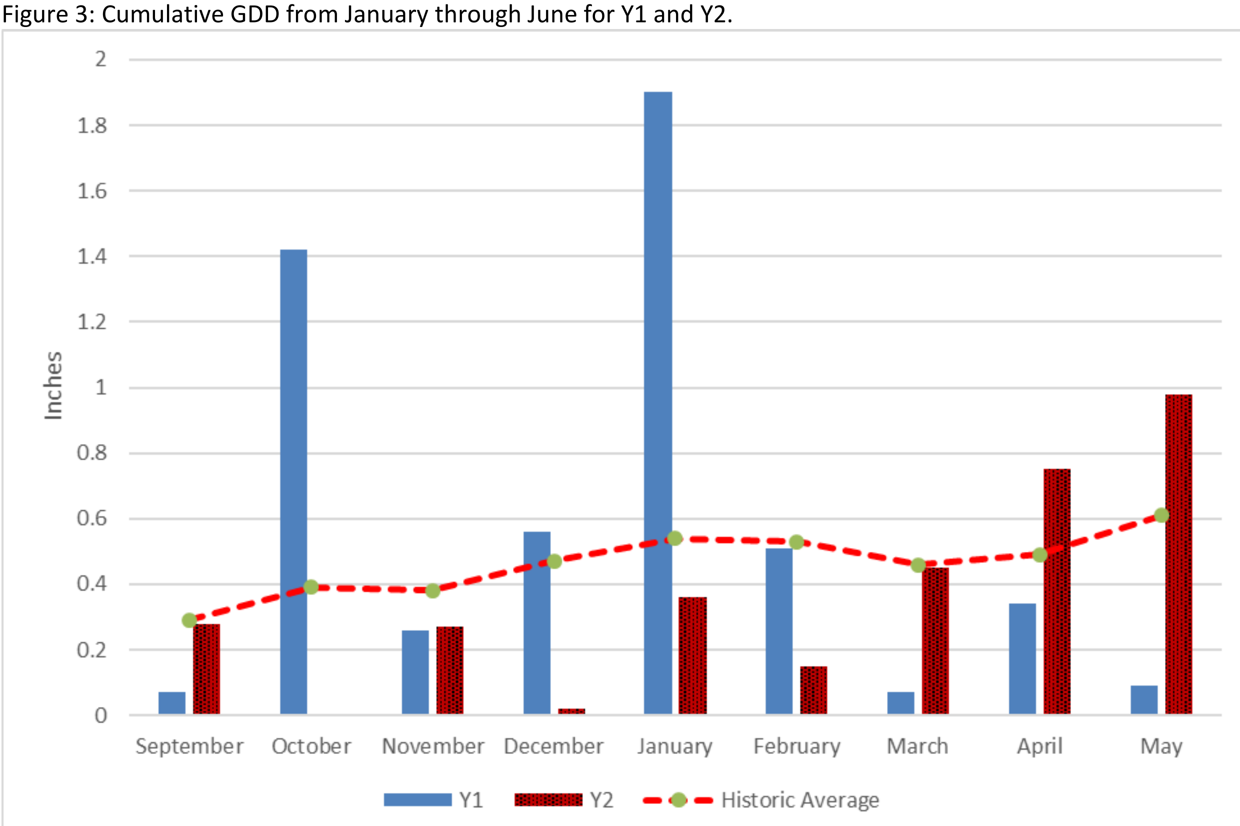

Figure 4: Monthly rainfall for Y1, Y2, and the historic average, Fallon, NV.

Figure 5: Weed Pressure for Y2. Cereal Rye plots clearly visible while all others are dominated by annual mustard.

A two sample t-test was used to compare the two years per species for emergence and percent winter hardiness (Table 2). It was expected that Y2 performance for all variables would be superior to Y1 due to fertilization, irrigation, and more GDD prior to nightly frosts. There was greater emergence by 7 DAP in Y2 for cereal rye ($p<0.0000$), daikon radish ($p<0.0000$), crimson clover ($p<0.0000$), red clover ($p<0.0000$), and the oats. Of these, by 14 DAP cereal rye had superior emergence in Y2 ($p=0.0343$), and red clover had superior performance in Y1 ($p=0.0444$). Austrian winter pea and hairy vetch were slower to emerge, but by 14 DAP Y1 was greater than Y2 ($p<0.0000$ and $p=0.0012$ respectively). Hairy vetch Y1 emergence remained greater than Y2 for all dates tested. With the exception of hairy vetch, no difference between years in emergence was recorded for any cover crop species at 21 DAP and 28 DAP.

Percent winter hardiness per year varied by species. There was no difference between years for oats, daikon radishes, and hairy vetch. Survival in Y1 was better than Y2 for cereal rye ($p=0.0091$) and Austrian winter pea ($p=0.0001$), while survival in Y1 was less than Y2 for balansa clover, crimson clover ($p<0.0000$), and red clover ($p<0.0000$). This demonstrates that planting time, fertilization, and irrigation can influence frost survival, but not uniformly for all species. This has implications when considering species mixes.

Table 2. Species comparison of Year 1 (Y1) and Year 2 (Y2) for emergence at 7, 14, 21, and 28 Days After Planting and percent winter survival. USDA-NRCS Fallon, NV. Two sample t-test (H_0: Y1 = Y2; $\alpha<0.05$)

	Days After Planting Emergence								Percent Winter Survival	
	7		14		21		28			
	Y1vsY2	P-Value	Y1vsY2	P-Value	Y1vsY2	P-Value	Y1vsY2	P-Value	Y1vsY2	P-Value
Cereal Rye	<	0.0000	<	0.0343	=	*	=	*	>	0.0091
Austrian Winter Pea			>	0.0000	=	0.7533	=	0.0886	>	0.0001
Balansa Clover			=	1.0000	=	0.3343	=	0.3343	<	*
Black Oats	<	*	=	*	=	*	=	*	=	*
Black Seeded Oats	<	*	=	*	=	*	=	*	=	*
Daikon Radish	<	0.0000	=	0.1326	=	0.0931	=	0.8147	=	0.4218
Crimson Clover	<	0.0278	=	0.8577	=	0.3374	=	0.1431	<	0.0000
Hairy Vetch			>	0.0012	>	0.0002	>	0.0000	=	0.3672
Red Clover	<	0.0000	>	0.0444	=	0.8823	=	0.5912	<	0.0000

*Data nearly constant. (Example: Almost all cereal rye for Y1 and Y2 at 28 DAP had a value of 3.)

Balansa Clover

Balansa clover cultivars performed poorly for both years. 'Frontier' had poor performance for both years while 'Fixation' did slightly, but not significantly, better in Y2 with moderate emergence at 21 DAP (Table 3). No additional data was collected in Y1 due to no stand establishment. Y2 had poorly established stands that did exhibit good winter hardiness ('Frontier'=74%, 'Fixation'=70%; Table 3). Additional data was limited due to water stress increasing mortality prior to reaching 50% flower and annual mustard dominating plots with 100% cover.

Balansa clover's poor overall performance suggests that this cover crop would not be suited in the Great Basin. However, cover crop evaluations in the eastern U.S. have found balansa clover to be adapted to a wide range of soil types (particularly silty clay), tolerate pH from 4.5 to 8.0, and is hardy throughout zone 7A; becoming marginal in zone 6B (Clark 2012). The GBPMC fields are loamy sand with a pH of ~7.8, and are in zone 7A, which suggests that balansa clover should have had better performance and may have been limited by our loamy sand soils.

Table 3. Mean values and standard deviations of emergence groups (see below) of balansa clover at 7, 14, 21 and 28 days after planting in 2016-2017. USDA-NRCS Fallon, NV

Cultivar	Days after planting/Year							
	7		14		21		28	
	Y1	Y2	Y1	Y2	Y1	Y2	Y1	Y2
Fixation	0	0.8	0.3	0.5	0.3	0.8	0.3	0.8
Frontier	0	0	0.3	0	0.3	0.3	0.3	0.3
Mean		0.34	0.25	0.25	0.25	0.5	0.25	0.5
SD[2/]		0.52	0.46	0.46	0.46	0.53	0.46	0.53

[1/] 0 = poor (<25% emergence); 1 = moderate (30-60% emergence); 2 = good (65-85% emergence); 3 = excellent (90-100% emergence). [2/] Standard deviation.

Table 4. Mean values and standard deviations for percent winter hardiness, plant height and days after planting to 50% bloom for black oats cultivars in 2017 and 2018 at the USDA-NRCS Fallon, NV

Cultivar	% Winter hardiness		Plant height (in.)		DAP to 50% bloom		Summer Cover
	Y1	Y2	Y1	Y2	Y1	Y2	Y1
Fixation	.	70	.	.	.	.	.
Frontier	.	75	.	4	.	228	.
Mean	.	72	.		.		.
SD[1/]	.	23	.	.	.	.	.

[1/] Standard deviation.
. – Plants did not survive to 50% bloom.

Oats

Field emergence for oats was similar for both years. Y1 recorded excellent emergence for both oats by 14 DAP while Y2 was faster with excellent emergence by 7 DAP (Table 5). The irrigation and fertilizer application for Y2 likely influenced the rapid Y2 emergence. The black seeded oat 'Cosaque' exhibited excellent winter hardiness while the black oat 'Soil Saver' was completely winter killed (Table 6). Black oats' poor frost hardiness was expected as it occasionally winter kills in zones 8b-10a in the lower coastal plains of the USA (Clark 2012). 'Soil Saver' has done well in fall plantings in plant hardiness zone 8b but is not recommended in colder zones due to insufficient cold hardiness and risk of winterkill (Dial 2014, USDA-ARS 2016). These results suggest that black oats may be useful in a system that uses freezing temperatures to terminate the cover crop, but are otherwise not suited for the Great Basin.

Plant height of 'Cosaque' averaged 19.6 inches in Y1 and more than doubled that in Y2 to 45.5 inches. This is not surprising as Y2 had more time before winter dormancy and was irrigated and fertilized. Oats are known to be a reliable cover crop that winter kills in zone 6 and much of zone 7. The typical low cost of oats makes it a good option to keep overall cover crop costs low, minimizing financial risks (Fan et al. 2019). Our results suggest that 'Cosaque' may be suitable for the Great Basin. A greater variety of oat cultivars should be evaluated to increase our knowledge of suitable cultivars. Biomass data would be useful in determining organic matter produced per cultivar in our region.

Table 5. Mean values and standard deviations of emergence groups (see below) of black seeded oats and black oats at 7, 14, 21 and 28 days after planting in 2016-2017. USDA-NRCS Fallon, NV

Cultivar	Days after planting							
	7		14		21		28	
	Y1	Y2	Y1	Y2	Y1	Y2	Y1	Y2
Cosaque	0	3	3	3	3	3	3	3
Soil Saver	0	2.5	3	2.75	3	3	3	3
Mean		2.75	3	2.87	3	3	3	3
SD[2/]		0.46		0.35				

[1/] 0 = poor (<25% emergence); 1 = moderate (30-60% emergence); 2 = good (65-85% emergence); 3 = excellent (90-100% emergence). [2/]SD standard deviation.

Table 6. Mean values and standard deviations for percent winter hardiness, plant height and days after planting to 50% bloom for black oats cultivars in 2017 and 2018 at the USDA-NRCS Fallon, NV

Cultivar	% Winter hardiness		Plant height (in.)		DAP to 50% bloom		Summer Cover
	Y1	Y2	Y1	Y2	Y1	Y2	Y1
Cosaque	100	99	20	46	219	267	3[2/]
Soil saver	0	1	.	.	.	.	0
Mean	50	50	20	46	219	267	1.71
SD[1/]	53.5	52.6	7	3.3			1.60

[1/] Standard deviation
[2/] 0 = poor (<25% emergence); 1 = moderate (30-60% emergence; 2 = good (65-85% emergence); 3 = excellent (90-100%)

Cereal Rye

Cereal rye cultivar emergence varied for the two years. Y1 had poor to good emergence at 7 DAP, with all but 'Guardian' reaching excellent emergence by 14 DAP. 'Hazlet' had the greatest emergence on 7 DAP while 'Guardian' had the lowest. By 28 DAP there was no significant difference between emergence of any cultivar. Y2 had excellent emergence for all cultivars by 7 DAP (Table 7). Winter cover crops that quickly emerge and accumulate fall growth are important attributes for reducing soil erosion, scavenging residual soil nutrients, reducing groundwater contamination of leached nitrates, and suppressing weeds (Meisinger et al. 1991, Shipley et al. 1992).

Percent winter hardiness was greater than 99% for all cultivars for Y1. This was despite a low of -5.64°F and -7.77°F on January 5 and January 6 Y1. Y2 winter hardiness ranged from 21% to 100% and averaged 91.74±24.8% (mean and standard deviation; Table 7). 'Florida 101' had the lowest winter hardiness (21%) (that's likely causing the variation). Height ranged from 26 to 46 inches with a mean of

34.84±7.84 inches. No difference between cultivar height was detected for Y2 (53.31±5.6 inches). Blooming date is important when determining the best time to terminate the cover crop. Cereal rye may become a weed if allowed to go to seed, and is listed as a Class C noxious weed in Washington (NWCB 2020). It is recommended that cereal rye is terminated prior to seed production, at least two weeks before the subsequent crop (Clark 2012).

Cereal rye was the only cover crop that recorded excellent summer cover for both years. Weed pressure was particularly high in Y2, but plots of cereal rye were clearly visible (Fig. 5) while all other cover crops had poor cover. Cereal rye is known as one of the hardiest cereals for fall planting, and for weed suppression (Ruffo et al. 2004, Clark 2012). These characteristics were confirmed with this study. While cereal rye in general was a superior performer, 'FL 101' and 'Guardian' did not match the high performance of the other cultivars.

The cereal rye in Y1 was hit with high levels of deer herbivory in December. Utilization was non-uniform with 'Merced' experiencing the highest rate of utilization and 'Guardian' the lowest (mean 6941±2836 lb/ac; Table 9). Cultivars that can withstand high herbivory while still producing biomass may be useful for providing forage, organic matter, or distracting herbivores away from target crops.

Table 7. Mean values and standard deviations for field emergence of emergence groups (see below) of cereal rye cultivars at 7, 14, 21 and 28 days after planting in 2016-2017. USDA-NRCS Fallon, NV

Cultivar	Days after planting							
	7		14		21		28	
	Y1	Y2	Y1	Y2	Y1	Y2	Y1	Y2
Aroostock	1.8	3	3	3	3	3	3	3
Bates	0.8	3	3	3	3	3	3	3
Brasetto	1.8	3	3	3	3	3	3	3
Elbon	1.3	3	3	3	2.8	3	3	3
FL 101	1.3	3	3	3	3	3	3	3
Guardian	0	3	1	3	1.8	3	2	3
Hazlet	2.3	3	3	3	3	3	3	3
Maton	1.5	3	3	3	3	3	3	3
Maton II	0	2.5	2.8	2.8	3	3	3	3
Merced	1.5	3	3	3	3	3	3	3
Oklon	0.5	3	3	3	3	3	3	3
Prima	0.8	2.8	2.8	3	3	3	3	3
Rymin	2	3	3	3	3	3	3	3
Wheeler	0.5	3	3	3	3	3	3	3
Wintergrazer 70	1.8	3	3	3	3	3	3	3
Wren Abruzzi	1.3	3	3	3	3	3	3	3
Mean	1.14	2.95	2.84	2.98	2.91	3	2.93	3
SD[2]	0.81	0.21	0.51	0.12	0.34		0.24	

[1/] 0 = poor (<25% emergence); 1 = moderate (30-60% emergence); 2 = good (65-85% emergence); 3 = excellent (90-100% emergence). SD[2/] standard deviation.

Table 8. Mean values and standard deviations for percent winter hardiness, plant height and days after planting to 50% bloom for cereal rye cultivars in 2017 and 2018 at the USDA-NRCS Fallon, NV

Cultivar	% Winter hardiness		Plant height (in.)		DAP to 50% bloom		Summer Cover
	Y1	Y2	Y1	Y2	Y1	Y2	Y1
Aroostock	100	99	34	51	191	228	3[2/]
Bates	100	100	33	53	191	228	3
Brasetto	100	100	26	47	204	239	3
Elbon	100	100	37	57	191	228	3
FL 101	100	21	28	54	191	239	3
Guardian	100	100	40	52	211	239	2.3
Hazlet	99	100	30	52	206	239	3
Maton	100	99	41	57	191	228	3
Maton II	100	96	35	55	191	234	3
Merced	100	53	28	53	191	228	3
Oklon	100	100	35	53	191	228	3
Prima	100	100	32	58	204	239	3
Rymin	100	100	36	51	204	239	3
Wheeler	100	100	46	58	211	245	3
Wintergrazer 70	100	100	39	54	191	228	3
Wren Abruzzi	100	99	36	52	191	228	3
Mean	100	92	34.8	53.3	197	234	2.95
SD[1/]	0.4	24.8	7.84	5.6	7.9	6.3	0.21

[1/]SD - Standard deviation.
[2/] 0 = poor (<25% emergence); 1 = moderate (30-60% emergence; 2 = good (65-85% emergence); 3 = excellent (90-100%)

Table 9. Year 1 cereal rye herbivory rank and biomass. USDA-NRCS Fallon, NV

Cultivar	Herbivory[1/]	Pounds per acre	Cultivar	Herbivory[1/]	Pounds Per Acre
Aroostock	1.7	6494	**Maton II**	1.3	7114
Bates	2.3	5816	**Merced**	3.5	5802
Brasetto	1.5	7078	**Oklon**	1.3	8559
Elbon	1.8	7578	**Prima**	0.5	8474
FL 101	2.3	5972	**Rymin**	2.8	9572
Guardian	0	5945	**Wheeler**	1.8	9184
Hazlet	2	7435	**Wintergrazer 70**	2.3	8390
Maton	1	9389	**Wren Abruzzi**	2.5	7712
Mean	1.65	6941			
SD[/2]	1.16	2836			

[1/] 0 = None (0-5% herbivory); 1 = low (6-25% herbivory); 2 = medium (26-50% herbivory); 3 = high (51-75% herbivory); 4 = very high (>75% herbivory). SD[2/] standard deviation.

Crimson Clover

Crimson clover cultivars ranged in emergence from poor to excellent by 28 DAP in both years (Table 10). In Y1, 'AU Robin' had significantly more emergence than the other cultivars at 7 DAP. 'Kentucky Pride' surpassed 'AU Robin' for the highest emergence from 14-28 DAP. The best emergence cultivars in Y2 were not the same in Y1.

Winter hardiness ranged from 0-39% in Y1 and 22-78% in Y2 (Mean 19.68±22.6% and 41.44±33.2% respectively; Table 11). No significant winter hardiness differences were detected between cultivars per year (Table 2), but Y2 had significantly higher winter hardiness than Y1 ($p=0.0000$). The difference suggests that an earlier planting may increase winter hardiness. Industry recommendations suggest planting crimson clover six to eight weeks prior to the average date of first frost (Clark 2012). The 50% frost date in Fallon is September 30th, indicating that an early August planting date may be more appropriate. However, producers are cautioned to avoid planting too early as crimson clover will go to seed.

‘AU Sunup’ didn’t survive to flowering in Y1, and ‘AU Robin’ and ‘Kentucky Pride’ failed to flower in Y2. Of the remaining cultivars, plant height didn’t vary, but was relatively low with a mean of 4±0.7 inches for Y1 and 10.6±2.9 inches for Y2. The earlier planting date, irrigation, and fertilizer used on Y2 may account for these differences. Failure to flower, especially after moderate to high winter hardiness, was likely caused by weed competition and water stress at green-up.

Y1 summer cover ranged from poor to moderate (mean 0.38±0.58). The poor cover performance was related to the poor winter hardiness. Y2 had poor summer cover due to corresponding weed cover of 100%. Crimson clovers are known for their excellent weed suppression (Young-Mathews 2013), but in Fallon they were unable to compete with annual mustards.

Table 10. Mean values and standard deviations of emergence groups (see below) of crimson clover cultivars at 7, 14, 21 and 28 days after planting in 2016-2017. USDA-NRCS Fallon, NV

Cultivar	Days after planting							
	7		14		21		28	
	Y1	Y2	Y1	Y2	Y1	Y2	Y1	Y2
AU Robin	1.3	1	1.5	1	2	1	2.3	1
AU Sunrise	1	1.8	1.3	1.5	2	2.3	2.3	2.3
AU Sunup	0	0.3	0	0.3	0	0.3	0	0.3
Contea	0.8	1	1.5	1.5	2.3	2	2.5	2
Dixie	0.5	1.8	1.5	1.8	1.8	2	2	2
Kentucky Pride	1	1.5	1.8	1.8	2.8	1.5	2.8	1.5
Mean	0.75	1.21	1.25	1.29	1.79	1.5	1.95	1.5
SD/2	0.61	0.77	0.79	0.81	1.01	10.2	1.16	1.02

1/ 0 = poor (<25% emergence); 1 = moderate (30-60% emergence; 2 = good (65-85% emergence); 3 = excellent (90-100% emergence). SD2/ standard deviation.

Table 11. Mean values and standard deviations for percent winter hardiness, plant height and days after planting to 50% bloom for crimson clover cultivars in 2017 and 2018 at the USDA-NRCS Fallon, NV

Cultivar	% Winter hardiness		Plant height (in.)		DAP to 50% bloom		Summer Cover2/
	Y1	Y2	Y1	Y2	Y1	Y2	Y1
AU Robin	10	78	4	.	194	.	0.25
AU Sunrise	39	20	4	10	195	228	1
AU Sunup	.	22	.	7	.	228	0
Contea	28	22	4	14	198	252	0.25
Dixie	11	53	4	12	198	228	0.25
Kentucky Pride	11	53	4	.	204	.	0.5
Mean	20	41.4	4	11	198	233	0.38
SD1/	22.6	33.2	0.7	2.9	4.4	10.7	0.58

1/SD - Standard deviation.
. – No plants survived to 50% bloom.
2/ 0 = poor (<25% emergence); 1 = moderate (30-60% emergence; 2 = good (65-85% emergence); 3 = excellent (90-100%)

Hairy Vetch

Hairy vetch cultivars had poor early field emergence at 7 DAP for both years (Table 12). 'Lana' and 'TNT' recorded the highest emergence percentages for both years. Overall winter hardiness was high, with no significant differences detected between cultivars (Y1: Mean 77.9±24.9%; Y2: 71.6±23.03%). High winter hardiness is one of many characteristics of hairy vetch (Clark 2012). Plant height was recorded, but the data was confounded due to weed contamination and hairy vetch's habit of climbing. Bloom dates were significantly different, with 'Lana' blooming 20 days earlier than 'Villana', 'TNT', and 'CCS Groff' in Y1, and 15 days earlier than 'CCS Groff' in Y2. Hairy vetch should be terminated prior to seed production as it volunteers profusely when allowed to disseminate seed (NRCS 2002).

Summer cover was good to excellent in Y1, but was poor in Y2 when the planting was dominated by annual mustard. Hairy vetch is known for vigorous spring growth and early weed suppression (Clark 2012). This was not observed in Fallon. While hairy vetch survived weed pressure, spring growth was slow and provided minimal weed suppression. However, hairy vetch did climb the weeds and covered them, but this occurred after the weeds had matured and gone to seed. Hairy vetch could be useful in a mix, especially if the climbing could occur on another cover crop such as cereal rye.

Table 12. Mean values and standard deviations of emergence groups (see below) of hairy vetch cultivars at 7, 14, 21 and 28 days after planting in 2016-2017. USDA-NRCS Fallon, NV

Cultivar	Days after planting							
	7		14		21		28	
	Y1	Y2	Y1	Y2	Y1	Y2	Y1	Y2
CCS Groff	0	0	1	0.3	2	1.3	2	1.3
Lana	0.5	0	1.5	0.8	2.8	1.8	3	2
Purple Bounty	0	0	0.5	0	1.8	1	2.3	1
Purple Prosperity	0	0	1	0.3	2	1.5	2.5	1.5
TNT	0	0	1	1	2.5	1.8	3	1.8
Villana	0	0	0.5	0.3	1.8	1.3	2.3	1.3
Mean	0.08	0	0.92	0.41	2.13	1.41	2.5	1.46
SD/2	0.41	0	0.50	0.50	0.61	0.58	0.89	0.66

1/ 0 = poor (<25% emergence); 1 = moderate (30-60% emergence); 2 = good (65-85% emergence); 3 = excellent (90-100% emergence). SD2/ standard deviation.

Table 13. Mean values and standard deviations for percent winter hardiness, plant height and days after planting to 50% bloom for hairy vetch cultivars in 2017 and 2018 at the USDA-NRCS Fallon, NV.

Cultivar	% Winter hardiness		Plant height (in.)		DAP to 50% bloom		Summer Cover2/
	Y1	Y2	Y1	Y2	Y1	Y2	Y1
CCS Groff	60	71	10	10	211	247	2.3
Lana	86	73	9	31	191	232	2.5
Purple Bounty	69	70	13	40	206	247	2.8
Purple Prosperity	100	86	13	39	204	245	2.5
TNT	74	68	14	34	211	249	2.8
Villana	78	61	13	41	211	247	2
Mean	80	72	12	37	205	244	2.48
SD1/	25	23	3.6	6.6	7.8	7.1	0.8

1/SD - Standard deviation.
2/ 0 = poor (<25% emergence); 1 = moderate (30-60% emergence; 2 = good (65-85% emergence); 3 = excellent (90-100%)

Daikon Radish

Percent field emergence of daikon radish cultivars were excellent by 28 DAP for both years, except for 'Graza' which had good emergence (Table 14). Emergence was significantly more rapid in Y2 than Y1 ($p<0.000$; Table 2), ranging from poor to moderate for Y1 and moderate to excellent for Y2 at DAP 7. This was likely due to the applied fertilizer since Y1 had more GDD than Y2 by 28 DAP. The best early germinating cultivars varied by year, with 'EcoTill' at 7 DAP and 'Driller', 'EcoTill', 'Nitro', and 'Concord' at 14 DAP for Y1, and 'Driller' at 7 DAP and 'Driller' and 'Big Dog' at 14 DAP for Y2.

Winter hardiness was poor, with some variation between cultivars (Table 15). Y1 winter hardiness ranged from 0-40% (mean 8.6±16.8%) and Y2 ranged from 0%-42% (mean 11.8±21.15%). No significant difference was detected between years, but performance of individual cultivars varied. For example, 'Graza' had low winter hardiness in Y1 (5%) while it had the highest in Y2 (42%), and 'Control' had the highest winter hardiness in Y1 (40%), but an average winter hardiness in Y2 (20%). Radishes are tolerant of light frost but tend to die when freezing temperatures reach 25° to 20° F (Sundermeier 2008). Fallon is regularly below those temperatures and recorded an average low below 20° F for December for both years. Surviving plants were limited and showed signs of drought stress prior to flowering, thus plant height and 50% bloom data was unavailable for many cultivars. While winter hardiness was poor, several cultivars maintained a presence in the field. These may become contaminants in subsequent crops and require additional termination management. Cultivars with no winter survival may be useful as winter cover crops that utilize freezing temperatures for termination.

Summer cover for Y1 ranged from poor to moderate (0.23±0.63). This was likely negatively impacted by poor winter hardiness and continued mortality caused by water stress at green-up (personal observations). Y2 had similar winter hardiness, increased precipitation during spring green-up, but did not appear to control weeds. Annual mustard reached 100% cover in all daikon radish plots. Despite this poor performance, daikon radish under favorable conditions are known to establish quickly and to aggressively suppress weeds (Jacobs 2012).

Table 14. Mean values and standard deviations of emergence groups (see below) of daikon radish sources at 7, 14, 21 and 28 days after planting in 2016-2017. USDA-NRCS Fallon, NV.

Cultivar	Days after planting							
	7		14		21		28	
	Y1	Y2	Y1	Y2	Y1	Y2	Y1	Y2
Big Dog	1	2.5	1.8	2.8	3	3	3	3
Concorde	1	2	2.3	2.3	2.8	3	3	3
Control	1	2	2	2.3	2.8	3	3	3
Defender	0.3	1.3	2	1.5	2.8	3	3	3
Driller	1	3	2.5	3	2.8	3	3	3
EcoTill	1.3	2.5	2.3	2.5	3	3	3	3
Graza	0	0	0.5	0.3	1.3	1.8	1.8	1.8
Groundhog	0.5	2.5	2	2.5	3	3	3	3
Lunch	0.5	1.8	2	1.8	2.5	3	3	3
Nitro	0.8	2.3	2.3	2.5	2.5	3	3	3
Nitro	0.8	2.3	2.3	2.5	2.5	3	3	3
Sodbuster	0.3	2.3	1.8	2.3	3	2.8	3	2.8
Tillage	1	2.5	2	2.5	3	3	3	3
Mean	0.70	2.04	1.93	2.16	2.68	2.87	2.90	2.88
SD[2/]	0.50	0.87	0.60	0.86	0.59	0.49	0.37	0.49

[1/] 0 = poor (<25% emergence); 1 = moderate (30-60% emergence); 2 = good (65-85% emergence); 3 = excellent (90-100% emergence). SD[2/] standard deviation.

Table 15. Mean values and standard deviations for percent winter hardiness, plant height and days after planting to 50% bloom for daikon radish cultivars in 2017 and 2018 at the USDA-NRCS Fallon, NV.

Cultivar	% Winter hardiness		Plant height (in.)		DAP to 50% bloom		Summer Cover[2/]
	Y1	Y2	Y1	Y2	Y1	Y2	Y1
Big Dog	15	4	8	.	191	.	0
Concorde	9	6	10	28	207	245	0
Control	40	20	9	19	200	236	1.3
Defender	16	22	11	23	198	245	1
Driller	0	0	.	.	.	.	0
EcoTill	2	3	7	.	198	.	0
Graza	5	42	.	23.5	.	239	0
Groundhog	0	7	.	.	.	.	0.3
Lunch	11	30	.	.	191	.	0.3
Nitro	6	2	6	.	198	.	0
Sodbuster	0	2	.	.	.	.	0
Tillage	0	2	.	.	.	.	0
Mean	9	12	9	22	198	239	0.23
SD[1/]	16.8	21.2	2.8	5.3	5.5	9.0	0.63

. – Zero survival to 50% bloom date.; [1/]SD - Standard deviation.
[2/] 0 = poor (<25% emergence); 1 = moderate (30-60% emergence; 2 = good (65-85% emergence); 3 = excellent (90-100%)

Red Clover

Red clover cultivars were slow to emerge, and by 28 DAP ranged from moderate to excellent emergence for Y1 and moderate to good emergence for Y2 (Table 16). In Y1, 14 DAP emergence recorded significant differences, with 'Dynamite' and 'Wildcat' having the highest emergence (2 each), and 'Starfire II' having the lowest emergence (0.25). This difference dissipated by 21 DAP, and no other difference in emergence was recorded for either year.

Winter hardiness was significantly different between the two years tested ($p<0.0000$; Table 2). Y1 had a high winter hardiness of 3% while Y2 had a high of 86% (Mean 0.61±2.28% and 68.68±29.51%, respectively). It is recommended that fall plantings occur six weeks prior to frost to ensure crop establishment prior to freezing (John and Ogle 2008). This may be why Y2 recorded higher winter hardiness than Y1. No significant winter hardiness difference was detected between cultivars per year. Red clover is known as a reliable winter hardy cover crop that germinates relatively quickly, grows at temperatures as low as 40° F, and is adapted to Zone 4 and warmer (Clark 2012). This suggests that red clover may be adapted to Fallon, NV. However, red clover is not drought tolerant and does not perform well on extremely sandy soils (Undersander et al. 1990). The loamy sand soils and limited precipitation at spring green-up were likely contributing factors to the red clover's poor overall performance. It may be worth evaluating red clover on different soils at higher precipitation zones.

All cultivars showed signs of water stress after spring green-up (personal observation). No plot survived to flowering and no plant height or 50% bloom data was collected. No plants survived to provide summer cover data. Weed competition in Y2 may have contributed to reduced clover fitness. Annual mustard cover was 100% by the end of the study.

Table 16. Mean values and standard deviations of emergence groups (see below) of red clover cultivars at 7, 14, 21 and 28 days after planting in 2016-2017. USDA-NRCS Fallon, NV.

Cultivar	Days after planting							
	7		14		21		28	
	Y1	Y2	Y1	Y2	Y1	Y2	Y1	Y2
Cinnamon Plus	0.25	1	1.3	1.3	1	1.8	1.5	1.8
Cyclone II	0.25	1.25	1.3	1.3	1.8	1.3	1.8	1.3
Dynamite	0.75	1	2	1	2.5	1.8	2.8	1.8
Freedom	0	0.75	1	1.3	1.5	1.8	1.5	1.8
Kenland	0.25	0.75	1.3	0.8	1.3	1	1.3	1
Mammoth	0	0.5	1.3	0.8	1.5	1.8	1.3	1.8
Starfire II	0	0.25	0.5	0.3	1	1	1	1
Wildcat	0.25	1.5	2	1.3	2	2	2.3	2
Mean	0.21	0.87	1.31	0.96	1.56	1.53	1.65	1.53
SD[/2]	0.42	0.70	0.59	0.74	0.91	0.76	1.06	0.76

[1/] 0 = poor (<25% emergence); 1 = moderate (30-60% emergence; 2 = good (65-85% emergence); 3 = excellent (90-100% emergence). SD[2/] standard deviation.

Table 17. Mean values and standard deviations for percent winter hardiness, plant height and days after planting to 50% bloom for red clover cultivars in 2016 and 2017 at the USDA-NRCS Fallon, NV.

Cultivar	% Winter hardiness		Plant height (in.)		DAP to 50% bloom	
	Y1	Y2	Y1	Y2	Y1	Y2
Cinnamon Plus	0	68	.	.	.	.
Cyclone II	0.89	86	.	.	.	.
Dynamite	0	77	.	.	.	.
Freedom	3	61	.	.	.	.
Kenland	0	42	.	.	.	.
Mammoth	1.04	60	.	.	.	.
Starfire II	0	83	.	.	.	.
Wildcat	0	71	.	.	.	.
Mean	0.6	67	.	.	.	.
SD[1/]	2.3	29.5	.	.	.	.

. – Zero plants survived to 50% bloom.
[1/]SD - Standard deviation.

Austrian Winter Pea

Austrian winter pea cultivars had poor early field emergence for both years, but improved from moderate to excellent by 28 DAP. There were emergence differences between 21 and 28 DAP in both years, and 14 DAP for Y1 (Table 18). Winter hardiness was different between the two years ($p=0.0001$; Table 2), with the later planted Y1 having greater survival than Y2 (mean 61.41±30.43% and 26.72±34.46% respectively; Table 19). This may have been caused by the cold acclimation response known to occur with Austrian winter pea. At the right physiological stage cold temperatures, shorter days, and the change in light spectra quality will trigger cold acclimation, hardening the plant to subsequent frost (McGee 2017). The earlier planted peas may not have been exposed to the specific conditions at the appropriate physiological stage, and thus had an increased sensitivity to frost. Y2 was also colder than Y1, which may have reduced winter hardiness. However, McGee et al. 2017's pacific northwest studies found 'Whistler', 'Windham', and 'Lynx' to be winter hardy to temperatures colder than experienced in Fallon. There were significant differences between cultivars for each year. 'Maxum' (87%) and 'Whistler' (93%) had the highest winter hardiness for Y1, and 'Frost Master' (28%) had the lowest. The best performer in Y2 was 'Whistler (72%) and the lowest was "Dunn" (0%) and 'Arvica 4010' (0%). It is interesting to note that the best winter hardiness performer for both years was 'Whistler' while the second best for Y1 ('Arvica 4010') had 0% winter hardiness in Y2.

Summer cover was significantly different between the cultivars. 'Whistler' performed the best with excellent cover followed by 'Arvica 4010' and 'Survivor 15', while 'Lynx' and 'Frost master' were both ranked the lowest with poor cover. Y2 was dominated by 100% cover of annual mustard. Austrian winter pea is known to be a poor competitor against weeds (Pavek 2012) and may be better suited in a mix than a mono-culture when weed pressure is expected to be high.

It should be noted that several cultivars had no height or 50% bloom data recorded despite having non-zero winter hardiness. This was caused by mortality after green-up that prevented the plot from maturing to the reproductive stage. Both water stress and weed pressure played a role in reducing crop fitness. Several plots appeared heavily desiccated shortly after green-up for both years tested (personal observation), despite the above average winter precipitation in Y1, or the above average precipitation at green-up in Y2. It appears that supplemental irrigation is needed at green-up to improve crop performance.

Table 18. Mean values and standard deviations of emergence groups (see below) of winter pea cultivars at 7, 14, 21 and 28 days after planting in 2016-2017. USDA-NRCS Fallon, NV.

Cultivar	Days after planting							
	7		14		21		28	
	Y1	Y2	Y1	Y2	Y1	Y2	Y1	Y2
Arvica 4010	0	0.3	2.0	1.3	3.0	3.0	3.0	3.0
Dunn	0	0	1.3	0.5	2.3	2.8	3.0	2.8
Frost Master	0	0	1.0	0.3	1.8	1.0	2.0	1.0
Lynx	0	0	0.8	0.3	1.5	1.0	2.0	1.0
Maxum	0	0	1.8	0.8	2.3	3.0	2.8	3.0
Survivor 15	0	0.5	2.5	1.0	2.8	3.0	3.0	3.0
Whistler	0	0.5	1.5	1.0	2.5	2.8	2.8	2.8
Windham	0	0	1.0	0.5	2.0	2.0	2.5	2.0
Mean		0.16	1.47	0.69	2.25	2.31	2.63	2.31
SD[/2]		0.37	0.67	0.64	0.67	0.90	0.49	0.90

[1/] 0 = poor (<25% emergence); 1 = moderate (30-60% emergence); 2 = good (65-85% emergence); 3 = excellent (90-100% emergence).
[2/] SD standard deviation.

Table 19. Mean values for percent winter hardiness, plant height and days after planting to 50% bloom for winter pea cultivars in 2017 and 2018 at the USDA-NRCS Fallon, NV.

Cultivar	% Winter hardiness		Plant height (in.)		DAP to 50% bloom		Summer Cover[2/]
	Y1	Y2	Y1	Y2	Y1	Y2	Y1
Arvica 4010	86	0	3	.	219	.	2.8
Dunn	48	0	15	.	215	.	0.8
Frost Master	28	16	.	.	.	.	0.5
Lynx	63	13	.	.	.	.	0.5
Maxum	87	15	13	20	220	256	2
Survivor 15	53	60	30	.	225	.	2.5
Whistler	93	72	11	.	219	.	3
Windham	34	40	6	.	219	.	1.5
Mean	61	27	17	20	219	256	1.68
SD[1/]	30.4	34.5	8.7	.	3.2	.	1.06

. – Zero survival to 50% bloom. [1/]SD - Standard deviation.
[2/] 0 = poor (<25% emergence); 1 = moderate (30-60% emergence; 2 = good (65-85% emergence); 3 = excellent (90-100%)

CONCLUSIONS

Choosing the best adapted cover crop is the first step to a successful cover crop planting. The two-year evaluation of commercially available cereal rye, crimson clover, hairy vetch, red clover, daikon radish, Austrian winter pea, balansa clover, and black oats and black seeded oats provided beneficial information on best adapted cultivars and varieties for the cold desert of the Great Basin in Nevada. All species tested showed cultivar specific variability for the characteristics evaluated.

In general, cereal rye and oats were the most reliable in establishment, winter hardiness, and end of season cover. These also tend to have cheaper seeds, which makes them a great cover crop candidate either alone or as the primary seed in a mix. Hairy vetch had moderate to excellent germination, good winter hardiness, no weed suppression and was slow to grow. It may perform better in a mix where it can climb on other cover crops. Black oats had excellent establishment, but was completely winter killed and is not recommended for the Great Basin. Balansa clover failed to establish while crimson clover and red clovers struggled at green-up due to weed pressure and low water availability. It should be noted that the late September planting (Y2) had higher winter hardiness than the late October planting (Y1) and green-up survival may be increased with irrigation. Austrian winter pea performance was highly cultivar specific, ranging from poor to excellent for almost all characteristics. Austrian winter pea winter hardiness was higher planted later than earlier. This is an opposite response to that of clovers, which suggests that a mix of clovers and Austrian winter peas could have some compatibility issues. Daikon radishes failed to overwinter. Establishment was mostly excellent, but winter hardiness averaged below 12% for both years and summer cover was poor in the few plots that survived the winter. Although the daikon radishes and black oats did not provide an overwinter cover crop, they may have application as a fall planted cover crop that utilizes freezing temperature for termination, rather than chemical or mechanical treatments.

Results from this trial provide a framework for designing cover crop and cover crop mixes. Additional data is needed on biomass of the best performing cultivars to maximize cover crop benefits and further describe their productivity and adaptation to the region. Continued evaluation of other cover crop species and cultivars would be beneficial to the region.

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