United States Department of Agriculture

June 2020

FINAL STUDY REPORT
Tucson Plant Materials Center
Tucson, Arizona

Evaluation of Cool Season Cover Crops in Southern Arizona

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ABSTRACT

Cool season, annual cover crops can provide multiple benefits to production agriculture when planted as a cover crop such as weed suppression, erosion control, nitrogen fixation and increased soil organic matter. However, cover crop success depends on selection of the best adapted cultivar or variety that meets the planting objective. The purpose of this study was to evaluate fifty-eight commercially available cultivars and varieties of eight common annual, coo1 season species for their adaptation to southern Arizona. 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 [*Vicia villosa* Roth ssp. *varia* (Host) Corb] were evaluated for field emergence, winter hardiness, plant height, maturity date, and disease and insect resistance at the Tucson, Arizona Plant Materials Center in 2016-2017 and 2017-2018. Tucson proved too hot and dry for balansa, crimson and red clover in single species stands in both years of this trial. Black oats and black seeded oats performed modestly well in both years of the study. Cereal rye consistently provided rapid cover and a tall, dense canopy in both years of the study. All evaluated cultivars tolerated warm temperatures and drought stress. Some cultivars, Oklon, Bates, Wintergrazer 70, Elbon, and Brasetto, performed slightly better in the hotter, drier conditions of 2017-2018 than they did the previous year. Vetch establishes slowly, but grows well over the cool season, producing good cover despite temperature extremes and drought. Peas provided good cool-season cover that established moderately quickly. Winter pea varieties performed better than spring pea varieties in both years of the trial. Lynx, Survivor 15, and Windham were the latest blooming winter pea varieties. Daikon radishes have the potential to establish quickly and provide the most biomass of any of the species evaluated in this trial. Unfortunately, they attracted aphids and bagrada bugs (*Bagrada hilaris*), a serious insect pest. Radishes or other brassica cover crops grown in the hot desert should be scouted for insect pests, particularly bagrada bugs, to prevent potential problems. Other cool season grasses and forbs need to be evaluated for winter cover crop. In addition, biomass production of the best performing cultivars from this trial need to be evaluated to further describe their productivity and adaptation in southern Arizona.

INTRODUCTION

Incorporating cover crops into a cropping system improves soil health, conserves energy, and builds resilience in the cropping system, and helps sequester atmospheric CO2 (Lal, 2004; Reicosky and Forcella, 1998; Hargrove, 1986; Reeves, 1994; Follett, 2001). Leguminous cover crop species provide a nitrogen source for subsequent commodity crops (Singh et al., 2004; Smith et al., 1987). Non-leguminous cover crops such as small grains and radishes, can scavenge post-season nitrogen, reduce soil erosion, and suppress weeds (Meisinger et al., 1991). Utilizing a mix of leguminous and non-leguminous cover crop species can provide multiple benefits. For cover crops to produce benefits, they must both meet the objectives of the producer and be adapted the environmental conditions of the location where they are planted.

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The objective of this study was to evaluate the growth characteristics and attributes of commercially available varieties/cultivars of selected cool season cover crops to determine which are best adapted to conditions in the hot desert regions of southern Arizona.

MATERIALS AND METHODS

The study was conducted at the USDA-Natural Resources Conservation Service Plant Materials Center (PMC), Tucson, AZ in 2016-2017 and 2017-2018. Soil test results were used to develop a fertilizer application rate of 20 units of nitrogen and 30 units of phosphorus, which was broadcast as granular ammonium sulfate and monoammonium phosphate fertilizer and incorporated with a cultipacker and irrigation prior to planting. Annual, cool season species were planted on a pure live seed (PLS) basis (Table 1). Legumes were inoculated with appropriate rhizobia before seeding. Plots were planted into a Comoro silt loam soil 18 October 2016 and 20 October 2017 with a Kincaid cone planter (Kincaid Equipment, Haven, KS) with 4 planters spaced on 15-inch centers. Plots were moved to a new field location in 2017 to avoid contamination from the previous year. Precipitation data was measured with a gauge on site. Temperature data were obtained from the Arizona Meteorological Network (University of Arizona Cooperative Extension, 2019) (Figure 1).

Irrigation amounts were calculated using well output. In 2016, the trial received a total of 5.8 inches of irrigation water while in 2017, the trial received a total of 7.5 inches of irrigation water. Weeds were controlled by hand rogueing.

Approximately every 7 days field emergence was estimated in each plot for four weeks after planting using the following rating scale: 0 = poor (<25% germination), 1 = moderate (30-60%), 2 = good (65–85%), 3 = excellent 90-100%). Entries were visually evaluated twice for disease and pest damage (rated from 0–5, where 0 = no damage and 5 = severe damage) following spring green-up (average last frost date in Tucson) and at 50% bloom (varied by species and cultivar). Winter survival (winter hardiness) was evaluated from an interior row marked in each plot. Seedlings in a 1-meter span were counted at 1-inch increments in the fall and following spring green-up of the 2016-2017 and 2017-2018 fall to spring season. Bloom period was monitored by noting the date of beginning bloom and 50% bloom. Average plant height was determined from measurements taken from the interior rows of the plot.

The experimental design was a randomized complete block with 4 replications. To determine variation among varieties within a species, a mean and standard deviation are reported for field emergence, % winter hardiness, plant height and days after planting (DAP) to 50% bloom using Statistix 10 (Analytical Software, Tallahassee, FL).

Table 1. Species, cultivars and seeding rates of annual cool seasons planted in 2016 and 2017 at the USDA NRCS Tucson, Arizona 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		
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

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

Common name	Species	Cultivar	PLS lb/acre	% PLS	Seeding rate lb/acre
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
Oilseed radish	*Raphanus sativus*	Big Dog	9	93	10
Oilseed radish	*Raphanus sativus*	Concorde	9	88	10
Oilseed radish	*Raphanus sativus*	Control	9	88	10
Oilseed radish	*Raphanus sativus*	Defender	9	97	9
Oilseed radish	*Raphanus sativus*	Driller	9	97	9
Oilseed radish	*Raphanus sativus*	Eco-till	9	88	10
Oilseed radish	*Raphanus sativus*	Graza	9	93	10
Oilseed radish	*Raphanus sativus*	Groundhog	9	85	11
Oilseed radish	*Raphanus sativus*	Lunch	9	93	10
Oilseed radish	*Raphanus sativus*	Nitro	9	98	9
Oilseed radish	*Raphanus sativus*	Sodbuster Blend	9	94	10
Oilseed 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

Total precipitation between 18 October 2016 and 17 April 2017 at the Tucson PMC was 3.3 inches, while total precipitation was 2.3 inches between 20 October 2017 and 8 May 2018. The 30-year normal for the months of October-April is 5.67 inches (PRISM, 2020).

In the 2016-2017 trial period, the average daily high temperature from planting through the first of March was 72.7ºF, and the average daily high in January, the coldest month, was 64.9ºF (Figure 1) (NWS, 2019). There was a total of 14 (non-consecutive) days with temperatures below freezing, with the first frost date November 29 and the last frost date February 24. The low winter temperature was 24.4ºF on January 28.

In the 2017-2018 trial period, the average daily high temperature from planting through the first of April was 75.5ºF (Figure 1). January 2018 was the warmest January on record in Tucson, with an average daily high temperature of 73.6ºF (NWS, 2019). There was a total of 24 (non-consecutive) days with temperatures below freezing, with the first frost date December 8 and the last frost date March 1. The low winter temperature was 22.6ºF on January 23.

Despite numerous mornings with temperatures below freezing in both trial periods, no cover crops in the trial were cold damaged or winter killed. Winter hardiness was 100% across all species and cultivars. No cover crop species slowed growth during the winter months, so there was no beginning of spring regrowth that could be measured and compared between cultivars/varieties. The average last frost date for Tucson, AZ was used as the spring regrowth date for both trial periods.

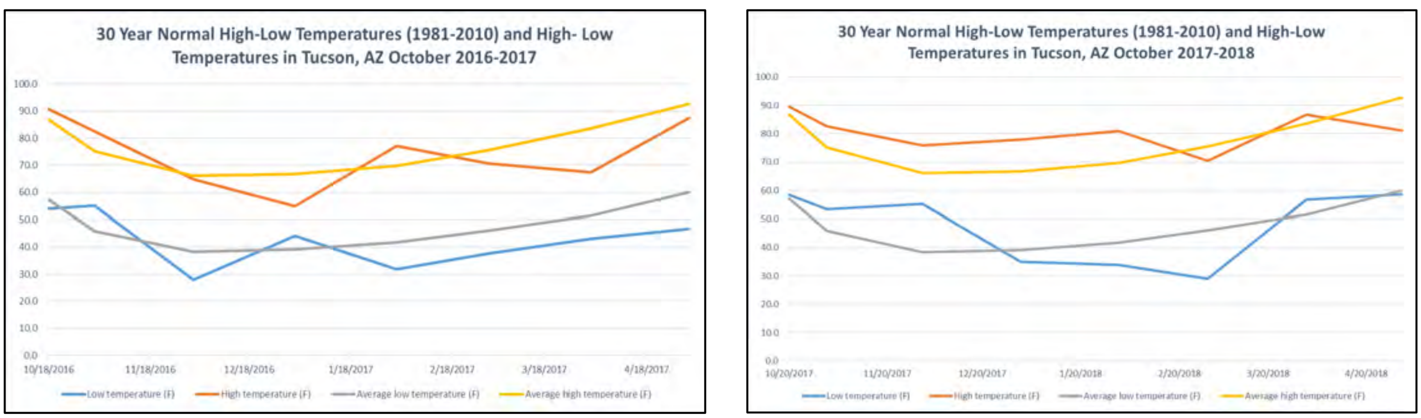

Figure 1: High-low temperatures for October-April in 2016-2017 and 2017-2018 compared to the 30-year average high-low temperature in Tucson, AZ.

Balansa Clover

Balansa clover exhibited poor emergence both years. By 28 DAP, the mean emergence ranking for balansa clover was 1.0 ± 0.5 in 2016 and 0.1 ± 0.4 in 2017 (Table 2). The situation for balansa clover did not improve as fall temperatures cooled. All clover species remained stunted and had high mortality. Rabbits preferred the struggling clover over other cover crop species and grazed heavily. Bloom period or height was not evaluated, as only a few plants grew enough to bloom. Plants protected by adjacent rows grew better than those exposed to the sun and hot soil, suggesting clovers might perform better in the hot desert as part of a mix with taller plants that can protect them from sun, heat, and wildlife. Based on two years of this trial, planting balansa clover as single species cover crops is not recommended for the hot desert.

Table 2. 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 Tucson, AZ.

Cultivar	Days after planting/Year							
	7		14		21		28	
	2016	2017	2016	2017	2016	2017	2016	2017
Fixation	0.3[1/]	0	0.3	0	1.3	0.3	1.3	0.3
Frontier	0	0	0	0	0.3	0.0	0.8	0
Mean	0.1	0	0.1	0	0.8	0.1	1	0.1
SD[2/]	0.4	0	0.4	0	0.7	0.4	0.5	0.4

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

Black Oats

'Soil Saver' black oat (*Avena strigosa*) and 'Cosaque' black seeded oat (*Avena sativa*), performed similarly in Tucson. In 2016, at 28 DAP, mean emergence was rated 2.9 ± 0.4. In 2017, mean emergence was rated lower at 1.6 ± 0.7 (Table 3). The lower emergence in 2017 corresponded with mean shorter plant height, 33.1 ±3 inches in 2016 versus 21.5 ± 3.6 inches in 2017 (Table 4). This is likely due to the hot and dry winter conditions in 2017-2018.

Soil Saver reached 50% bloom >20 days earlier than Cosaque both years (Table 4). By the end of February in both years, both varieties showed observable drought stress, but survived through the end of the trial. No insect or disease damage was observed on either variety. The oat species performed moderately well in this trial and show good potential for a cool season crop in the southwest.

Table 3. 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 Tucson, AZ.

Cultivar	Days after planting							
	7		14		21		28	
	2016	2017	2016	2017	2016	2017	2016	2017
Cosaque	2.5[1/]	0.3	2.8	0.5	2.8	1	2.8	1.3
Soil Saver	2.8	0.8	3	1	3	1.5	3	2
Mean	2.6	0.5	2.9	0.8	2.9	1.3	2.9	1.6
SD[2/]	0.5	0.5	0.4	0.5	0.4	0.7	0.4	0.7

[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 4. Mean values and standard deviations for plant height and days after planting to 50% bloom for black oats cultivars in 2017 and 2018 at the USDA-NRCS Tucson, AZ.

Cultivar	Plant height (in.)		DAP to 50% bloom	
	2017	2018	2017	2018
Cosaque	34	24	177	174
Soil saver	32	19	147	160
Mean	33	22	162	167
SD[1/]	3	7	17	8

[1/] Standard deviation

Cereal Rye

All cereal rye varieties emerged strongly but emergence was slower in the 2017-2018 trial periods. The mean emergence ranking across all cultivars in 2017 was 2.1 ± 0.5 at 28 DAP, whereas in the previous year, the mean emergence ranking was 2.9 ± 0.3 by 7 DAP (Table 5). The slower emergence in fall 2017 indicates that cereal rye may not always provide rapid cover in southern Arizona's climate. Most varieties grew shorter in 2018 than they did the previous year, probably in response to hot and dry winter conditions. A few varieties maintained or exceeded their 2017 height, including Aroostock, Bates, Guardian, and Hazlet (Table 6). Across all rye varieties, the mean 50% anthesis date both years was 153 DAP.

Table 5. 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 at the USDA-NRCS Tucson, AZ.

Cultivar	Days after planting							
	7		14		21		28	
	2016	2017	2016	2017	2016	2017	2016	2017
Aroostock	3[1/]	1	3	1.8	3	2.3	3	2.3
Bates	3	1	3	1.8	3	2	3	2.3
Brasetto	2.8	0.3	3	1	3	1	3	1
Elbon	3	1	3	1.8	3	2	3	2.5
FL 101	3	1	3	1.8	3	2	3	2
Guardian	3	0.8	3	1	3	1.8	3	2
Hazlet	3	0.8	3	1.3	3	1.8	3	1.8
Maton	2.8	1	2.8	1.8	2.8	2	2.8	2.3
Maton II	3	0.5	3	1.3	3	1.3	3	1.8
Merced	2.8	1	3	1.8	3	2	3	2.3
Oklon	3	1	3	2	3	2	3	2.3
Rymin	2.5	1	2.5	1.5	2.5	1.8	2.5	1.8
Wheeler	2.8	1	2.8	1	2.8	1.5	2.8	2
Wintergrazer 70	2.75	1	3	2	3	2.5	3	3
Wren Abruzzi	3	1	3	2	3	2	3	2
Mean	2.9	0.9	2.9	1.6	2.9	1.9	2.9	2.1
SD[/2]	0.3	0.3	0.3	0.5	0.3	0.5	0.3	0.5

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

There was no insect or disease damage to the cereal rye, although a few replications were kept grazed close to the ground by rabbits. Both years, cereal rye showed symptoms of water stress by the end of February but survived until termination. Producers concerned about volunteer cereal rye seedlings could choose later flowering varieties.

Table 6. Mean values and standard deviations for plant height and days after planting to 50% bloom for cereal rye cultivars in 2017 and 2018 at the USDA-NRCS Tucson, AZ.

Cultivar	Plant height (in.)		DAP to 50% bloom	
	2017	2018	2017	2018
Aroostock	41	41	149	145
Bates	40	40	146	153
Brasetto	39	39	155	158
Elbon	39	38	155	141
FL 101	38	37	152	157
Guardian	36	37	153	158
Hazlet	36	37	155	153
Maton	35	33	112	162
Maton II	32	31	156	169
Merced	31	30	178	93
Oklon	31	29	178	105
Rymin	30	26	119	183
Wheeler	29	26	178	183
Wintergrazer 70	28	26	177	183
Wren Abruzzi	26	21	154	178
Mean	35	33	153	153
SD[1/]	6	7	20	26

[1/]SD - Standard deviation.

Crimson Clover

Crimson clover exhibited the highest emergence of all the clovers tested despite seldomly exceeding a moderate emergence rating. In 2016, by 28 DAP, the mean emergence ranking was 2.0 ± 0.8 for crimson clover. In 2017, emergence ranking fell to 0.8 ± 0.6 (Table 7). This is likely due to warmer winter temperatures in 2017-2018 (Fig.1). January 2018 was the warmest January on record in Tucson (NWS, 2019).

Bloom period and height were not evaluated for crimson clovers because growth and bloom were so consistent. Herbivory was a consistent issue. Because of their poor performance, crimson clover is not recommended as single species cover crop for the hot desert. Plants that were protected by adjacent rows grew better than those exposed to the sun and hot soil, suggesting crimson clovers might perform better in the hot desert as part of a mix with taller plants to protect them from sun, heat, and grazing.

Table 7. 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 at the USDA-NRCS Tucson, AZ.

Cultivar	Days after planting							
	7		14		21		28	
	2016	2017	2016	2017	2016	2017	2016	2017
AU Robin	1.3[1/]	0.3	1.3	0.8	1.8	1	1.8	1
AU Sunrise	2	0.3	2	1	2	1	2	1.3
AU Sunup	0.3	0	0.8	0	1.3	0	1.8	0.3
Contea	1	0	1.3	0	1.8	0	1.8	0.3
Dixie	1.8	0	1.8	0.3	2.5	0.8	2.5	0.8
Kentucky Pride	2.5	0	2.5	0.5	2.5	0.8	2.5	1.3
Mean	1.4	0.1	1.6	0.4	1.9	0.6	2	0.8
SD[/2]	1.1	0.3	1.1	0.5	0.8	0.5	0.8	0.6

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

Hairy Vetch

All tested hairy vetch cultivars emerged slowly in Tucson. At 7 DAP, no vetch cultivars had emerged in either trial period. By 28 DAP, mean emergence was 1.8 ± 0.4 in 2016 and 1.4 ± 0.5 in 2017 (Table 7). Despite the slow emergence and some rabbit damage, all vetch cultivars grew very quickly after the first month and performed well, with vigorous growth, good cover and weed suppression, and abundant flowers.

Mean height across cultivars was 17 ± 5 inches in 2017 with an increase to 23 ± 5 inches in 2018 (Table 9). In 2017-18, the hot, dry conditions did not appear to affect vetch negatively. Rabbits did not graze the vetch until the end of the winter, when it was big enough to outpace their damage. The rabbits avoided Lana, the wooliest variety. Across all vetch cultivars, the average mean time to reach 50% bloom was 158 DAP. No insect or disease damage was observed. Vetch can become a persistent volunteer if it is allowed to set seed (Clark, 2007). Its phenology should be carefully monitored over the winter if used as a cover crop.

Table 8. 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 Tucson, AZ.

Cultivar	Days after planting							
	7		14		21		28	
	2016	2017	2016	2017	2016	2017	2016	2017
CCS Groff	0[1/]	0	1	0	1.3	0.8	1.5	1.5
Lana	0	0	1	1	1.3	1.3	1.5	2
Purple Bounty	0	0	0.5	0	1.5	1	1.8	1
Purple Prosperity	0	0	1.3	0	1.5	1	2	1.3
TNT	0	0	1	0.5	2	1	2	1.5
Villana	0	0	1	0	1.8	0.8	1.8	1.3
Mean	0	0	1	0.3	1.5	1	1.8	1.4
SD[/2]	0	0	0.5	0.4	0.5	0.5	0.4	0.5

[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 9. Mean values and standard deviations for plant height and days after planting to 50% bloom for hairy vetch cultivars in 2017 and 2018 at the USDA-NRCS Tucson, AZ.

Cultivar	Plant height (in.)		DAP to 50% bloom	
	2017	2018	2017	2018
CCS Groff	18	28	157	154
Lana	18	25	151	154
Purple Bounty	17	24	157	158
Purple Prosperity	15	21	165	165
TNT	20	20	153	165
Villana	14	22	153	158
Mean	17	23	157	159
SD[1/]	5	5	8	7

[1/]SD - Standard deviation.

Daikon Radish

All cultivars of radish emerged quickly and provided rapid ground cover. The 2016 mean emergence ratings at 7, 14, 21, and 28 DAP were higher than 2017 ratings (Table 10). This is likely due to the hotter winter temperatures in 2017-2018. The plants quickly grew a dense, tall canopy with a mean height across varieties of 39 ± 8 inches at 50% bloom in 2017 and 33 ± 3 inches in 2018 (Table 11). Graza was the latest-blooming variety in 2017, reaching 50% bloom just prior to the termination date in mid-April.

Radish plants attracted aphids and bagrada bugs (Figure 2). In some varieties, the pests inflicted a damage rating of 5 on a 0-5 scale. Bagrada bugs prefer plants in the mustard family but have also been reported on crops such as melons, peppers, cotton, legumes and grain (Natwick et al., 2013). An unchecked bagrada bug infestation in a cover crop could lead to serious problems in a nearby or subsequent cash crop. To prevent the spread of bagrada bugs to other areas of the PMC in 2018, all radish plants were removed from the trial on March 26, and the soil rototilled to disrupt the bagrada bugs' life cycle. Many radish rows had not reached 50% bloom when they were destroyed, so bloom and height data are missing for some replications.

Figure 2: Bagrada bugs on daikon radish at the Tucson PMC, spring 2018.

The potential for insect infestations indicate that daikon radish could create management problems as a winter cover crop in the hot desert. However, if rapid cover crop biomass is needed for a short window between cash crops, and insects can be controlled, daikon radish might be an appropriate cover crop choice for southern Arizona.

Table 10. 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 Tucson, AZ.

Cultivar	Days after planting							
	7		14		21		28	
	2016	2017	2016	2017	2016	2017	2016	2017
Big Dog	2.5[1/]	1	2.5	1.3	2.8	1.8	2.8	2
Concorde	2.5	1	2.5	1.5	2.8	1.8	2.8	1.8
Control	2	1	2.8	1.5	3	2	3	2
Defender	1	0.3	1	0.3	1.8	1.3	1.8	1.3
Driller	1.5	1	1.5	1.8	2	1.8	2	1.8
EcoTill	1.5	1	2	1.3	2	2	2	2
Graza	1	0	1	0	1.8	0.3	1.8	0.5
Groundhog	1.8	1	1.8	1.5	2	1.8	2.3	2
Lunch	1	0.3	1	0.5	2	1.5	2	1.5
Nitro	1	1	1.8	1.3	1.8	1.8	2	1.8
Sodbuster	0.8	0	1	0.8	1.5	1.3	1.8	1.3
Tillage	1.5	0.8	1.5	1.3	2	1.8	2	1.8
Mean	1.5	0.7	1.7	1.1	2.1	1.6	2.2	1.6
SD[2/]	0.7	0.5	0.7	0.7	0.6	0.6	0.5	0.6

[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 11. Mean values and standard deviations for plant height and days after planting to 50% bloom for daikon radish cultivars in 2017 and 2018 at the USDA-NRCS Tucson, AZ.

Cultivar	Plant height (in.)		DAP to 50% bloom	
	2017	2018	2017	2018
Big Dog	36	33	132	141
Concorde	46	34	127	134
Control	41	35	123	131
Defender	45	34	128	127
Driller	40	34	130	141
EcoTill	38	33	129	138
Graza	28	27	160	141
Groundhog	40	32	128	138
Lunch	31	30	131	140
Nitro	33	32	127	141
Sodbuster	39	33	128	139
Tillage	46	32	130	138
Mean	39	33	130	137
SD[1/]	8	3	9	6

[1/]SD - Standard deviation.

Red Clover

Red clover exhibited the lowest emergence of all the clovers tested. In 2016, by 28 DAP, the mean emergence ranking was 0.9 ± 0.4 for red clover. In 2017, emergence ranking fell to 0.3 ± 0.5 (Table 12). This is likely due to the hotter winter temperatures in 2017-2018 (Fig. 1.).

Bloom period and height were not evaluated for any red clover variety because growth and bloom were inconsistent. Herbivory damage from rabbits was also an issue. Red clover is not recommended as single species cover crop for the hot desert. However, plants shaded from adjacent rows grew better than those exposed to the sun and hot soil, suggesting red clovers may perform better in a mix with taller plants that can protect them from sun, heat, and wildlife grazing.

Austrian Winter Pea

Peas on average ranked good for emergence at 14 DAP. In 2016, mean emergence ranking across pea varieties was 1.9 ± 0.3 at 28 DAP and 1.8 ± 0.4 in 2017 (Table 13). Differences in phenology occurred later in the season, with the spring pea varieties, Arvica 4010, Dunn, and Maxum, blooming an average of 82 days before the winter pea varieties (Table 14). In 2017, Lynx had still not bloomed by the termination date in mid-April. In 2018, Survivor 15 and Windham had not bloomed by the termination date in May. None of the peas were affected by insects or disease, but spring varieties showed heat and drought stress, especially further from the irrigation water source. Spring peas had a vining habit and spread out as they increased in height. Later blooming winter pea varieties tended to have a more compact, dense habit held together with tendrils, and higher tolerance to heat and drought stress. For a cover crop in the Southwest or southern Arizona, spring peas may perform best in a short window combined in a mix with taller plants that they can climb on for support. Winter pea cultivars' habit, phenology, and relative heat/drought tolerance would be a better choice for a longer cover crop window in the hot desert.

Table 12. 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 Tucson, AZ.

Cultivar	Days after planting							
	7		14		21		28	
	2016	2017	2016	2017	2016	2017	2016	2017
Cinnamon Plus	0[1/]	0	0.8	0	0.8	0	0.8	0.5
Cyclone II	0.5	0	0.5	0	0.8	0	1	0
Dynamite	0	0	1	0	1	0	1	0.5
Freedom	0	0	1	0	1	0	1	0.5
Kenland	0	0	0.3	0	0.3	0	0.5	0
Mammoth	0.8	0	1	0	1	0	1.3	0.8
Starfire II	0	0	0.5	0	1	0	1	0
Wildcat	0	0	1	0	0.8	0	1	0
Mean	0.2	0	0.8	0	0.8	0	0.9	0.3
SD[/2]	0.4	0	0.4	0	0.4	0	0.4	0.5

[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 13. 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 Tucson, AZ.

Cultivar	Days after planting							
	7		14		21		28	
	2016	2017	2016	2017	2016	2017	2016	2017
Arvica 4010	1[1/]	0.3	1.8	1.5	2	2	2	2
Dunn	1	0.5	2	1.8	2	2	2	2
Frost Master	0.5	0	1.3	1.5	1.8	2	1.8	2
Lynx	0.3	0	1.3	1	1.5	1	1.8	1.3
Maxum	1	0	1.5	1.3	2	1.3	2	0.5
Survivor 15	1	0.3	1.8	1.8	2	2	2	2
Whistler	0.8	0	1.8	1.3	2	1.3	2	1.5
Windham	0.8	0.5	1.5	1.3	1.8	1.5	1.8	1.8
Mean	0.8	0.2	1.6	1.4	1.9	1.6	1.9	1.8
SD[/2]	0.4	0.4	0.5	0.6	0.3	0.5	0.3	0.4

[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 14. Mean values for plant height and days after planting to 50% bloom for winter pea cultivars in 2017 and 2018 at the USDA-NRCS Tucson, AZ.

Cultivar	Plant height (in.)		DAP to 50% bloom	
	2017	2018	2017	2018
Arvica 4010	16	17	94	93
Dunn	12	17	95	93
Frost Master	15	19	178	169
Lynx[2/]	-	13	-	169
Maxum	16	18	94	97
Survivor 15[2/]	18	-	176	-
Whistler	21	12	176	169
Windham[2/]	20	-	177	-
Mean	16	16	124	113
SD[1/]	4	3	41	34

[1/]SD - Standard deviation.
[2/]-Plant did not bloom

CONCLUSIONS

Cool season cover crops in the hot deserts have distinct growing challenges. Hot and dry conditions over the fall and winter create stressors for cool season species not seen in other regions. However, light winter frosts have killed warm season cover crops like buckwheat (*Fagopyrum esculentum*) and sorghum-sudan (*Sorghum bicolor* x *S. bicolor var. Sudanese)* at the Tucson PMC so they cannot be reliably used in the winter for cover cropping.

Tucson was too hot and dry for clovers, but they might perform better in the shade of other species in a mix. Daikon radishes grew large, bolted early, and attracted aphids. They fit well into a cropping system where there is a short growing window prior to termination. Graza radish did not get as big or bolt and would be easier to manage in a cover crop mix. Rye and oats emerge quickly and are good choices for rapid establishment of cover for soil protection. Cultivars demonstrating rapid, early growth and slow maturity under warm winter conditions are recommended in southern Arizona. Early maturing cultivars produce seed that volunteer in the subsequent cropping season. Other cool season grasses and forbs need to be evaluated for winter cover crops in the hot deserts, e.g. other small grains, smaller brassicas, and non-brassica, broadleafs. Additional information is needed on biomass production of best performing cultivars to maximize cover crop benefits and to further describe their productivity and adaptation in the region.

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