United States Department of Agriculture

July 2021 **FINAL STUDY REPORT**
Lockeford Plant Materials Center, Lockeford, CA

Adaptation of Warm Season Cover Crops for California

Valerie Bullard and Margaret Smither-Kopperl

ABSTRACT

Warm season cover crops are rarely grown in California, as irrigation is required during the hot, dry summers of the Mediterranean climate. Without plant cover, soil health suffers, leading to a reduction in soil organic matter, weeds, and soil erosion from wind and fall rains. This trial evaluated a range of warm season cover crops with minimal irrigation water applied for adaptation to California's Central Valley in 2017-2020. The species selected for the trial were drought tolerant and included grasses, legumes, and forbs. The non-native grasses included sudangrass (*Sorghum bicolor*), Japanese millet (*Echinochloa esculenta)*, proso millet (*Panicum miliaceum)*, and teff (*Eragrostis tef*). The non-native legumes included a variety of cowpea cultivars (*Vigna unguiculata*), sunn hemp (*Crotalaria juncea*), and pigeon pea (*Cajanus cajan*). Legumes native to the US were bigpod sesbania (*Sesbania herbacea*) and tepary bean (*Phaseolus acutifolius*). The forbs planted were native black seed sunflower (*Helianthus annuus*) and non-native buckwheat (*Fagopyrum esculentum*). Mechanical and chemical methods were used to control germinating summer weeds. The area was pre-irrigated, disked and cultipacked prior to planting. The trial was planted as a randomized complete block design with four replications. An additional 1 to 2 inches of irrigation water was applied by sprinkler over the first 60 days of growth. Data collected in 2018 and 2020 included germination, insect and disease resistance, 50% bloom date, height, fresh weight aboveground biomass, estimated dry matter yield, total nitrogen content and estimated nitrogen yield. During 2019, soil crusting resulted in poor emergence, and biomass data was not collected. The species and varieties evaluated all performed well with minimal irrigation and are adapted to California's Central Valley.

INTRODUCTION

Agriculture in California is diverse with over 400 different crops harvested and a cash value of over $50 billion in 2019 (CDFA, 2019-2020). A Mediterranean climate, with no rain from April through October, dominates the majority of crop production areas of the Central Valley and along the coast. Precipitation falls on a gradient with the wetter areas in the north and dryer areas to the south, which depend on stored snow melt from the Sierra Nevada for irrigation. Recently, droughts and higher temperatures, along with reduced snowfall, have severely limited water available for irrigation.

Cover crops provide numerous agronomic advantages including increased organic matter, improved soil quality, enhanced nutrient cycling, increased infiltration and water holding capacity, and weed suppression. Cover crop use in California generally coincides with winter rains in perennial crops and fallow periods for annual crops (Brennan and Acosta-Martinez, 2017; Mitchell et al., 2016).

Margaret Smither-Kopperl, Manager; Valerie Bullard, Agronomist, Lockeford Plant Materials Center, 21001 N. Elliott Rd., Lockeford, CA 95237.

Cool season cover crops germinate with precipitation in the fall, grow over the winter and into spring. Optimal termination time is generally recommended at 50% bloom as this coincides with maximum nitrogen accumulation, however termination time must be compatible with the demands of the commodity crop (Clark, 2007).

A significant limitation to the adoption of cool season cover crops in California's Central Valley is the concern for delayed planting of high-value row and vegetable crops. Without supplemental irrigation, cool season cover crops will not emerge until after the fall rains, in some cases the cover crop may not emerge until December or January and won't mature until later in the spring. While, cash crops, such as tomatoes, are planted as early as January or February in some areas. Cool season cover crops terminated early have low biomass and little nitrogen fixation. In contrast, an actively growing cover crop maybe a problem to terminate, especially in wet years when green residue may pose a planting problem.

Alternatively, warm season cover crops are sown any time after soils warm up in the spring and before they cool in fall. They do require some irrigation for germination and establishment, although they are frequently drought tolerant and adapted to high temperatures with high growth rates. They do not tolerate cold temperatures, showing a marked slow-down in growth in the fall followed by death when frost occurs. Maturity dates also vary with the species and cultivar (Bullard, 2018). Seeding a fast-growing annual warm season cover crop directly after harvest or between vegetable crop rotations provides a potential alternative for these cropping systems. Warm season cover crops also can provide the benefits of a winter cover crop, including erosion control with the first fall rains, increased organic matter and nutrient cycling, weed suppression, and breaking of pest and disease cycles.

The species selected for the trial were drought tolerant and included a mixture of grasses (used for biomass production and residue), legumes (for nitrogen fixation), and forbs (for pollinator services). The grasses included sudangrass (*Sorghum bicolor* (L.) Moench and hybrids) (Dial, 2012), Japanese millet (*Echinochloa esculenta* (A. Braun) H. Scholz) (Sheehan, 2014), proso millet (*Panicum miliaceum* L.) (Sheehan, 2014), and teff (*Eragrostis tef* (Zuccagni) Trotter) (Miller, 2008). None of these grasses are native to the US, although sudangrass is widely grown locally in California's Central Valley for forage in the dairy industry. The non-native legumes included a variety of cowpea cultivars (*Vigna unguiculata* (L.) Walpe) (Sheahan, 2012), sunn hemp (*Crotalaria juncea* L.) (Sheahan, 2012), and pigeon pea (*Cajanus cajan* (L). Millsp) (Sheahan, 2012). Legumes native to the US were bigpod sesbania (*Sesbania herbacea* (Mill.) McVaugh) (Sheahan, 2013) and tepary bean (*Phaseolus acutifolius* A. Gray) (Wolf, 2018). The forbs planted included black seed sunflower (*Helianthus annuus* L.) (Stevens and Anderson, 2000) and buckwheat (*Fagopyrum esculentum* Moench.) (Pavek, 2016).

Cover crops are being promoted to sequester carbon, improve soil heath, reduce erosion, and reduce fertilizer inputs, among multiple other benefits. However, water is scarce or expensive in the summer in California, making it unusual for producers to grow a summer cover crop. We applied minimal irrigation to this trial; and generally applied 2-3 inches during the 60-day growing period.

The purpose of this trial was to conduct an evaluation of the adaptation of drought-tolerant summer cover crops in California's Central Valley. We evaluated performance of warm season cover crops including time to maturity to determine if those with a short life cycle can fit into an expanded range of cropping systems.

MATERIALS AND METHODS

The warm season adaptation trial was conducted over four seasons (2017-2020) at the Plant Materials Center in Lockeford, California (CAPMC). The CAPMC is located on the eastern side of the San Joaquin Valley in central California and sits on a historical flood plain on the west bank of the Mokelumne River. The soil series are Columbia and Vina fine sandy loams on 0-2 percent slopes. They are both very deep, well-drained soils with pH ranging from moderately acid to slightly alkaline. The mean annual maximum temperature in this area is 73.6°F and minimum temperature is 46°F (WRCC, 2021). The mean annual precipitation is 17.24 inches, mainly occurring between the months of December and March (WRCC, 2021). Maximum temperatures were slightly above the historical average during June, July and August during all four years (Figure 1). Precipitation totals were half of average (8.1 inches) between January 1, 2020 and December 31, 2020 (WWG, 2021).

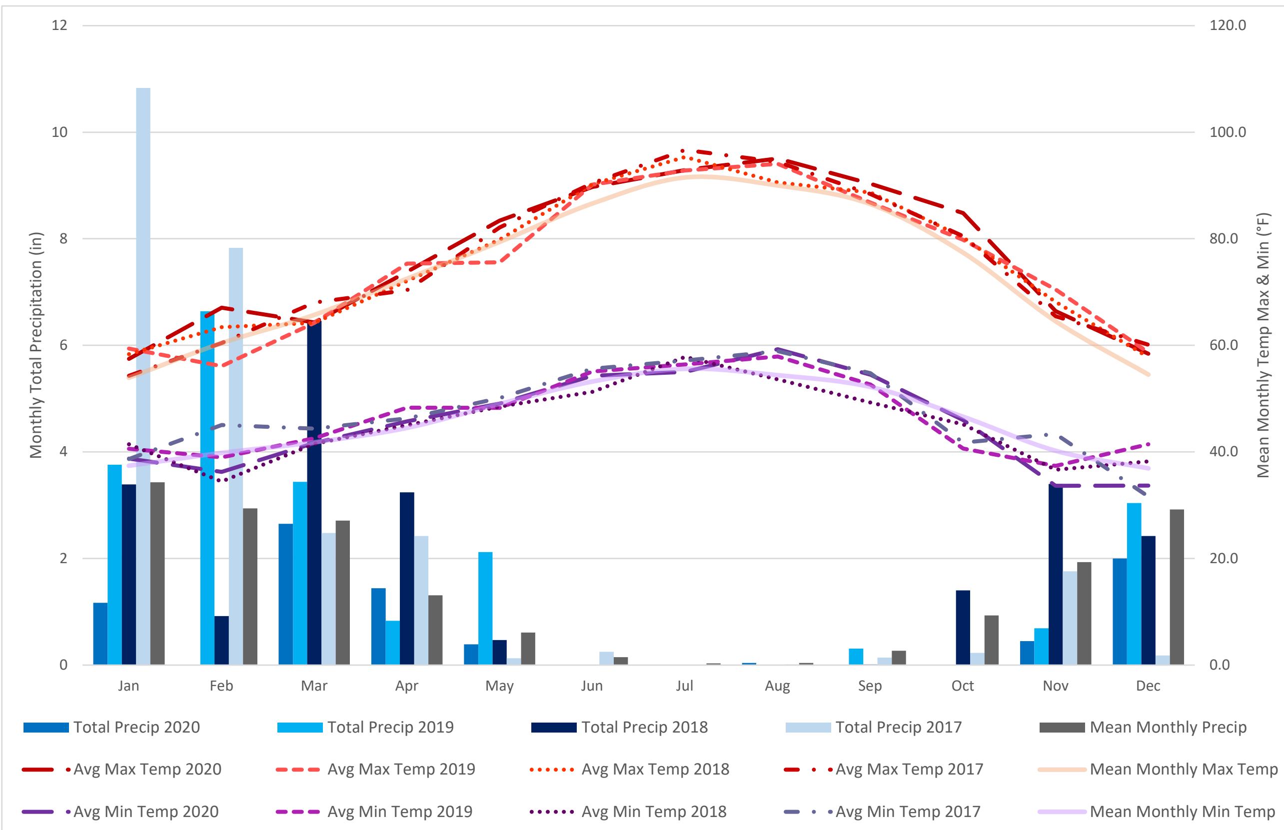

Figure 1. Mean maximum temperatures in the 2017, 2018, 2019, and 2020 growing seasons were slightly higher than historical annual averages in June, July and August. Total precipitation was half the annual average in 2020. Monthly weather data from January through December was provided from Western Weather Group Lockeford Weather Station located directly across the river from the CAPMC. Average weather summaries from 1893-2015 for the Lodi area were provided from Western Regional Climate Center.

The trial was drilled on 7/10/2017, 6/20/2018, 7/2/2019 and 6/25/2020 with a Kincade Great Plains No-Till Cone Seeder. During the previous years, the four trial locations were fallow or planted to a winter cover crop. Mechanical and chemical methods were used to control germinating summer weeds. Each year the trial area was pre-irrigated, disked and cultipacked prior to planting. The trial was a randomized complete block design with four replications running from north to south. Plots were approximately 25 feet long by 5 feet wide with 9 rows at 7-inch spacing. After seeding, irrigation was applied several times during the growing season either by a linear irrigation set or overhead sprinkler. Irrigation amounts totaled 1-2 additional inches (in addition to the pre-irrigation) during the first 60 days of growth. Legumes were not inoculated prior to planting.

A total of 15 different species and varieties were evaluated in the trial, including black sunflower, buckwheat, five cowpea cultivars (‘California Blackeye 46’, ‘Chinese Red’, ‘Iron & Clay’, ‘Red Ripper’, and an experimental cultivar), bigpod sesbania, Japanese millet, pigeon pea, sudangrass (‘Piper’), sunn hemp (‘Tropic Sun’), teff (‘Excalibur’), tepary bean, and proso millet (‘White’) (Table 1). Target seeding rates of pounds per acre were standardized across species in the protocol. Actual seeding rates were adjusted based on Pure Live Seed (PLS) calculated from the germination and purity of the seed lot.

Evaluations collected on the plots during the four growing seasons include: germination, disease and insect resistance, bloom and flowering period, plant height, and fresh weight aboveground biomass (FWAB). Additional composite samples collected by CAPMC staff included dry matter yield (DM) and total nitrogen (TN) content.

Figure 2. Warm season cover crop adaptation trial at the CAPMC in August 2020.

Table 1. Target seeding rates of 15 cultivars and species planted at the Lockeford Plant Materials Center, CA 2017-2020.

Cultivar	Species Name	Target Seeding Rate (lbs/ac)
Legumes		
California Blackeye 46 Cowpea	*Vigna unguiculata*	40
Chinese Red Cowpea	*Vigna unguiculata*	40
Iron & Clay Cowpea	*Vigna unguiculata*	40
Red Ripper Cowpea	*Vigna unguiculata*	40
Experimental Cultivar Cowpea	*Vigna unguiculata*	40
Tepary Bean	*Phaseolus acutifolius*	30
Tropic Sun Sunn Hemp	*Crotalaria juncea*	38
Bigpod Sesbania	*Sesbania exaltata*	18
Pigeon Pea	*Cajanus cajan*	40
Grasses		
Japanese Millet	*Echinochloa esculenta*	25
White Proso Millet	*Panicum miliaceum*	25
Piper Sudangrass	*Sorgum bicolor*	35
Excalibur Teff	*Eragrostis tef*	10
Forbs		
Black Sunflower	*Helianthus annuus*	8
Buckwheat	*Fagopyrum esculentum*	60

Germination was defined as how well the species germinated and emerged after planting. Germination was visually evaluated at 7, 14, 21 and 28 days after planting (DAP) on a 0 - 4 scale, where 0 = poor (<25% germination), 1 = fair (30-45%), 2 = good (50-65%), 3 = very good (70-85%), 4 = excellent (90-100%). Disease and insect resistance ratings were a visual estimate of the resistance to foliar diseases and insect damage. Plots were rated at 50% bloom/anthesis on a 0 - 5 scale, where 0 = no damage and 5 = severe damage. Timing of 50% bloom or anthesis was recorded to provide flowering information for pollinators, indicate optimum nitrogen content in the aboveground biomass, and was also the termination date of the cover crop. Plant height was defined as the average height of lush canopy growth at 50% bloom/anthesis. Plant height was collected in inches from three random locations within each plot from the base of the plant to the top of the inflorescence. Fresh weight aboveground biomass (FWAB) was defined as the aboveground accumulation of plant growth taken at ground level at 50% bloom/anthesis. A square foot area was harvested leaving no more than ¼ inch stubble height from a representative area within each plot and then weighed. Composite FWAB samples were dried and weighed to get a dry matter (DM) determination for percent DM yield and sent to a lab for percent total nitrogen (TN) analysis. TN content was defined as the nitrogen concentration in the aboveground portion of the biomass and expressed as a percent. Estimated nitrogen yield (lb/ac) was calculated using the percent DM yield and percent TN content (both not replicated).

Statistical analysis was completed on all four years of trial evaluations using Statistix 10 (Analytical Software, Tallahassee, FL). Ordinal data (germination, disease and insect resistance) was analyzed using Kruskal-Wallis one-way analysis of variance (AOV) and Dunn's All-Pairwise Comparisons Test to separate means at the 5% level. Analysis was done on quantitative plant measurements (plant height, FWAB) using the analysis of variance (AOV) procedure for a randomized complete block design (RCBD) along with Tukey's 1 Degree of Freedom test for non-additivity. Significant means were separated with Tukey's Honestly Significant Difference (HSD) All-Pairwise Comparisons Test at the 5% level.

RESULTS AND DISCUSSION

Warm Season Legumes

A total of nine different warm season legume species and cultivars were evaluated from 2017 to 2020 for germination, insect and disease resistance, 50% bloom date, height, fresh weight aboveground biomass (FWAB), estimated dry matter (DM) yield, total nitrogen (TN) content and estimated nitrogen yield. The pigeon pea and experimental cultivar cowpea seed were provided from the UC Riverside, Department of Nematology.

Germination

Four years of legume germination evaluations from the warm season cover crop trial are located in Table 2. In 2017, only two legume species were evaluated due to a planter malfunction and a shortage of replications. Bigpod sesbania had significantly better germination at 21 and 28 days after planting (DAP) (good to very good) than Tropic Sun sunn hemp (fair germination). In 2018, Red Ripper cowpea had significantly better germination at 14 to 28 DAP (very good) than sunn hemp (poor to fair). Red Ripper cowpea was closely followed by Chinese Red cowpea and Iron & Clay cowpea with good to very good emergence. Tepary bean, California Blackeye 46 cowpea and bigpod sesbania had fair to good emergence. No emergence data was collected at 7 DAP in 2018, due to lack of staff on site. Issues with soil crusting in 2019, resulted in lower germination rates across all varieties. From 14 to 28 DAP, Chinese Red cowpea and Iron & Clay cowpea had significantly better germination (fair to good) than sunn hemp (poor). All other evaluated legumes had fair germination. In 2020, all five of the evaluated cowpea cultivars had good to very good emergence from 7 to 28 DAP. At 7 DAP, Iron & Clay cowpea had significantly better germination (very good) than bigpod sesbania (fair) or pigeon pea (poor). At 14 DAP, Chinese Red, Iron & Clay, and Red Ripper cowpea all had significantly better germination (very good) than pigeon pea (fair). There was a decrease in germination rates for Tropic Sun sunn hemp due to rabbit grazing damage at 21 to 28 DAP.

Pest Resistance

Insect damage (shown on Table 2) for 2017 to 2020 was observed as aphid damage or as chewed holes in leaves. Slight insect damage was seen on bigpod sesbania in 2017, and very little insect damage was observed on sunn hemp. In 2018, slight insect damage was seen on California Blackeye 46 cowpea, Iron & Clay cowpea, and bigpod sesbania. All other legumes had very little to no insect damage. In 2019, Red Ripper and experimental cultivar cowpea had moderate damage, while California Blackeye 46, Chinese Red, and Iron & Clay cowpea had slight damage. In 2020, moderate insect damage was observed on all cowpea varieties, with very little to slight damage on sunn hemp, bigpod sesbania and pigeon pea. Very little to no disease damage was seen across all four years of evaluations.

50% Bloom

Results for legume 50% bloom, height, and FWAB evaluations are located in Table 3, Figure 3 and Figure 4. The legume species and cultivars that were the first to reach 50% bloom across all four years were California Blackeye 46 cowpea and tepary bean (45 to 58 DAP). Chinese Red cowpea, Red Ripper cowpea, bigpod sesbania, and pigeon pea were the next group of legumes to bloom (63 to 77 DAP). Last to reach 50% bloom were Tropic Sun sunn hemp and experimental cultivar cowpea (77 to 92 DAP). Iron & Clay cowpea never bloomed during the four years of evaluations at the CAPMC. In order to collect some maturity data, evaluations and samples were collected prior to a frost event that would likely result in winterkill of Iron & Clay cowpea.

Height

Tropic Sun sunn hemp and bigpod sesbania were the tallest of the legume species, ranging from 40 to 58 inches in height (Table 3 and Figure 3). The shortest legumes were California Blackeye 46 cowpea (12 to 14 inches) and tepary bean (9 to 11 inches). In 2020, sunn hemp and bigpod sesbania were significantly taller than all other legumes evaluated (47 to 55 inches tall). Pigeon pea was significantly taller (36 inches tall) than all cowpeas, while California Blackeye 46 cowpea was significantly shorter than all other legumes (12 inches tall).

Biomass

FWAB was only collected in 2018 and 2020 (Table 3 and Figure 4). In 2018, Iron & Clay cowpea produced significantly more FWAB (53,361 lb/ac) than California Blackeye 46 cowpea (18,513 lb/ac), or tepary bean (7,667 lb/ac). In 2020, no significant differences were seen, but Iron & Clay and experimental cultivar cowpea had the largest FWAB production (52,337 lb/ac; 67,078 lb/ac), while pigeon pea had the smallest (18,462 lb/ac).

Dry Matter Yield, Total Nitrogen Content and Nitrogen Yield

Estimated DM yield and TN content from samples collected in 2018 and 2020 were used to calculate an estimated nitrogen yield for legumes. Results are shown in Table 4. Legumes with the largest amounts of FWAB, also had high DM yields, including Iron & Clay cowpea (10,013 lb/ac; 7,331 lb/ac), experimental cultivar cowpea (11,221 lb/ac), and Tropic Sun sunn hemp (9,013 lb/ac; 11,167 lb/ac). Species with the lowest DM yield included tepary bean (1,864 lb/ac) and California Blackeye 46 cowpea (3,332 lb/ac; 3,589 lb/ac). TN contents varied from 2018 to 2020, possibly due to the seed not being inoculated prior to planting. In 2018, bigpod sesbania had the highest TN content of the legumes (2.8%), closely followed by Red Ripper cowpea (2.3%). In 2020 California Blackeye 46 cowpea had the highest TN content (4.4%), again followed by Red Ripper cowpea (3.1%). The three legume species with the highest estimated nitrogen yield during both years were bigpod sesbania (163 lb/ac; 208 lb/ac), Tropic Sun sunn hemp (167 lb/ac; 245 lb/ac), and Iron & Clay cowpea (190 lb/ac; 204 lb/ac).

Table 2. Warm season legume average germination and insect resistance evaluations collected at the CAPMC.

Cultivar	2017					2018				2019					2020				
	Germination[¥]				Insect Resistance[£]	Germination[¥]			Insect Resistance[£]	Germination[¥]				Insect Resistance[£]	Germination[¥]				Insect Resistance[£]
	7 DAP	14 DAP	21 DAP	28 DAP	50% Bloom	14 DAP	21 DAP	28 DAP	50% Bloom	7 DAP	14 DAP	21 DAP	28 DAP	50% Bloom	7 DAP	14 DAP	21 DAP	28 DAP	50% Boom
California Blackeye 46 Cowpea	-	-	-	-	-	1.8 ab	1.8 ab	2.0 ab	1.0	0.7	1.0 ab	1.0 ab	1.0 ab	1.7	2.0 abc	2.5 ab	2.5	2.8	2.0 ab
Chinese Red Cowpea	-	-	-	-	-	2.3 ab	2.5 ab	2.8 ab	0.0	0.8	1.5 a	1.8 a	2.0 a	1.5	2.5 ab	3.0 a	3.0	3.0	2.0 ab
Iron & Clay Cowpea	-	-	-	-	-	2.3 ab	2.5 ab	2.8 ab	1.3	0.5	1.5 a	1.5 a	1.5 ab	1.3	3.0 a	3.0 a	3.0	3.0	2.0 ab
Red Ripper Cowpea	-	-	-	-	-	3.0 a	3.0 a	3.0 a	0.0	0.0	1.0 ab	1.0 ab	1.0 ab	2.0	2.0 abc	3.0 a	3.0	3.0	2.0 ab
Tepary Bean	-	-	-	-	-	1.3 ab	1.5 ab	1.5 ab	0.0	0.0	0.8 ab	0.8 ab	1.0 ab	0.0	-	-	-	-	-
Tropic Sun Sunn Hemp	0.0	0.0	0.8 b*	0.8 b	0.8	0.0 b	0.5 b	0.5 b	0.8	0.0	0.0 b	0.0 b	0.0 b	0.0	1.5 abc	2.0 ab	1.8	1.8	1.0 ab
Bigpod Sesbania	0.3	0.3	2.0 a	3.0 a	1.3	1.0 ab	1.0 ab	1.5 ab	1.3	0.8	0.8 ab	1.4 ab	1.4 ab	0.8	1.0 bc	2.0 ab	2.0	2.8	1.8 ab
Pigeon Pea	-	-	-	-	-	- -	- -	- -	-	0.5	1.0 ab	1.0 ab	1.3 ab	0.0	0.0 c	1.3 b	2.0	2.0	0.8 b
Experimental Cultivar Cowpea	-	-	-	-	-	- -	- -	- -	-	0.8	1.0 ab	1.3 ab	1.3 ab	2.3	2.5 ab	2.8 ab	2.8	2.8	2.0 ab
Mean	0.1	0.1	1.4	1.9	1.0	1.6	1.8	2.0	0.6	0.5	1.0	1.1	1.2	1.0	1.8	2.4	2.5	2.6	1.7
SD[#]	0.4	0.4	0.9	1.2	0.0	1.2	1.1	1.1	0.6	0.5	0.6	0.6	0.6	1.0	1.0	0.7	0.7	0.7	0.5

[#]Standard deviation

*Means followed by the same letter are not significantly different as determined by Dunn's test at α=0.05.

[¥]Germination rated on the following scale: 0 = poor (<25% germination), 1 = fair (30-45%), 2 = good (50-65%), 3 = very good (70-85%, 4 = excellent (90-100%).

[£]Insect Resistance rated on the following scale: 0=no damage, 1=slight damage, 3=moderate damage, 5=severe damage.

DAP = days after planting.

Table 3. Warm season legume average quantitative measurements at 50% bloom including days after planting, height, and fresh weight aboveground biomass collected at the CAPMC.

	2017		2018			2019		2020		
Cultivar	DAP	Height	DAP	Height	Fresh Weight Aboveground Biomass	DAP	Height	DAP	Height	Fresh Weight Aboveground Biomass
		—in—		—in—	———lb/ac———		—in—		—in—	———lb/ac———
California Blackeye 46 Cowpea	-	-	55	13.9	18,513 bc*	58	12.3	54	12.0 d	32,291
Chinese Red Cowpea	-	-	63	19.3	33,367 abc	77	17.0	72	25.0 c	39,757
Iron & Clay Cowpea	-	-	N/A	26.7	53,361 a	N/A	15.9	N/A	27.7 c	52,337
Red Ripper Cowpea	-	-	63	19.6	31,080 abc	77	11.4	68	21.6 c	37,837
Tepary Bean	-	-	55	11.1	7,667 c	45	9.1	-	-	-
Tropic Sun Sunn Hemp	92	55.0	77	56.7	37,767 ab	77	40.3	92	55.3 a	43,983
Bigpod Sesbania	79	58.3	68	40.5	26,267 abc	77	51.7	68	47.2 a	29,434
Pigeon Pea	-	-	-	-	-	77	31.0	72	35.8 b	18,462
Experimental Cultivar Cowpea	-	-	-	-	-	77	16.5	89	25.8 c	67,078
Mean	85	56.7	67	26.8	29,717	70	22.9	73	30.7	40,024
SD#	7	3.6	12	15.9	16,805	12	14.9	12	13.2	21,930

#Standard deviation

* Means followed by the same letter are not significantly different as determined by Tukey's HSD test at P<0.05.

All measurements were collected at 50% bloom.

DAP = days after planting; in = inches; lb/ac = pounds/acre.

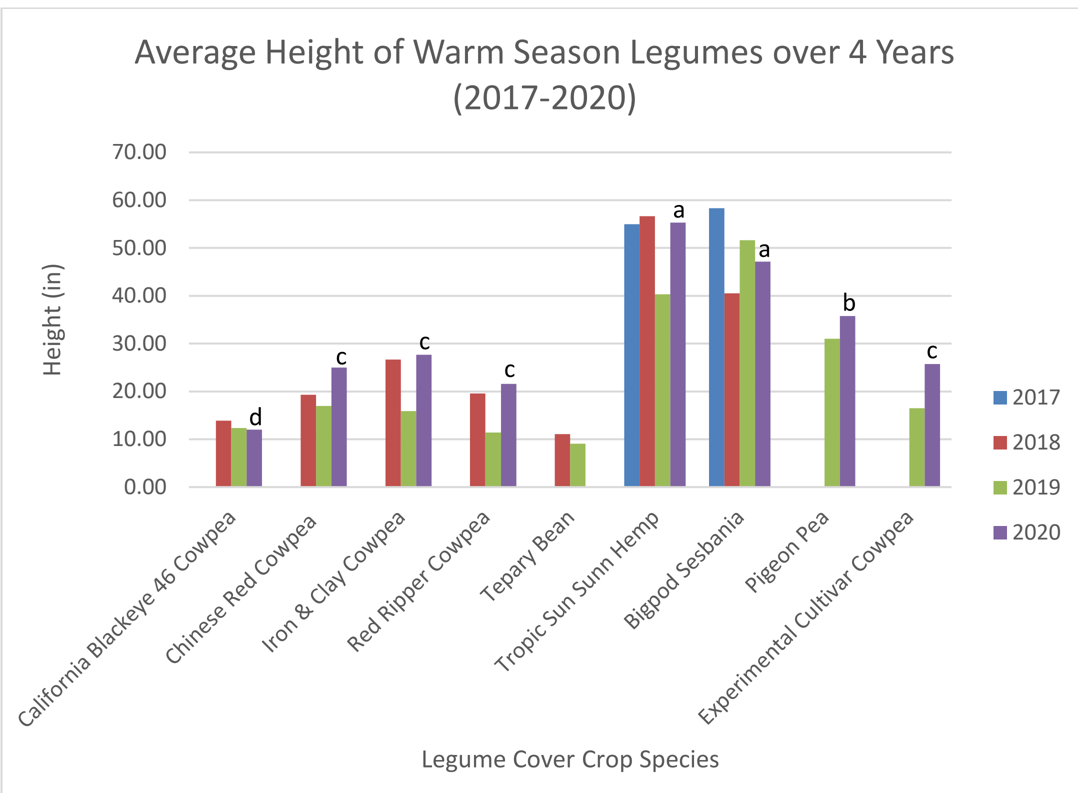

Figure 3. Differences in height of warm season legumes across four growing seasons. Tropic Sun sunn hemp and bigpod sesbania were the tallest legumes across all years. In 2020, sunn hemp and bigpod sesbania were significantly the tallest, while California Blackeye 46 cowpea was significantly the shortest warm season legume using Tukey's HSD at the 5% level. Columns with the same letters are not significantly different at $P < 0.05$.

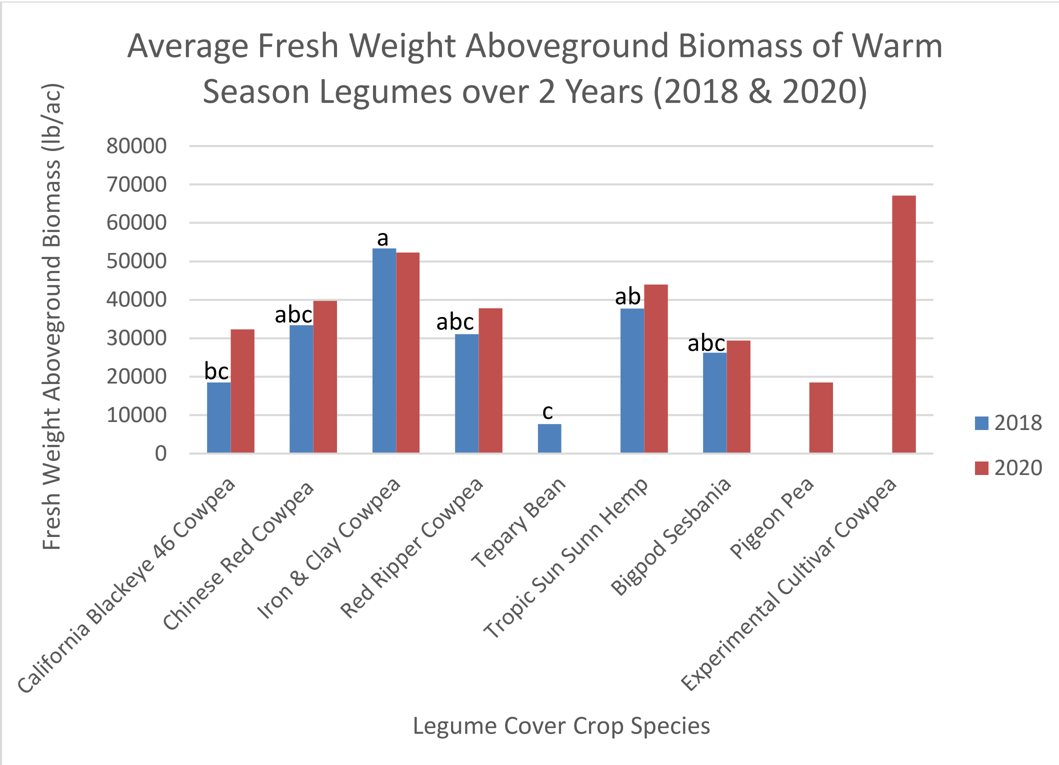

Figure 4. Differences in fresh weight aboveground biomass of warm season legumes during two growing seasons. Iron & Clay cowpea and the experimental cultivar cowpea had the largest biomass production across both years. In 2018, Iron & Clay cowpea biomass was significantly larger than tepary bean and California Blackeye 46 cowpea using Tukey's HSD at the 5% level. Columns with the same letters are not significantly different at $P < 0.05$.

Table 4. Warm season legume estimated dry matter yield, total percent nitrogen, and estimated nitrogen yield.

	2018			2020		
Cultivar	Estimated DM Yield	Total N	Estimated N Yield	Estimated DM Yield	Total N	Estimated N Yield
	––lb/ac––	–%–	––lb/ac––	––lb/ac––	–%–	––lb/ac––
California Blackeye 46 Cowpea	3,332	1.8	60.3	3,589	4.4	156.5
Chinese Red Cowpea	5,671	2.0	115.7	5,241	2.2	116.9
Iron & Clay Cowpea	10,013	1.9	190.3	7,331	2.8	203.8
Red Ripper Cowpea	5,193	2.3	117.4	4,776	3.1	145.7
Tepary Bean	1,864	2.0	37.8	-	-	-
Tropic Sun Sunn Hemp	9,013	1.9	166.7	11,167	2.2	244.5
Bigpod Sesbania	5,918	2.8	163.3	7,276	2.9	208.1
Pigeon Pea	-	-	-	6,057	2.9	173.8
Experimental Cultivar Cowpea	-	-	-	11,221	1.6	178.4
Mean	5,858	2.1	121.6	7,082	2.7	178.5
SD[#]	2,888	0.3	56.7	2,825	0.8	40.1

[#]Standard deviation

DM and N were measurements of composite samples collected at 50% bloom.

Est. DM Calculation: Fresh Weight Aboveground Biomass x (DM/100)

Est. Total N Yield Calculation: (N/100) x DM Yield

DM = dry matter, N = nitrogen, lb/ac = pounds/acre.

These results indicate that different legume species and cultivars may have different benefits for California agricultural systems. Germination trends across four years of data show that from 2017 to 2019, Tropic Sun sunn hemp was slow to emerge and had poor germination. In 2020, germination rates improved, likely helped by the use of a new seed lot, resulting in good germination, and then unfortunately suffered vertebrate grazing damage. From 2018 to 2020, Chinese Red, Iron & Clay, and Red Ripper cowpea all had the best emergence rates across legume species and cultivars with good to very good emergence, indicating that these cultivars would be good choices if quick establishment is desired. All legumes evaluated seem to be well adapted to the areas, with little insect damage and essentially no disease damage. California Blackeye 46 cowpea would be a good option for an early blooming cowpea variety with high TN content but lower FWAB and DM production. For late blooming cowpea cultivars with high FWAB production and high nitrogen yield Iron & Clay and experimental cultivar cowpea (if commercially available) would be good options. If cover crop height is not a concern, mid and late maturing species like bigpod sesbania and Tropic Sun sunn hemp with high FWAB, DM yield and estimated nitrogen yield, could be useful for green manure and nitrogen contributions.

Warm Season Grasses

Four different warm season grass species were evaluated from 2017 to 2020 for germination, insect and disease resistance, 50% anthesis, height, FWAB, estimated DM yield, and TN content.

Germination

Four years of warm season grass germination results are located in Table 5. In 2017, Excalibur teff had significantly slower germination (poor to fair) than Japanese millet at 14 DAP (fair), and White proso millet and Piper sudangrass (both very good to excellent) at 21 and 28 DAP. In 2018, Piper sudangrass had significantly better germination (very good to excellent) than teff (poor to good) from 14 to 28 DAP. Japanese millet also had significantly better germination (excellent) than teff (good) by 28 DAP. In 2019, no teff was planted, but at 7 DAP Piper sudangrass had significantly better germination (good) than Japanese millet (poor). By 28 DAP all warm season grasses had good to very good germination, even with soil crusting issues. No significant differences were seen in 2020, but by 7 DAP, Piper sudangrass and White proso millet both already had good germination. By 14 DAP, Japanese millet had caught up and also had good germination. By 28 DAP all three had very good germination, while teff had fair germination.

Pest Resistance

Insect damage was slight on Excalibur teff in 2017, observed as holes in leaves. This was significantly higher than Piper sudangrass, which had no visible damage that year. In 2018, insect damage was slight to moderate on White proso millet at 50% bloom. This was significant compared to all other warm season grasses with no damage (Table 5). In 2019, little to no insect damage was observed on all evaluated grass species. Slight insect damage was observed in 2020 on Japanese millet, as holes in leaves. Other species had significantly less damage, with little to none observed. No disease damage was observed on the warm season grass species during the four years of the trial.

Table 5. Warm season grass average germination and insect resistance evaluations collected at the CAPMC.

Cultivar	2017					2018				2019					2020				
	Germination¥				Insect Resistance£	Germination¥			Insect Resistance£	Germination¥				Insect Resistance£	Germination¥				Insect Resistance£
	7 DAP	14 DAP	21 DAP	28 DAP	50% Bloom	14 DAP	21 DAP	28 DAP	50% Bloom	7 DAP	14 DAP	21 DAP	28 DAP	50% Bloom	7 DAP	14 DAP	21 DAP	28 DAP	50% Boom
Japanese Millet	0.8	1.0 a*	2.5 ab	3.3 ab	0.3 ab	3.0 ab	3.3 ab	4.0 a	0.0 b	0.3 b	1.7	1.8	2.3	0.0	0.0	2.3	2.5	3.0	1.0 a
White Proso Millet	0.8	0.8 ab	3.0 a	3.8 a	0.5 ab	1.0 ab	2.3 ab	3.0 ab	2.0 a	1.8 ab	2.5	2.8	3.0	0.3	2.5	2.5	2.8	3.5	0.3 ab
Piper Sudangrass	0.5	0.8 ab	2.8 a	3.5 ab	0.0 b	3.5 a	3.5 a	4.0 a	0.0 b	2.0 a	2.8	2.8	3.0	0.0	2.5	2.5	2.8	3.3	0.0 b
Excalibur Teff	0.0	0.0 b	1.0 b	1.3 b	1.0 a	0.8 b	1.5 b	1.8 b	0.0 b	-	-	-	-	-	0.0	1.5	1.5	1.5	0.3 ab
Mean	0.5	0.6	2.3	2.9	0.4	2.1	2.6	3.2	0.5	1.5	2.4	2.5	2.8	0.1	1.3	2.2	2.4	2.8	0.4
SD#	0.5	0.5	0.9	1.1	0.5	1.4	1.0	1.0	0.9	0.8	0.8	0.7	0.8	0.3	1.3	0.8	0.8	1.2	0.5

#Standard deviation

*Means followed by the same letter are not significantly different as determined by Dunn's test at α=0.05.

¥Germination rated on the following scale: 0 = poor (<25% germination), 1 = fair (30-45%), 2 = good (50-65%), 3 = very good (70-85%, 4 = excellent (90-100%).

£Insect Resistance rated on the following scale: 0=no damage, 1=slight damage, 3=moderate damage, 5=severe damage.

DAP = days after planting.

50% Anthesis
Results for grass 50% anthesis, height, and FWAB evaluations are located in Table 6, Figure 5 and Figure 6. The first warm season grass to reach 50% bloom or anthesis across all four years was White proso millet, which matured in 45 to 55 DAP. Excalibur teff was next to mature, and reached 50% anthesis in 59 to 77 DAP, while Piper sudangrass and Japanese millet reached 50% anthesis in 69 to 80 DAP.

Height
Piper sudangrass was by far the tallest warm season grass and was significantly taller than White proso millet or Excalibur teff (Table 6 and Figure 5). Piper sudangrass ranged from 54 to 72 inches tall, while proso millet and teff were 20 to 28 inches tall. Japanese millet ranged from 24 to 48 inches in height.

Biomass
In both 2018 and 2020, Piper sudangrass and Japanese millet produced significantly more FWAB than Excalibur teff (Table 6 and Figure 6). In 2018, the FWAB of sudangrass was 45,128 lb/ac and for Japanese millet was 43,320 lb/ac, which were significantly more FWAB than either Excalibur teff (23,392 lb/ac) or White proso millet (27,116 lb/ac). In 2020, Piper suudangrass (38,005 lb/ac) and Japanese millet (47,824 lb/ac) again produced significantly larger amounts of FWAB than teff (16,277 lb/ac).

Dry Matter Yield and Total Nitrogen Content
Estimated DM yield was highest for Piper sudangrass and Japanese millet in 2018 and 2020 (Table 7). TN content of the warm season grasses varied across both years but was slightly higher in White proso millet and Excalibur teff (1.4% to 2.0%) than the other two grass species (0.7% to 1.1%). The TN content in the grasses is an indicator of nitrogen uptake and scavenging from the soil, which is then incorporated into their biomass when it would otherwise be leached from the system.

Performance differences of the warm season grass species may meet different conservation goals in California agricultural systems. Piper sudangrass, Japanese millet and White proso millet all germinated quickly and had very good to excellent germination by 28 DAP, indicating that these would be good species for quick establishment and weed suppression. All grasses evaluated also had little insect damage and no disease damage. White proso millet was the first to reach 50% bloom, indicating that it would be a great option for quick cover in a system with less than a 60-day window for a cover crop. Piper sudangrass was very tall and, along with Japanese millet, produced large amounts FWAB and DM yield. However, high residue cover crops can also be a challenge to manage. Excalibur teff was slow to germinate and typically only had fair germination by 28 DAP but is low growing and is known to provide good quality forage.

Table 6. Warm season grasses average quantitative measurements at 50% anthesis including days after planting, height, and fresh weight aboveground biomass collected at the CAPMC.

	2017		2018			2019		2020		
Cultivar	DAP	Height	DAP	Height	Fresh Weight Aboveground Biomass	DAP	Height	DAP	Height	Fresh Weight Aboveground Biomass
		—in—		—in—	———lb/ac———		—in—		—in—	———lb/ac———
Japanese Millet	72	38.4	69	31.9	43320 a*	77	23.9	80	47.5 b	47824 a
White Proso Millet	46	28.0	49	21.5	27116 b	55	15.7	50	25.8 c	34115 ab
Piper Sudangrass	72	72.0	69	69.5	45128 a	77	53.6	75	67.1 a	38005 a
Excalibur Teff	77	20.6	63	24.0	23392 b	-	-	59	23.9 c	16277 b
Mean	67	39.7	62	36.7	34739	69.0	31.7	66	41.1	34055
SD#	13	20.4	9	20.1	11469	11.0	18.0	14	18.9	14121

#Standard deviation

* Means followed by the same letter are not significantly different as determined by Tukey's HSD test at P<0.05.

All measurements were collected at 50% bloom.

DAP = days after planting; in = inches; lb/ac = pounds/acre.

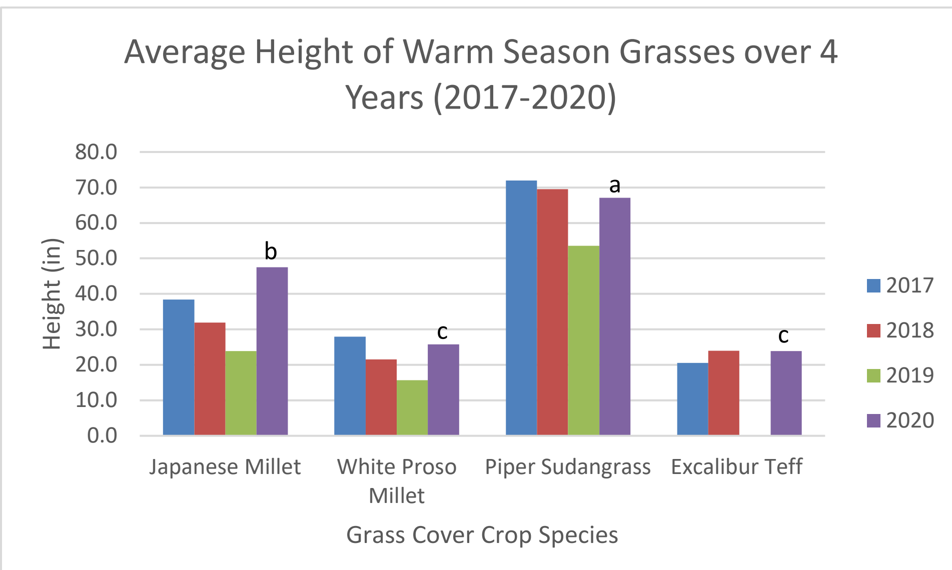

Figure 5. Differences in height of warm season grasses across four growing seasons. Piper sudangrass was the tallest grass across all years. In 2020, sudangrass was significantly the tallest, while White proso millet and Excalibur teff were significantly the shortest warm season grasses using Tukey's HSD at the 5% level. Columns with the same letters are not significantly different at P <0.05.

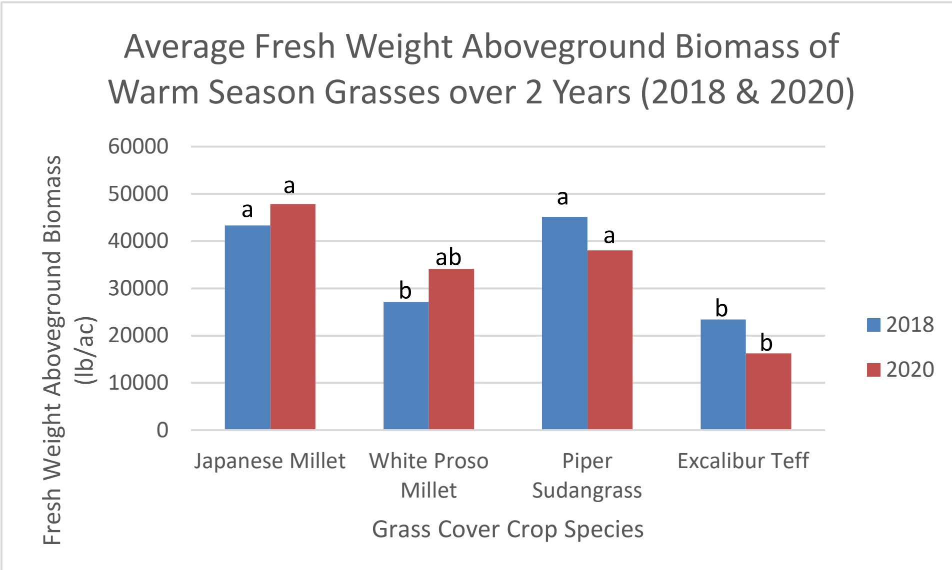

Figure 6. Differences in fresh weight aboveground biomass of warm season grasses during two growing seasons. Piper sudangrass and Japanese millet had significantly the largest biomass production across both years using Tukey's HSD at the 5% level. Columns with the same letters are not significantly different at *P* <0.05.

Table 7. Warm season grass estimated dry matter yield and total percent nitrogen.

	2018		2020	
Cultivar	Estimated DM Yield	Total N	Estimated DM Yield	Total N
	––lb/ac––	–%–	––lb/ac––	–%–
Japanese Millet	10839	0.8	14932	1.1
White Proso Millet	8210	1.4	6329	2.0
Piper Sudangrass	13079	0.7	11875	1.1
Excalibur Teff	8226	1.4	5826	1.6
Mean	10089	1.1	9740	1.4
SD#	2345	0.4	4415	0.4

#Standard deviation

DM and N were measurements of composite samples collected at 50% bloom.

Est. DM Calculation: Fresh Weight Aboveground Biomass x (DM/100)

DM = dry matter, N = nitrogen, lb/ac = pounds/acre.

Warm Season Forbs

Two different warm season forbs were evaluated from 2018 to 2020 for germination, insect and disease resistance, 50% bloom, height, FWAB, estimated DM yield, TN content, and estimated nitrogen yield.

Germination

Three years of warm season forb germination results are shown in Table 8. In 2018, no significant differences were observed between black sunflower and buckwheat. Both had good to very good germination from 14 DAP to 28 DAP. In 2019, buckwheat had better germination (fair) than black sunflower (poor) at 7 DAP. From 14 to 28 DAP, buckwheat had good germination, while black sunflower had fair germination. In 2020, buckwheat had significantly better germination than black sunflower, with very good germination from 7 to 28 DAP. Black sunflower had poor germination at 7 DAP, which then increased to fair from 14 to 28 DAP.

Pest Resistance
In 2018, no insect damage was visible on buckwheat and only very slight damage on black sunflower (Table 8). In 2019, slight insect damage in the form of holes in leaves was observed on black sunflower, while buckwheat had no visible insect damage. In 2020, slight damage was again observed on black sunflower, which was significant compared to very little damage on buckwheat. No disease was observed on either of the forbs in the three years of evaluations.

50% Bloom
Results for 50% bloom, height, and FWAB forb evaluations are located in Table 9, Figure 7 and Figure 8. The first warm season forb to reach 50% bloom was buckwheat at 34 to 38 DAP. This was the earliest bloom date across all species and cultivars evaluated in the trial. Black sunflower reached 50% bloom around 60 to 77 DAP.

Height
Black sunflower was the tallest forb across all three years and was significantly taller than buckwheat (Table 9 and Figure 7). Black sunflower ranged in height from 35 to 40 inches tall, while buckwheat was 15 to 23 inches tall.

Biomass
In both 2018 and 2020, black sunflower produced more FWAB than buckwheat (Table 9 and Figure 8). In 2018 black sunflower averaged 25,395 lb/ac of FWAB, while buckwheat averaged 11,805 lb/ac FWAB. In 2020, black sunflower produced a significantly larger amount of FWAB at 51,521 lb/ac, compared to buckwheat at 15,845 lb/ac.

Dry Matter Yield, Total Nitrogen Content and Nitrogen Yield
Forb estimated DM yield and TN content from 2018 and 2020 were used to calculate an estimated nitrogen yield. Results are shown in Table 10. Black sunflower, with the largest production of FWAB, also had high DM yields during both years (4,621 lb/ac; 6,907 lb/ac) compared to buckwheat (1,564 lb/ac; 1,722 lb/ac). Forbs are also good nitrogen scavengers, bringing up nitrogen from below the root zone of annual crops where it might otherwise be lost. Buckwheat had higher TN content across both 2018 and 2020, ranging from 2.6% to 3.4%, compared to black sunflower with 1.3% to 2.5% TN content. Due to its higher DM yield production, black sunflower calculates out to have a higher estimated nitrogen yield during both years (61 lb/ac; 173 lb/ac), indicating good green manure potential. However, the carbon to nitrogen ratio is the key to nitrogen release. Buckwheat may contribute more nitrogen from the aboveground biomass due to its C:N ratio and higher TN content, since the two-year average was above 3%. Black sunflower may temporarily tie up nitrogen due to the lower TN content.

Table 8. Warm season forb average germination and insect resistance evaluations collected at the CAPMC.

Cultivar	2018				2019					2020				
	Germination¥			Insect Resistance£	Germination¥				Insect Resistance£	Germination¥				Insect Resistance£
	14 DAP	21 DAP	28 DAP	50% Bloom	7 DAP	14 DAP	21 DAP	28 DAP	50% Bloom	7 DAP	14 DAP	21 DAP	28 DAP	50% Boom
Black Sunflower	2.5	2.5	2.5	0.5	0.3	1.3	1.3	1.7	1.0	0.3 b	1.8 b	1.8 b	1.8 b	1.0 a
Buckwheat	2.3	2.5	3.0	0.0	1.5	2.3	2.0	2.3	0.0	3.0 a	3.0 a	3.0 a	3.3 a	0.3 b
Mean	2.4	2.5	2.8	0.3	1.0	1.9	1.7	2.0	0.4	1.6	2.4	2.4	2.5	0.6
SD#	1.1	0.9	0.7	0.5	1.0	0.7	0.8	1.0	0.5	1.5	0.7	0.7	0.9	0.5

#Standard deviation

*Means followed by the same letter are not significantly different as determined by Dunn's test at α=0.05.

¥Germination rated on the following scale: 0 = poor (<25% germination), 1 = fair (30-45%), 2 = good (50-65%), 3 = very good (70-85%, 4 = excellent (90-100%).

£Insect Resistance rated on the following scale: 0=no damage, 1=slight damage, 3=moderate damage, 5=severe damage.

DAP = days after planting.

Table 9. Warm season forb average quantitative measurements at 50% bloom including days after planting, height, and fresh weight aboveground biomass collected at the CAPMC.

	2018			2019		2020		
Cultivar	DAP	Height	Fresh Weight Aboveground Biomass	DAP	Height	DAP	Height	Fresh Weight Aboveground Biomass
Forbs		—in—	——lb/ac——		—in—		—in—	——lb/ac——
Black Sunflower	63	40.0 a*	25395	77	34.6 a	60	35.6 a	51521 a
Buckwheat	34	23.4 b	11805	38	15.0 b	38	17.6 b	15845 b
Mean	49	31.7	18600	55	23.4	49	26.6	33683
SD#	16	9.2	9427	21	11.9	12	10.4	22421

#Standard deviation

*Means followed by the same letter are not significantly different as determined by Tukey's HSD test at P<0.05.

All measurements were collected at 50% bloom.

DAP = days after planting; in = inches; lb/ac = pounds/acre.

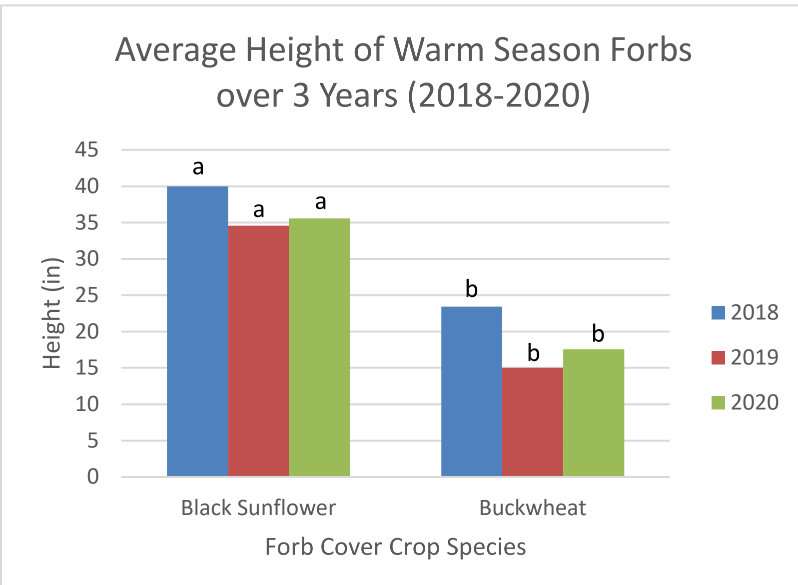

Figure 7. Differences in height of warm season forbs across three growing seasons. Black sunflower was significantly taller than buckwheat across all three years using Tukey's HSD at the 5% level. Columns with the same letters are not significantly different at $P < 0.05$

Differences in performance between the two forbs indicate two different uses for these cover crops, other than being very attractive to pollinator species. Due to its fast germination, buckwheat would be great for providing quick cover and weed suppression. However, with its early maturity, buckwheat can reseed and quickly turn into a weed problem if not managed properly. Black sunflower is slower to germinate and slower to mature but can produce a fair amount of biomass. It would probably do best in a mix with more weed competitive species.

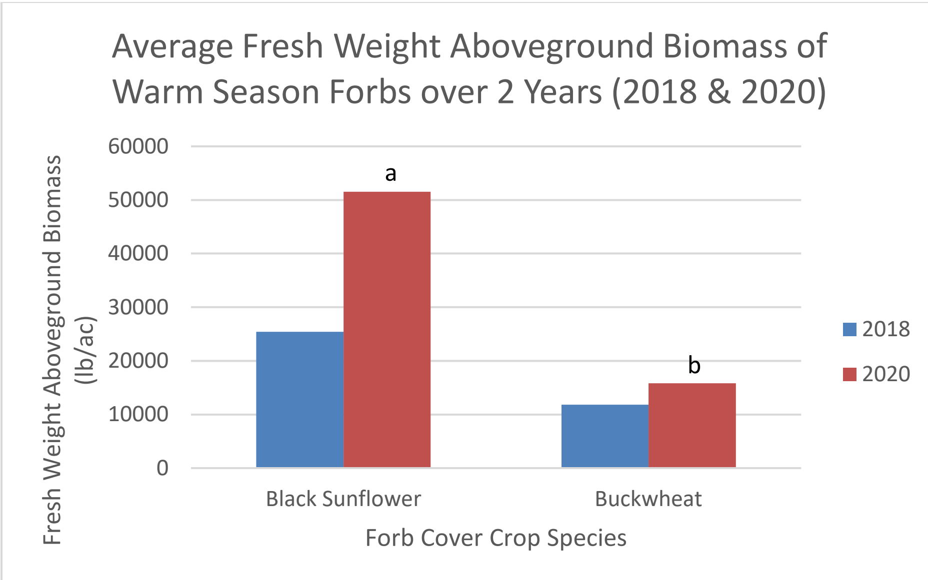

Figure 8. Differences in fresh weight aboveground biomass of warm season forbs during two growing seasons. Black sunflower had the larger biomass production during both years and significantly larger production in 2020 using Tukey's HSD at the 5% level. Columns with the same letters are not significantly different at $P < 0.05$.

Table 10. Warm season forb estimated dry matter yield, total percent nitrogen, and estimated nitrogen yield.

	2018			2020		
Cultivar	Estimated DM Yield	Total N	Estimated N Yield	Estimated DM Yield	Total N	Estimated N Yield
	––lb/ac––	–%–	––lb/ac––	––lb/ac––	–%–	––lb/ac––
Black Sunflower	4621	1.3	60.5	6907	2.5	172.7
Buckwheat	1564	2.6	40.4	1722	3.4	58.2
Mean	3093	1.9	50.4	4315	2.9	115.4
SD#	2162	0.9	14.3	3666	0.6	80.9

#Standard deviation

DM and N were measurements of composite samples collected at 50% bloom.

Est. DM Calculation: Fresh Weight Aboveground Biomass x (DM/100)

Est. Total N Yield Calculation: (N/100) x DM Yield

DM = dry matter, N = nitrogen, lb/ac = pounds/acre.

CONCLUSION

All of the species and varieties evaluated in the warm season cover crop trial were well adapted to California's Central Valley. Even though they are drought tolerant, some irrigation and soil moisture is required for establishment of the tested species and varieties. Differences in germination, bloom dates, growth, and nitrogen content show that species and variety choice can make a big difference in agronomic benefits.

Piper sudangrass and Japanese millet. Mid and late maturing legumes with high FWAB production and high nitrogen yield include Iron & Clay and experimental cultivar cowpea (if commercially available), or bigpod sesbania and Tropic Sun sunn hemp if height is not a concern. Piper sudangrass and Japanese millet are also tall and produced large amounts FWAB and DM yield, but may be challenging to manage. Other warm season cover crops like Excalibur teff are low growing and can provide quality forage, or black sunflower, which can be great for attracting pollinators.

Overall, their drought and heat tolerance, ability to winterkill in the fall, and range in bloom dates suggest great potential for warm season cover crops to be incorporated into many California cropping systems. Next steps include evaluating different planting dates and the adaptability of other warm season cover crops to arid regions in the U.S. with minimal irrigation. Finally, warm season cover crops need further evaluation in other regions within California and to be implemented into specific farming operations to observe their compatibility with different agricultural systems and practices.

LITERATURE CITED

Balkcom, K.S. and D.W. Reeves. Sunn-Hemp utilized as a legume cover crop for corn production. 2005. Agron. J. 97:26-31.

Brennan, E. B., and V. Acosta-Martinez. 2017. Cover cropping frequency is the main driver of soil microbial changes during six years of organic vegetable production. Soil Biology and Biochemistry. 109: 188-204.

Bullard, V. 2018. Case Study: Maturation dates of Warm Season Cover Crop Species-2017, CAPMC. https://efotg.sc.egov.usda.gov/references/public/CA/CaseStudy-MaturationDates_WarmSeasonCC_11-18.pdf

CDFA - California Department of Food and Agriculture. California Agricultural Statistics Review 2019-2020. (https://www.cdfa.ca.gov/Statistics/PDFs/2020_Ag_Stats_Review.pdf. Accessed 6/15/2021)

Clark, A. (ed). 2007. Managing cover crops profitably, 3rd edition. Handbook 9. Sustainable Agriculture Research & Education (SARE) program, College Park, MD. http://www.sare.org/Learning-Center/Books/Managing-Cover-Crops-Profitably-3rdEdition/Text-Version

Dial, H.L. 2012. Plant guide for sorghum (*Sorghum bicolor* L.). USDA-Natural Resources Conservation Service, Tucson Plant Materials Center, Tucson, AZ.

Mitchell, J.P., A. Shrestha, K. Mathesius, K.M. Scow, R. J. Southard, R.L. Haney, R. Schmidt, D.S. Munk, 2016. Cover cropping and no-tillage improve soil health in an arid irrigated cropping system in California's San Joaquin Valley, USA. Soil & Tillage Research 165:325–335.

Miller, D. 2008. Teff as an alternative summer forage. (https://alfalfa.ucdavis.edu/+symposium/proceedings/2008/08-229.pdf Accessed 6/15/21).

O'Connell, S., W. Shi, J. M. Grossman, G. D. Hoyt, K. L. Fager, and N. G. Creamer. 2015. Short-term nitrogen mineralization from warm season cover crops in organic farming systems. Plant Soil 396:353–367. (https://link.springer.com/content/pdf/10.1007/s11104-015-2594-2.pdf. Accessed 6/3/2021).

Pavek, P.L.S. 2016. Plant Guide for buckwheat (*Fagopyrum esculentum*). USDA-Natural Resources Conservation Service, Pullman Plant Materials Center. Pullman, WA.

Sheahan, C.M. 2012. Plant guide for cowpea (*Vigna unguiculata)*. USDA-Natural Resources Conservation Service, Cape May Plant Materials Center, Cape May, NJ.

Sheahan, C.M. 2012. Plant guide for pigeonpea (Cajanus cajan). USDA-Natural Resources Conservation Service, Cape May Plant Materials Center. Cape May, NJ. 08210.

Sheahan, C.M. 2012. Plant guide for sunn hemp (*Crotalaria juncea)*. USDA-Natural Resources Conservation Service, Cape May Plant Materials Center. Cape May, NJ.

Sheahan, C.M. 2013. Plant guide for bigpod sesbania (*Sesbania exaltata*). USDA-Natural Resources Conservation Service, Cape May Plant Materials Center. Cape May, NJ. 08210

Sheahan, C.M. 2014. Plant guide for Japanese millet *(Echinochloa esculenta)*. USDA-Natural Resources Conservation Service, Cape May Plant Materials Center, Cape May, NJ.

Sheahan, C.M. 2014. Plant guide for pearl millet (*Pennisetum glaucum)*. USDA-Natural Resources Conservation Service, Cape May Plant Materials Center, Cape May, NJ.

Sheahan, C.M. 2014. Plant guide for proso millet (*Panicum miliaceum)*. USDA-Natural Resources Conservation Service, Cape May Plant Materials Center. Cape May, NJ.

Stevens, M. and M.K. Anderson. 2000. Plant Guide for annual sunflower (*Helianthus annuus* L.) (USDA-Natural Resources Conservation Service, National Plant Data Center.

Statistix 10. 2013 Analytical software, Tallahassee, FL.

Western Regional Climate Center. Period of Record Monthly Climate Summary for Lodi, California (Accessed: 06/16/21): https://wrcc.dri.edu/cgi-bin/cliMAIN.pl?ca5032.

Western Weather Group. Historical Weather Database Monthly Summaries for Lockeford (Accessed: 06/16/21): https://westernwx.com/weatherdb/index.php?q=wwg/reports/wwgmonthly

Wolf, M. 2018. Plant Guide for tepary bean (*Phaseolus acutifolius*). USDA-Natural Resources Conservation Service, Tucson Plant Materials Center. Tucson, AZ 85705.

Young-Mathews, Annie. 2017. Irrigated Warm Season Cover Crops for Western Oregon. Corvallis Plant Materials Center, Corvallis, OR. (https://www.nrcs.usda.gov/Internet/FSE_PLANTMATERIALS/publications/orpmcsr13158.pdf, Accessed 06/03/2021)