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A One Year Warm Season Cover Crop Mix Assessment for California's Central Valley

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ABSTRACT

Warm season cover crops are sown between the time of soil warm-up in spring and cooling temperatures in fall. In 2025, six cover crop mixes were developed for different purposes: early maturing, high biomass, pollinator habitat, "kitchen sink" blend, weed suppression and long-term cover. All mixes incorporated twelve cover crop species previously evaluated that are adapted to high temperatures, drought tolerant, and have minimal irrigation requirements. The experimental design was a randomized complete block trial with 10 x 300-foot plots and 4 replications. Mixes were planted into a firm seed bed with irrigation water of 1.75 inches applied through a linear irrigation system prior to planting on July 15. Additional irrigation applied was 4 x 0.5 inches 9, 14, 25 and 37 days after planting (DAP). Total irrigation applied over the course of the study was 3.75 inches. Cover was assessed using line point intercept data at 33 and 66 DAP, average heights were recorded at 60 DAP, and biomass was collected at 67 DAP. The early maturing mix provided the best cover and weed suppression both at 33 and 66 DAP, followed by long-term cover at 66 DAP. Proso millet (*Panicum miliaceum*) was the most competitive of the species in reducing weeds and providing cover up to 66 DAP. Buckwheat (*Fagopyrum esculentum*) was most competitive in the pollinator mix in the absence of proso millet. All six warm season cover crop mixes produced similar biomass with minimal irrigation in California's Central Valley. Based on percent cover and weed suppression results, the early maturing mix composed of proso millet and buckwheat was most successful, while the long-term cover mix showed the potential for incorporating cool season cover crops into summer plantings.

INTRODUCTION

Summer cover crops are rarely used in California, due to a Mediterranean climate that provides little to no rain from April through October in the main crop production areas. Precipitation falls on a north-south gradient with the wetter areas in the north and dryer areas to the south. Supplemental water for irrigation depends either on surface water from stored snowmelt from the Sierra Nevada, or from groundwater. Droughts and higher temperatures severely limit water available for surface irrigation and groundwater use is regulated by the Sustainable Groundwater Management Act (SGMA) (Sustainable Conservation, 2024). Agriculture in California is diverse with over 400 different crops harvested and a cash value of over $55 billion in 2023 (CDFA, 2022-2023). It is estimated that about 5% of agricultural land is cover cropped; primarily over the winter rainy season with cool season cover crops (CDFA, 2020; Mitchell et al., 2016, 2017; Sustainable Conservation, 2024).

Cover crops provide numerous agronomic advantages including microbial changes with increased aggregation of soil particles (Brennan & Acosta-Martinez, 2017; Schaeffer et al., 2020), the reduction or prevention of soil erosion, increased infiltration from precipitation and irrigation events, and greater water holding capacity (Fageria et al., 2005; Magdoff & Van Es., 2009). A recent expert panel and literature report on California based research found consistent water-related benefits of cover cropping with increased infiltration of water into the soil (often ≥40%) and the reduction of runoff (often ≥40%) (De Vincentis et al. 2022; Sustainable Conservation, 2024). Legume cover crop species provide nitrogen, reducing the amount of synthetic nitrogen fertilizer required for commodity crops. The selection of nitrogen scavenging crops, such as cereals, supports nutrient cycling, reduces nitrous oxide emissions and nitrate run-off to

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surface and ground water (Fageria et al., 2005; Magdoff & Van Es., 2009; Menegat et al., 2022). In addition, specific cover crops compete with weeds, break pest cycles, and provide habitat for pollinator species and beneficial insects, reducing the need for pesticide use within a following crop and the cost of bees for pollination (Daryanto et al., 2018; Fernando & Shrestha, 2023; Haring et al., 2023; Magdoff & Van Es., 2009).

The Lockeford Plant Materials Center (CAPMC) first evaluated warm season cover crops at its Central Valley location in 2016 to assess growth at different planting dates (Bullard, 2018). Over the years, grasses, legumes, and forbs were evaluated, and millets (*Panicum spp*.) and cowpeas (*Vigna spp.)* were consistently among the most robust species (Bullard & Smither-Kopperl, 2022; Smither-Kopperl et al., 2025). Warm season cover crops, sown between the time of soil warm up in spring and before temperatures cool in fall, are drought tolerant, adapted to high temperatures, have high growth rates, and minimal irrigation is needed for germination and establishment. Maturity dates vary with species and cultivar (Bullard, 2018). They do not tolerate cold temperatures, showing a marked slow-down in growth in the fall followed by death, so there is no requirement for spring termination. Warm season cover crops provide soil cover over the summer, erosion control during the first fall rains, and maintain increased organic matter and nutrient cycling, weed suppression, and breaking of pest and disease cycles where planted (Bullard and Smither-Kopperl, 2021; Smither-Kopperl et al., 2025). Cover crop planting can be timed for the "window" following harvest of the commodity crop to take advantage of residual soil moisture and/or timed for the flushing of driplines as they require minimal irrigation for germination and establishment. 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, where limited irrigation water is available.

Previous warm season cover crop evaluations at the CAPMC were limited to single species and no studies evaluated their performance in mixtures. The purpose of this study was to evaluate six warm season cover crop mixes. The six different mixtures were designed for different purposes in order to test their potential for further use in agriculture in California's Central Valley and to assess the performance of individual species within the mixes (Table 1).

Table 1. Cover crop mixes with proposed purposes and maturation times, Lockeford, CA Plant Materials Center, 2025.

Mix Type	Purpose	Duration
Early Maturing	Erosion prevention, carbon sequestration, nitrogen scavenger, pollinator and beneficial insect habitat	Short: < 60 days
High Biomass	Erosion prevention, nitrogen neutral, carbon sequestration, substantial biomass for forage or weed suppression	~120 days- until cold temperatures
Pollinators	Pollinator habitat from August through October, nitrogen sequestration	~120 days - until cold temperatures
Kitchen Sink	Increase diversity, reduce erosion, nitrogen neutral, provide some pollinator benefit	~120 days - until cold temperatures
Weed suppression	Erosion prevention, high biomass production, weed suppression	~120 days - until cold temperatures
Long term	Erosion prevention, nitrogen neutral, early pollinator benefits, plus continual growth over the winter	~ 300 days -potentially into April following year

MATERIALS AND METHODS

This warm season cover crop mix trial took place in 2025 at the CAPMC. The CAPMC is in the northeastern corner of the San Joaquin Valley in central California and sits on a historical flood plain on the west bank of the Mokelumne River. This trial was planted into a Vina fine sandy loam with 0-2 percent slopes. This soil series has deep, well-drained soils with a pH ranging from moderately acid to slightly alkaline, available water storage (AWS) is estimated as 7 inches (NRCS California eVeg guide, 2024, NRCS Web Soil Survey, 2025). The area has a linear irrigation system enabling precision application. The study area was fallow, although a portion had been used for a warm season cover crop study from July through November 2024.

Site preparation was disking (x3) followed by cultipacking to give a firm seed bed. Irrigation (1.75 inches) was applied prior to planting on July 13. Fine sandy loam soils tend to form soil crusts with sprinkler irrigation increasing the likelihood of uneven emergence and patchy stands; planting into moisture provides seeds with adequate resources to germinate and emerge. The 6 cover crop mixes were prepared according to the compositions in Table 2. Planting occurred on July 15, 2025, using a Great Plains seed drill (Salina, KS). The plots were 10 x 300 feet (2 tractor and drill passes) with a 2-foot border between plots. The experimental design was a randomized complete block with 4 blocks. There is an anticipated slight moisture gradient with potential sub-surface moisture from the Mokelumne River on the west side of the study.

Fertilizer as sodium nitrate (soluble) was broadcast at 30 lb N/acre on July 23, after emergence of the cover crops, this was followed by the first post-plant irrigation of 0.5 inches on July 24. Additional irrigation events of 0.5 inches were made on July 29, August 7, and August 1, a soil probe was used to assess soil moisture. Total irrigation water applied, both pre-and post- planting was 3.75 inches.

Monitoring photos were taken at 7, 14, 24, 30, and 60 DAP, line point intercept data was read at 33 and 66 DAP, plant heights measured at 60 DAP, and biomass production sampled at 67 DAP.

Plant height (in) is the average height of the canopy measured from the base to the tallest point at 5 representative locations per plot. Fresh weight above ground biomass (FWAB) was defined as the above-ground accumulation of plant growth. For this procedure, biomass was collected as close to the ground as possible, leaving no more than ¼ inch stubble height. Locations for samples were selected by randomly placing 3 square foot quadrats in each plot and collecting the aboveground biomass that fell within the square foot perimeter. Weeds were excluded. After weighing and recording the FWAB, the samples were dried in a drying oven until their weights stabilized. The stabilized dry weight was recorded as dry matter weight (DM). Line point intercept data was collected using a 50-foot tape, with plant identification at each one-foot interval.

Statistical analysis was completed using Statistix 10 (Analytical Software, Tallahassee, FL). Analysis was done on quantitative plant measurements (plant height, FWAB, DM, and canopy cover) 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.

Table 2: Warm Season Cover Crop Mixes: Species Composition and Planting Rate, Lockeford, CA Plant Materials Center, 2025.

Mix Name	**Common Name**	**Species**	**Selection**	**Percent of mix**	**Seeding rate (lb/acre)**	**Seeds (sq.foot)**
Early maturing	buckwheat	*Fagopyrum esculentum*	VNS*	50	26.7	13
	proso millet	*Panicum miliaceum*	White	50	17.5	34
High Biomass	sudangrass	*Sorghum bicolor ssp. drummondii*	Piper	10	3.5	3
	pearl millet	*Pennisetum glaucum*	Leafy	10	3.5	7
	Japanese millet	*Echinochloa esculenta*	VNS	10	2.5	8
	cowpea	*Vigna unguiculata*	Iron and clay	70	31.5	3
Pollinator	buckwheat	*Fagopyrum esculentum*	VNS	40	21.4	11
	common sunflower	*Helianthus annuus*	Black oil	10	1.4	2
	sunn hemp	*Crotalaria juncea*	VNS	10	4	3
	cowpea	*Vigna unguiculata*	Red ripper	40	18	2
Kitchen sink	Japanese millet	*Echinochloa esculenta*	VNS	10	2.5	8
	teff grass	*Eragrostis tef*	VNS	5	0.4	11
	buckwheat	*Fagopyrum esculentum*	VNS	10	5.3	5
	sunn hemp	*Crotalaria juncea*	VNS	10	4	3
	sunflower	*Helianthus annuus*	Black oil	5	0.4	1
	proso millet	*Panicum miliaceum*	White	10	3.5	7
	pearl millet	*Pennisetum glaucum*	Leafy	10	3.5	7
	cowpea	*Vigna unguiculata*	Red ripper	20	9	1
	cowpea	*Vigna unguiculata*	Iron and clay	20	9	1
Weed Suppression	Japanese millet	*Echinochloa esculenta*	VNS	30	7.5	24
	proso millet	*Panicum miliaceum*	White	35	12.3	23
	pearl millet	*Pennisetum glaucum*	Leafy	35	12.3	23
Longterm cover	teff grass	*Eragrostis tef*	VNS	5	0.4	11
	buckwheat	*Fagopyrum esculentum*	VNS	15	8	5
	proso millet	*Panicum miliaceum*	White	10	3.5	7
	pearl millet	*Pennisetum glaucum*	Leafy	10	3.5	7
	spring pea	*Pisum sativum*	Dundale	40	32	2
	triticale	*Triticosecale rimpaui*	Winter	20	18.2	8

**VNS= Variety Not Stated*

RESULTS

Mix Comparison

Total cover as measured by all planted species, while excluding weeds and bare ground, was not significantly different (P<0.05 Tukey's (HSD) test) at 33 DAP (Figure 1, Table 3). The early maturing mix had significantly higher cover, 95%, by 66 DAP, while the pollinator and 'kitchen sink' mix had the lowest with 79.5% and 80% cover respectively. For early cover and weed suppression benefits, the early maturing mix with 73.5% cover at 33 DAP, followed by the weed suppression mix at 67.5% cover, were the best performers.

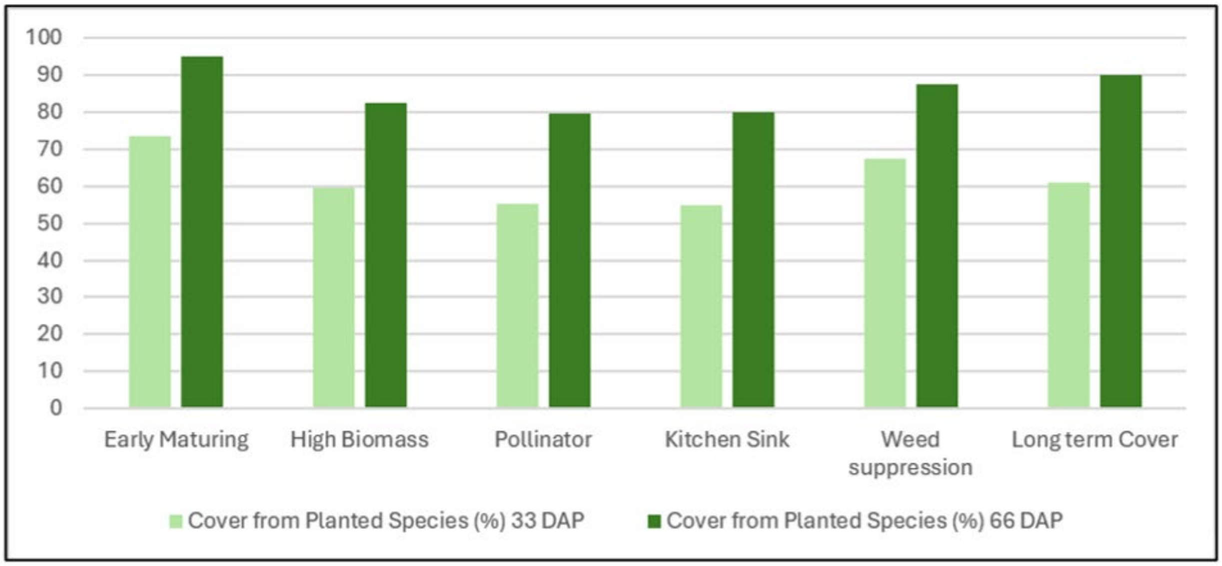

Figure 1. Cover (%) for planted species (excluding weeds) in six cover crop mixes at 33 and 66 DAP, Lockeford, CA Plant Materials Center, 2025.

Biomass produced by all six mixes were not significantly different (P<0.05 Tukey's (HSD) test) after 60 days (Table 3). Fresh weights at 30 DAP, were highest for the early maturing, high biomass and weed suppression mixes at 8.6, 9.0 and 8.9 tons/acre, respectively. At 60 DAP, the early maturing mix biomass was highest at 2.0 tons/acre, likely reflecting the early maturity of the plants within the mix. The poorest performing mix on the basis of biomass was the 9-component diverse kitchen sink mix.

Table 3. Average biomass production in tons/acre of warm season cover crop mixes taken 67 days after planting (DAP), Lockeford, CA Plant Materials Center, 2026.

Treatment Number	Mix Name	Cover from Planted Species (%) 33 DAP	Cover from Planted Species (%) 66 DAP	Fresh weight (tons/acre)	Dry weight (tons/acre)
1	Early Maturing	73.5 a*	95.0 a	8.6 a	2.0 a
2	High Biomass	59.5 a	82.5 ab	9.0 a	1.8 a
3	Pollinator	55.3 a	79.5 b	7.7 a	1.5 a
4	Kitchen Sink	54.8 a	80.0 ab	6.5 a	1.3 a
5	Weed suppression	67.5 a	87.5 ab	8.9 a	1.9 a
6	Long term Cover	60.8 a	90.0 ab	7.4 a	1.6 a

**Means in columns followed by the same letters are not significantly different at P<0.05 with Tukey's (HSD) test.*

Heights taken at 60 DAP were similar for these mixes 1) early maturing, 3) pollinator, 4) "kitchen sink", 5) weed suppression and 6) long-term cover. The exception was for 2) high biomass mix, which due to the growth of sudan grass, was significantly taller (Figure 2).

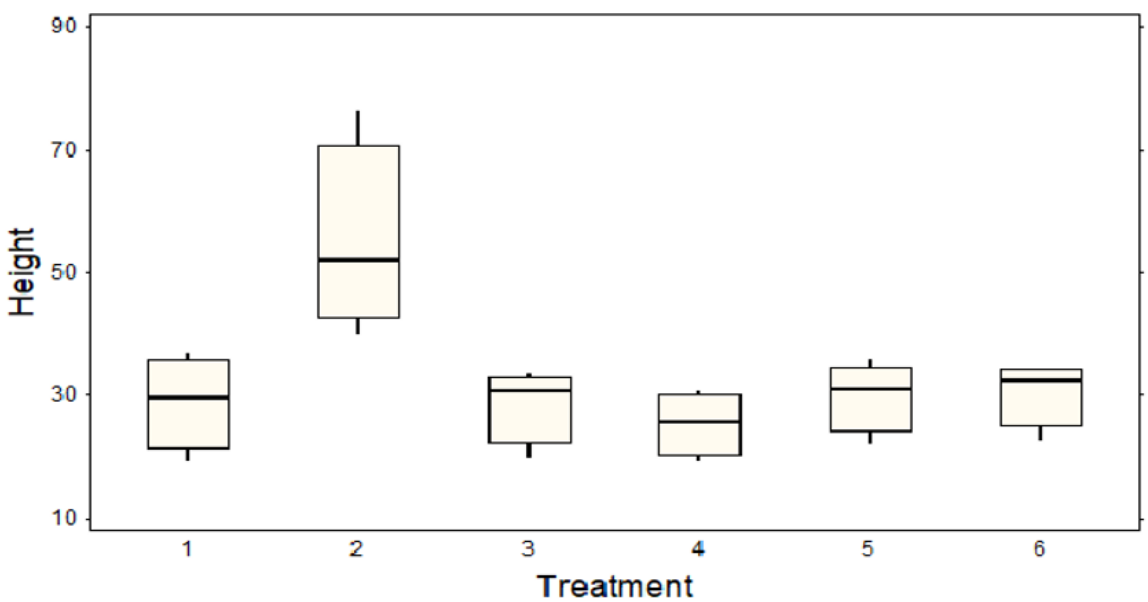

Figure 2. Average plant heights (inches), for 6 warm season cover crop mixes treatments at 60 DAP, Lockeford, CA Plant Materials Center, 2026.

Species Cover Comparison for Individual Mixes

Early Maturing Mix

This is the simplest mix with only 2 components, proso millet and buckwheat. Proso millet dominated with 54% cover at 33 DAP and 71% cover by 66 DAP, while buckwheat remained at 24% (Figures 3 and 4). This mix had the highest biomass dry weight (Table 3) and was particularly successful at suppressing weeds with only 2% weed cover and 3% bare ground by 66 DAP. Both species have a maturation date of 45 days, leading to good early growth and cover (Figure 5), with seed production and set by 60 DAP (Figure 6), meaning that this mix is most suitable for a short cover cropping 'window'.

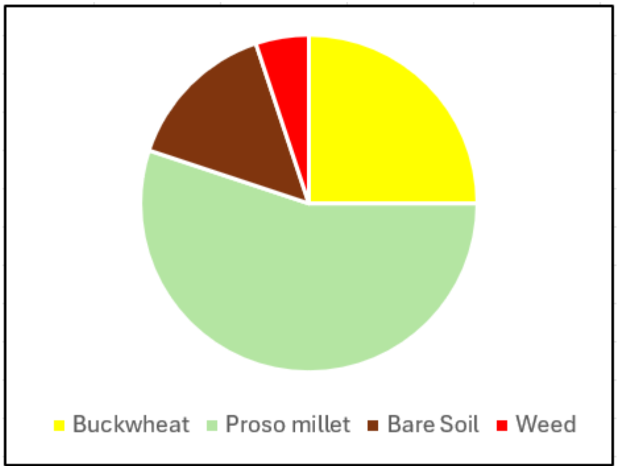

Figure 3. Early maturing warm season cover crop mix, % cover at 33 DAP, Lockeford, CA PMC, 2026.

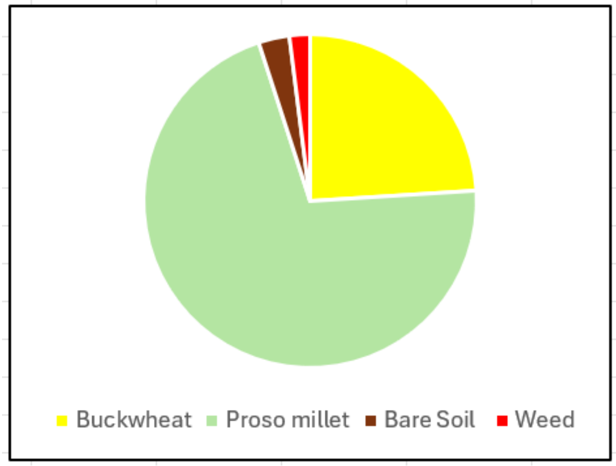

Figure 4. Early maturing cover crop mix, % cover 66 DAP, Lockeford, CA PMC, 2026.

Figure 5. Early maturing cover crop mix: Proso millet and buckwheat. 30 DAP, Lockeford, CA PMC, 2026.

Figure 6. Early maturing cover crop mix, 60 DAP, both Proso millet and buckwheat have set seed, Lockeford, CA PMC, 2026.

High Biomass Mix

This was a 4-component mix with three grasses, Japanese (*Echinochloa esculenta*) and pearl (*Pennisetum glaucum)* millets, Sudan grass (*Sorghum bicolor ssp. drummondii)*, and cowpea (*Vigna unguiculata)* as the legume to supply nitrogen. This is the only mix to both omit proso millet and contain Sudan grass, known for high biomass production. Although there were no significant differences between biomass for the different treatments, this mix had higher biomass fresh weight and slightly lower dry weight than the early maturing mix (Table 3). The 33 DAP data collection did not distinguish between the grasses at 45% cover, with weeds making up the next largest component at 28%, and both cowpeas and bare ground at 13.5% cover (Figure 7 and 9). By 66 DAP, Sudan grass was dominant at 53.5%, pearl millet at 15.5%, Japanese millet at only 0.5% and cowpea remained at 13% (Figure 8 and 10). This mix had 0.5% bare ground, while weed cover was 28% at 33 DAP and 17% at 66 DAP; this was the highest weed cover in any of the mixes, although not significantly different ($P<0.05$). This indicates that weed suppression was not a major advantage with this specific mix.

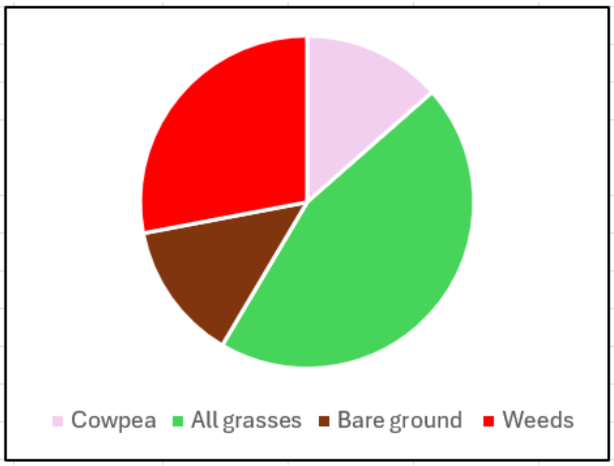

Figure 7, High biomass cover crop mix, % cover at 33 DAP, Lockeford, CA PMC, 2026..

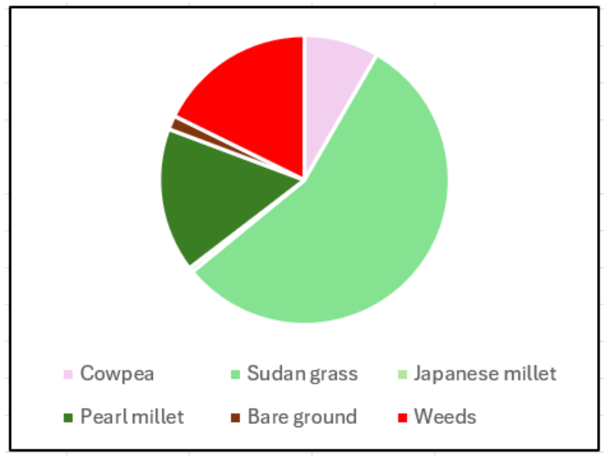

Figure 8. High biomass cover crop mix, % cover at 66 DAP, Lockeford, CA PMC, 2026..

Figure 9. High biomass cover crop mix dominated by grasses. 30 DAP, Lockeford, CA PMC, 2026.

Figure10. High biomass cover crop mix 60 DAP, dominated by sudan grass, Lockeford, CA PMC, 2026.

Pollinator Mix

The pollinator mix was composed of buckwheat and common sunflower (*Helianthus annuus)* with the legumes cowpea and sunnhemp (*Crotalaria juncea)*. Buckwheat and cowpea were both planted as 40% of the mix and sunflower and sunn hemp were both 10% of the mix. At 33 DAP, buckwheat was dominant at 43.5% cover, followed by 7% for cowpea (Figures 11 and 13). By 66 DAP, buckwheat retained dominance at 48% cover, cowpea at 24.5% cover and sunn hemp at 7 %, sunflower was present, but with a low incidence and did not show up in the data (Figure 11 and 13). There was some deer grazing on these plots and the deer preferred the cowpea to the buckwheat, this may have resulted in a lower reading for the cowpea. Bare ground and weed cover were 6% and 4.25% respectively by 66 DAP, indicating that this mix provided some weed suppression.

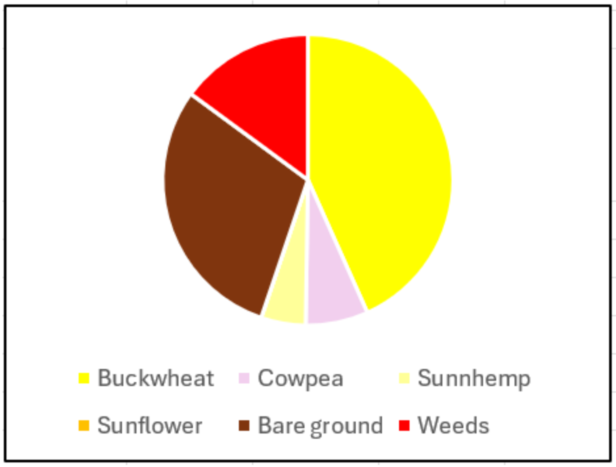

Figure 11. Pollinator cover crop mix, % cover at 33 DAP, Lockeford, CA PMC, 2026.

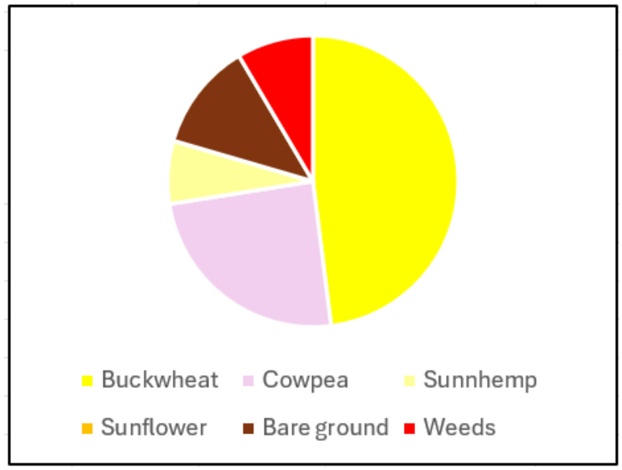

Figure 12. Pollinator cover crop mix, % cover at 66 DAP, Lockeford, CA PMC, 2026.

Figure 13. Pollinator cover crop mix, 30 DAP, buckwheat, cowpea, sunn hemp and sunflower (not shown). Lockeford, CA PMC, 2026.

Figure 14. Pollinator cover crop mix 60 DAP, dominated by buckwheat and cowpea. Lockeford, CA PMC, 2026.

Kitchen Sink Mix

This mix had 9 components including grasses with three types of millets, Japanese, pearl and proso plus teff (*Eragrostis tef)*, legumes including 2 cultivars of cowpea and sunnhemp, and forbs, buckwheat and sunflower. All 3 millets were planted at 10% of the mix, and at 66 DAP, cover for Japanese millet was 1%, pearl at 8.5% and proso performed best at 38.5% (Figures 15-18). Teff grass was not observed in any of the plots, the seed is very small and generally is broadcast and irrigated up. The 2 cowpea cultivars comprised 40% of the planted mix, and were only 10.5 % cover at 66 DAP, while sunnhemp, planted as 10% of the mix was 8.5% cover. The forbs, buckwheat and sunflower, were planted at 10% and 5% of the mix. At 66 DAP, buckwheat comprised 11 % cover and sunflower at 2% cover. At 66 DAP, weeds were 13% cover and there was 7% bare ground, showing that the greater diversity did not lead to greater weed suppression. This mix had the lowest biomass in both fresh and dry weights.

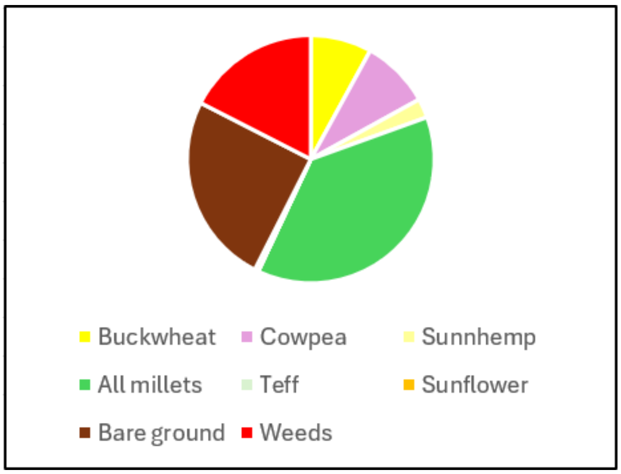

Figure 15. Kitchen sink cover crop mix, % cover at 33 DAP, Lockeford, CA PMC, 2026.

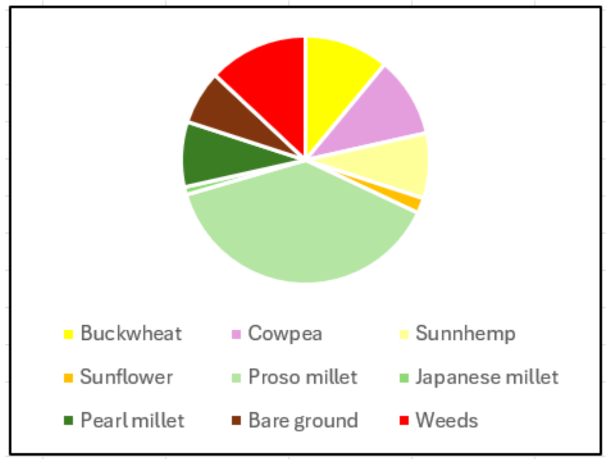

Figure 16. Kitchen sink cover crop mix, % cover at 66 DAP, Lockeford, CA PMC, 2026..

Figure 17. Kitchen sink cover crop mix. 30 DA. Bare ground visible with grasses and buckwheat. Lockeford, CA PMC, 2026.

Figure 18. Kitchen sink cover crop mix, 60 DAP buckwheat, cowpeas and sunnhemp. Lockeford, CA PMC, 2026.

Weed Suppression Mix

This three-component mix was composed of three millet species Japanese, pearl and proso millets (Figures 19-22). As with the previous mixes, the proso millet dominated the mix, with 71.5% cover at 66 DAP, pearl millet followed at 13.5% cover and Japanese millet only 2.5% cover. This indicates that the Japanese millet is not competitive with the proso millet in this study. Weed cover at 33 and 66 DAP was 6% and 7% respectively, lower than all other mixes except for the early maturing mix. This mix was competitive with weeds with proso millet the best performer. Bare ground was 21.5% at 33 DAP and 11% at 66 DAP.

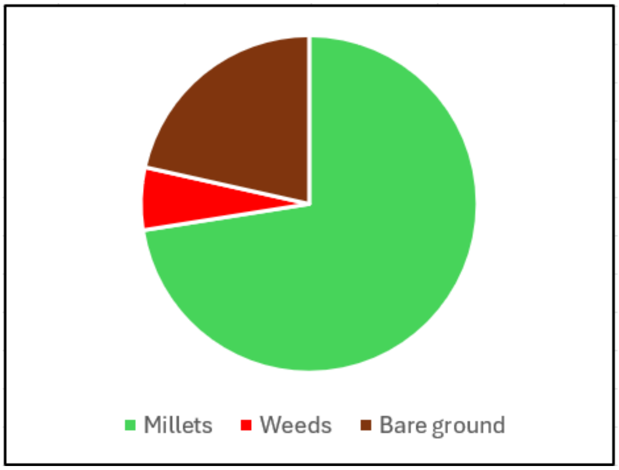

Figure 19. Weed suppression cover crop mix, % cover 33 DAP, Lockeford, CA PMC, 2026.

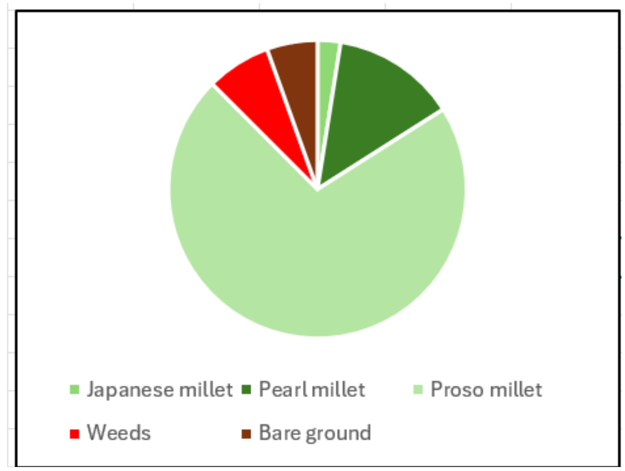

Figure 20. Weed suppression cover crop mix, % cover, 66 DAP, Lockeford, CA PMC, 2026.

Figure 21. Weed suppression cover crop mix. 30 DAP, Lockeford, CA PMC, 2026.

Figure 22. Weed suppression cover crop mix, inflorescence of proso millet, 60 DAP, Lockeford, CA PMC, 2026..

Long Term Cover Mix

The aim of this mix was to evaluate the possibility of including cool season cover crops in a warm season mix to provide continuous cover over the winter months without needing to replant. The grasses included were pearl and proso millets plus teff. The grasses performed similarly to the other mixes, at 66 DAP proso millet was most abundant at 42% cover, pearl millet at 17.5% cover, while teff was not observed (Figures 22-25). Buckwheat was planted as 15% of the mix and comprised 17% cover at 66 DAP. The cool season cover crops added were a winter triticale (*Triticosecale rimpaui)* and a spring pea (*Pisum sativum)*, with a percent of mix at 40% and 20% respectively. At 66 DAP, the spring pea comprised 7% cover and the triticale was 6.5%. Weed cover at 66 DAP was 9% with bare ground at 0.5% cover. The weed data was skewed with a 30% weed cover in one plot, while the other 3 plots averaged 1.5% cover.

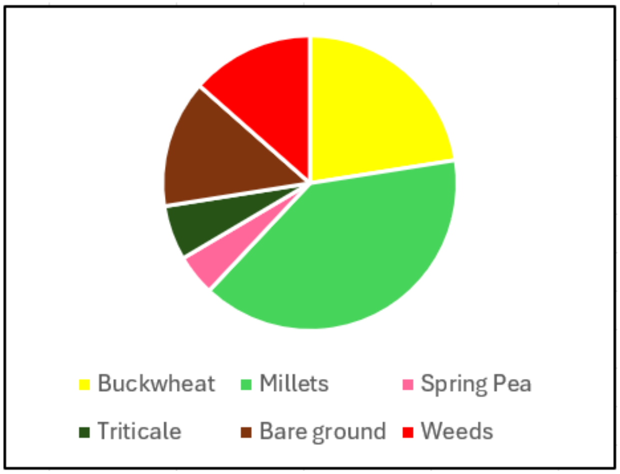

Figure 22. Long term cover crop mix. % cover at 33 DAP, Lockeford, CA PMC, 2026.

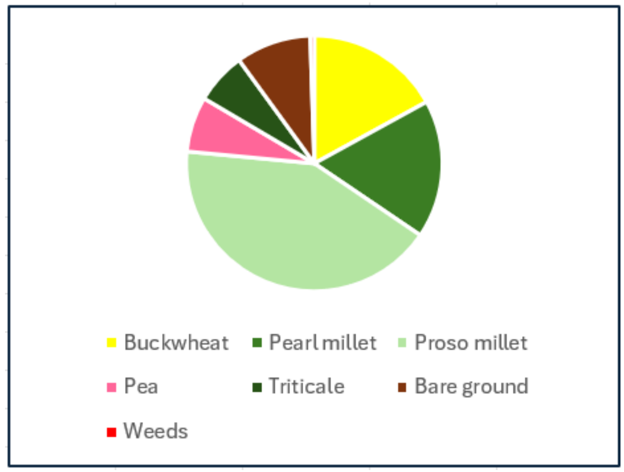

Figure 23. Long term cover crop mix, % cover at 66 DAP, Lockeford, CA PMC, 2026.

Figure 24. Long term cover crop mix 30 DA, Lockeford, CA PMC, 2026.

Figure 25. Long term cover crop mix. 60 DAP. Buckwheat, proso millet and spring pea are the most visible plants, Lockeford, CA PMC, 2026.

Table 4. Species performance across six warm season cover crop mixes as measured by proportion of seed within each mix by seeds/square foot / weight (%) / cover (%) at 66 DAP, Lockeford, CA Plant Materials Center, 2026.

Species	Mixes*					
	1-Early Maturing	2-High Biomass	3-Pollinator	4- Kitchen Sink	5-Weed Suppression	6-Long-term Cover
buckwheat	13/50/24		11/40/48	5/10/11		5/15/17
proso millet	34/50/71			7/10/39	23/35/72	7/10/42
pearl millet		7/10/16		7/10/9	23/35/14	710/18
Japanese millet		8/10/1		8/10/1	24/30/3	
Sudan grass		3/10/54				
teff grass				11/5/0		11/5/0
cowpea		3/70/13	2/40/25	2/40/11#		
sunnhemp			3/10/7	3/10/9		
sunflower			2/10/<1	1/5/2		
spring pea						2/40/7
triticale						8/20/7

*Values expressed as: proportion of seeding mix (lb) % / Cover % at 66 DAP.
#Combined values for 2 cowpea cultivars.

The competitiveness of individual species within mixes compared to seeds/foot^2 and mix % by weight is shown in Table 4. As already noted, proso millet was competitive in all 4 mixes in which it was a component. Buckwheat was outcompeted by proso millet in the early maturing mix, while it was the best performer in the pollinator mix, with no grass competitors. Pearl millet matures later than proso and was less competitive over the course of the study, while Japanese millet did poorly in all the mixes to which it was added. Sudan grass was very competitive with pearl and Japanese millet. Proso millet was not included in the high biomass mix so we are unable to make a direct comparison. Teff grass was not expressed in either of the mixes in which it was included. Cowpea cover was greatest in the pollinator mix compared to the high biomass and kitchen sink mixes; however, it has a vining habit and cover may have been underestimated due to the vines climbing the grasses, plus observations showed that it was favored by deer browsing. Cover of sunnhemp was proportional to % incidence in the planting mix, while sunflower cover was greatest in the kitchen sink mix. The cool season species, spring pea and triticale, were represented and continue growing into December.

DISCUSSION

The availability of water and irrigation requirements are a barrier to the use of warm season cover crops (Sustainable Conservation, 2024). This study confirms the potential for use of warm season cover crops with minimal irrigation, with a total of 3.75 inches applied over the season. Timing of irrigation is critical for success! In this study, almost ½ the total irrigation was applied prior to planting so that the seeds had adequate moisture for rapid germination and growth. Additional irrigation was applied after germination once the first shoots were visible. Previous studies at the PMC found that irrigation applied directly after seeding resulted in soil crusting leading to poor emergence (Bullard & Smither-Kopperl, 2022).

The limited water applied over the course of the study led to limited total biomass production compared to previous demonstration plantings at the PMC. In this study at 67 DAP, the early maturing mix produced a maximum biomass of 2 tons dry weight/acre. The previous year, a demonstration planting of single species plots with 12 inches of irrigation water, produced 4.2 and 8.1 tons/acre of proso millet and sudan grass (Piper) respectively. Limited biomass can be positive for summer planted cover crops as it provides cover to prevent erosion, while root growth enables infiltration, increased organic matter and nutrient cycling with no termination needed. Erratic and potentially heavy rainstorms in fall are common in California and warm season cover crops protect against this, while cool season cover crops, unless irrigated, do not germinate until after the fall rains and therefore cannot prevent early fall soil erosion.

The overall best performing species based on biomass production and weed suppression is clearly proso millet, which dominated the pearl and Japanese millet. Teff grass failed completely although it was grown successfully in demonstration plantings at the PMC in the past and used in mixes elsewhere (Mapanga, 2022). Teff has very small seed and needs to be broadcast and then raked in for good establishment. Buckwheat performed best out of the flowering species attractive to pollinators, although it was not as competitive as the proso millet. Cover crop selection is based on the resource concern to be solved, and certainly in this study, the early maturing mix performed best with respect to early cover and weed suppression.

Use of warm season cover crops offers the possibility of better utilizing the cover cropping "window". The early maturing mix is suitable for an annual cropping system where a very short cropping window, such as 60 days is needed. The long-term cover mix, with successful germination of triticale and peas, shows the potential for including small grains and legumes into a warm season mix. In 2024, in a demonstration planting at the PMC, winter triticale and wheat planted in mid-July continued vegetative growth over the winter and into the following year. More studies are needed to determine the best small grains and pea cultivars to incorporate with annual crops such as tomatoes and sweet corn in the Central Valley in what is currently a winter fallow period.

CONCLUSION

All six warm season cover crop mixes produced similar biomass with minimal irrigation in California's Central Valley. Based on percent cover and weed suppression, the early maturing mix composed of proso millet and buckwheat was most successful, while the long-term cover mix showed the potential for incorporating cool season cover crops into summer plantings. Additional evaluation is needed to assess the most suitable cover crops for long-term cover in annual cropping systems in the Central Valley.

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