United States Department of Agriculture

(June 2021) FINAL STUDY REPORT
Lockeford PMC
Lockeford, California

Efficacy of Management and Termination Methods for Insectary Cover Crop Mixes for Almond and Walnut Orchards, and Vineyards in California's Central Valley

Valerie Bullard and Margaret Smither-Kopperl

ABSTRACT

Permanent crops such as tree nuts, vineyards, stone fruits and pome fruit are widely grown in California, while cover crops and conservation cover are not widely used. There are several barriers to wider implementation and one of these is knowledge of methods for management and termination. This study was designed to assess the efficacy of management and termination methods for four insectary cover crop mixes used in almonds, vineyards, and walnut orchards. The four insectary cover crop mixes were planted in strips 10 feet wide by 400 feet in length next to a strip maintained as herbicide fallow. Each cover crop mix was a randomized complete block design with 1 factor and four replications. After site preparation in fall of 2017, four mixes, a commercial standard almond mix, an economical almond mix, a vineyard mix and a walnut mix, were broadcast with belly grinders at an estimated seeding rate of 30-35 seeds per square foot. A cultipacker ensured good soil to seed contact and no irrigation was applied after planting. Over three years, assessments were made of mix composition and ground cover, plant height, air temperature, soil health and reseeding. The planted species declined each year as they were outcompeted by weeds. The maximum percentage of seeded species present after 3 years was about 50% in the economical almond and walnut mixes, 40% in the vineyard mix and less than 30% in the standard almond mix. An early mow followed by a termination mow after seed set was more effective in weed reduction than a late mow after bloom followed by a termination mow . Termination by disking increased the incidence of legume species in the economical almond and walnut mixes in following years. This is likely because the larger legume seeds were buried during disking and had better soil to seed contact.

INTRODUCTION

Cover crops are used on only 5% of California crop lands, including permanent crops such as tree nuts, vineyards, stone fruits and pome fruit (Soil Health Institute, 2019). Yet cover crops provide immense benefits including: habitat and resources for pollinators and beneficial insects, improved soil health with increasing soil organic matter, additional nutrients and nutrient cycling, and increased infiltration and water holding capacity which can lead to drought resilience (Carvalheiro et al., 2007; Clark, 2007; Mitchell et al., 2017).

Almonds and grapes were the largest planted acreage in California in 2016 with 940,000 and 841,000 acres respectively, and each worth more than $5 billion in value (USDA NASS, 2016).

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

Walnuts were planted on 315,000 acres and valued at over $1.2 billion in 2016 (USDA NASS, 2016). Pollinators are essential for many crops including almonds, avocados, cherries, and seed-alfalfa. Each year in February and March, thousands of hives of European honeybees are transported to California to pollinate almonds while they are in bloom to ensure a good crop. The presence of additional flowering plants provides foraging resources of pollen and nectar and is important for health of bees. California is home to many native bee species which also pollinate crops. As with European honeybees, these native bee species flourish when there are more floral resources available. Their presence acts to increase the efficiency of European honeybee pollination, while foraging in the orchards (Garibaldi et al., 2004; Klein et al., 2012).

Native beneficial insects (those that prey upon or parasitize crop pests) contribute to natural suppression of crop pests and potentially save the US $4.5 billion annually in pesticide costs (M'Gonigle et al., 2015). With the advent of chemical pesticides, the contributions of beneficial insects were largely forgotten. However, pesticides alone have not solved the problem of crop pests. "Conservation Biological Control" is a strategy that seeks to integrate beneficial insects back into crop systems for natural pest control (Fiedler, 2008). This strategy is based upon ongoing research that demonstrates a link between the conservation of natural habitat and reduced pest problems on farms, orchards, and gardens (Blaauw and Isaacs, 2014; Klein et al., 2012).

There are specific management concerns for almonds, grapes and walnuts. Almonds bloom in February and frost injury during bloom is a concern. Some growers believe that bare ground will absorb and radiate heat thereby reducing the risk of frost compared to cover crop planted ground. However, cover crop species should be in bloom prior to and just after almond blooming. A "clean" floor, free of vegetation and debris, is a requirement during harvest, therefore the cover crop plantings must be easy to terminate and quickly decompose prior to harvest.

Grapes are wind pollinated but vineyard producers are interested in cover crops to support beneficial insects, as well as pollinators, for ecosystem services and sustainability marketing. Vineyard concerns with respect to pollinator and cover crop plantings are frost injury, excessive nitrogen production, and cover crop water use. Some areas in California, such as in Napa county, require the use of cover crops to prevent erosion, but in other areas, disking for weed control is common. Greater infiltration of precipitation and enhanced water holding capacity is important to vineyard owners (Ingals et al., 2002). Frost injury during bud break is of concern as it is believed high growing cover crops slow air flow which leads to greater cooling and frost injury (Ingels et al., 2002). Another issue is ice-nucleating bacteria present on the cover crop; the likelihood of frost injury increases if bacteria are transferred to the vine's growing tissue (Lindow, 1983).

Walnuts are also wind pollinated, but some producers are interested in expanding pollinator and beneficial insect habitat, as well as other benefits of cover crops, including water infiltration, nutrient input and cycling, and weed suppression. The orchard floor needs to be level for sweeping during harvest although due to the size of the walnuts, mowed vegetation and some debris is not a problem.

Other constraints to greater cover crop utilization include the perception of water use requirements by cover crops, frost injury, cost, and management issues. Precipitation in California falls between November and April. Irrigation is not typically used for cool season cover crops, although irrigation at planting promotes establishment. The presence of cover crops increases infiltration and eventually water holding capacity as organic matter increases, although the time of termination is critical (Mitchell, 2015). Water use by cover crops, in competition with the main crop, is of concern to producers especially in a low rainfall year and early termination may be required.

Planting cover crops, especially when combined with no-till practices, requires less inputs for production of the cash crop, while providing pollinator habitat, pest control and maintaining yields (Morandin et al., 2016; Mitchell et al., 2017). There is an economic cost to cover crop implementation and the benefits may not accrue for several years (DeVincentis, 2020). Financial assistance for producers is available with participation in programs from the Natural Resources Conservation Service (NRCS), and in California, the California Department of Food and Agriculture, Healthy Soils Program and Project ApisM, Seeds for Bees Program.

Another barrier to implementation of cover cropping is a lack of knowledge for optimal cover crop management within specific cropping systems. (DeVincentis, 2020; Clark, 2007). For instance, mowing height is important; a low mow will destroy the crop growing point and kill native species. Kay-Cruz et al. (2019) recommend a high mow of about 1 foot, while the Lockeford Plant Materials Center (CAPMC) recommends a mowing height of 6 inches. Currently, the effects of different times for mowing or termination strategies on survival of perennial species and reseeding annuals is not known (Liu et al., 2005; Magdoff et al., 2000).

Several pollinator seed mixes are commercially available and have been trialed at the CAPMC (Bullard and Smither-Kopperl, 2016). Cover Crop, NRCS Conservation Practice Standard 340, is an annual practice that requires replanting each year. Conservation Cover, NRCS Conservation Practice Standard 327, is assumed to last for five years and is typically restricted to perennial plants. Under the Mediterranean climate conditions of California, reseeding annuals are also considered for Conservation Cover.

The objective of this study was to assess the efficacy of management and termination methods for four insectary cover crop mixes used in almonds, vineyards, and walnut orchards. Assessments were made of mix composition and ground cover, plant height, air temperature, soil health and reseeding over three years. The influence of cover crop type and management practices on soil health were also evaluated at the end of this study.

MATERIALS AND METHODS

The insectary cover crop trial was conducted over three years (2017-2020) at the 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 is a Vina fine sandy loam on 0-2 percent slopes. It is a very deep, well-drained soil 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, 2018). The mean annual precipitation is 17.24 inches, mainly occurring between the months of December and March (WRCC, 2018). Precipitation totals were just below average (16.8 inches) between August 1, 2017 and July 1, 2018, were above average (24 inches) between August 1, 2018 and July 1, 2019, and were about half of average (9.7 inches) between August 1, 2019 and July 1, 2020 (Figure 1) (WWG, 2019).

The study was planted in Field 6, which had previously been fallow or planted to a winter cover crop. The area of the study was disked and cultipacked prior to planting. Irrigation was applied to allow for herbicide use on germinating fall weeds prior to planting in 2017.

A commercial almond orchard understory pollinator and beneficial insect seed mix was included in this trial as a standard (almond mix standard). Three other trial seed mixes were developed by the

Xerces Society specifically for different cropping systems and include both native wildflowers and non-native common cover crop species to lower the cost and improve soil health. The almond mix (almond mix economical) was composed of low growing, early maturing, annual species. The vineyard mix included perennials to provide bloom into the summer, and the walnut mix included large seeded, more robust species, that are able to germinate through walnut leaf litter.

Seeding was accomplished by broadcasting the four mixes (Table 1) at an estimated seeding rate of 30-35 seeds per square foot (bulk seed) by means of belly grinders, followed by a cultipacker to ensure good soil to seed contact. No irrigation was applied after planting. Large differences in seeded pounds per acre were due to differences in seed sizes across mixes and percent composition. Mixes composed primarily of small seeded native species, such as the standard almond mix had much lower seeding rates by weight than mixes with larger seeded species, such as bell beans, in the walnut mix.

The experimental design for this study was a randomized complete block design with 1 factor and four replications. The four insectary cover crop mixes were planted in strips 10 feet wide by 400 feet in length next to a strip maintained as herbicide fallow and was the same size as the mixes (Figure 2). Each cover crop mix was a separate study, with the herbicide fallow strip as a control. The five strips were surrounded by a 10-foot buffer planted to a mix of perennial rye grass and creeping red fescue.

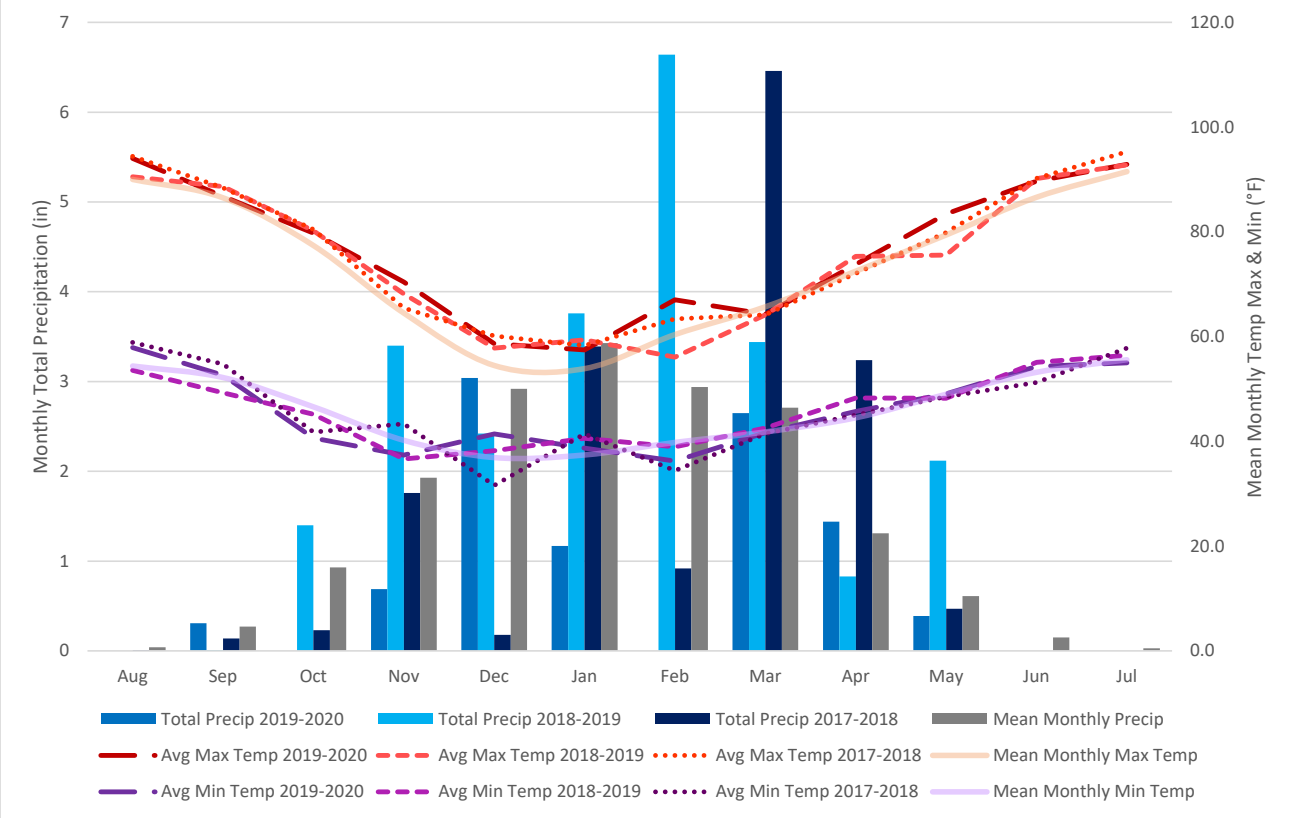

Figure 1. Mean minimum and maximum temperatures in the 2017-2018, 2018-2019, and 2019-2020 growing seasons generally followed annual averages, with maximum temperatures slightly above the mean in October, November, December. Total precipitation was nearly double the annual average in March of 2017-2018 and February of 2018-19, while precipitation in 2019-2020 was almost half of the yearly average. Monthly weather data from September through August 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.

Within each insectary strip there were four 100-foot blocks, consistent with a moisture gradient running from north to south down the field. Treatment plots were 20 ft. in length and were randomized within each block. The plots were made up of four different cover crop management treatments and one check. The timing of the four treatments coincided with important management stages for the orchard or vineyard (Table 2). The management treatments included a single cover crop termination mow, which was a mow prior to crop harvest; a frost reduction early mow plus cover crop termination mow, to reduce frost potential and mow prior to crop harvest; an end of bloom mow plus cover crop termination mow, which was a mow after cover crop mix bloom and a mow prior to crop harvest; and a shallow disking at cover crop termination prior to crop harvest. Early and late bloom mows consisted of a single pass with a flail mower, while cover crop termination mows consisted of two passes with a flail mower. Mower height was set to approximately 6 inches. A late bloom mow was included to 'clean up' plots after bloom.

Table 1. Species present in planted insectary cover crop mixes at the CAPMC in 2017.

Species	Common Name	Almond Mix Standard	Almond Mix Economical	Vineyard Mix	Walnut Mix
Native species					
Nemophila menziesii	Baby blue eyes	X	X	X	X
Eschscholzia californica	California poppy	X	X	X	X
Phacelia ciliata	Great Valley phacelia	X	X		
Lobularia maritima	Sweet alyssum	X	X		
Collinsia heterophyllus	Chinese houses	X	X		
Calandrinia menziesii	Red maids		X		
Layia platyglossa	Tidy tips		X	X	
Nemophila maculata	Five spot		X		
Achillea millefolium	Yarrow			X	
Bromus carinatus	California brome			X	
Clarkia unguiculata	Elegant Clarkia			X	
Grindelia camporum	Gumplant			X	
Acmispon americanus	Spanish lotus				X
Non-native					
Brassica hirta	White mustard		X		X
Bromus hordeaceus	Soft Chess			X	
Calendula officinalis	English marigold			X	X
Linum usitatissimum	Blue flax		X	X	X
Lotus corniculatus	Birdsfoot trefoil			X	
Pisum sativa	Winter pea				X
Raphanus sativus	Tillage radish		X	X	X
Trifolium incarnatum	Crimson clover		X		X
Trifolium mechelianum	Balansa clover		X		
Vicia faba	Bell bean				X
Vicia sativa	Common vetch		X		X

Weeds that were present in the plots during the first year of evaluations included shepherd's-purse (*Capsella bursa-pastoris*), little mallow (*Malva parviflora*), prickly lettuce (*Lactuca serriola*), ripgut brome (*Bromus diandrus*), annual ryegrass (*Festuca perennis*), field mustard (*Brassica nigra*),

'Zorro' fescue (*Vulpia myuros*), and sowthistle (*Sonchus spp.*). There were also cover crop volunteers, possibly from other mixes, including crimson clover, field pea, vetch, and radish. By the final year of the trial, weeds had transitioned to mainly annual grasses.

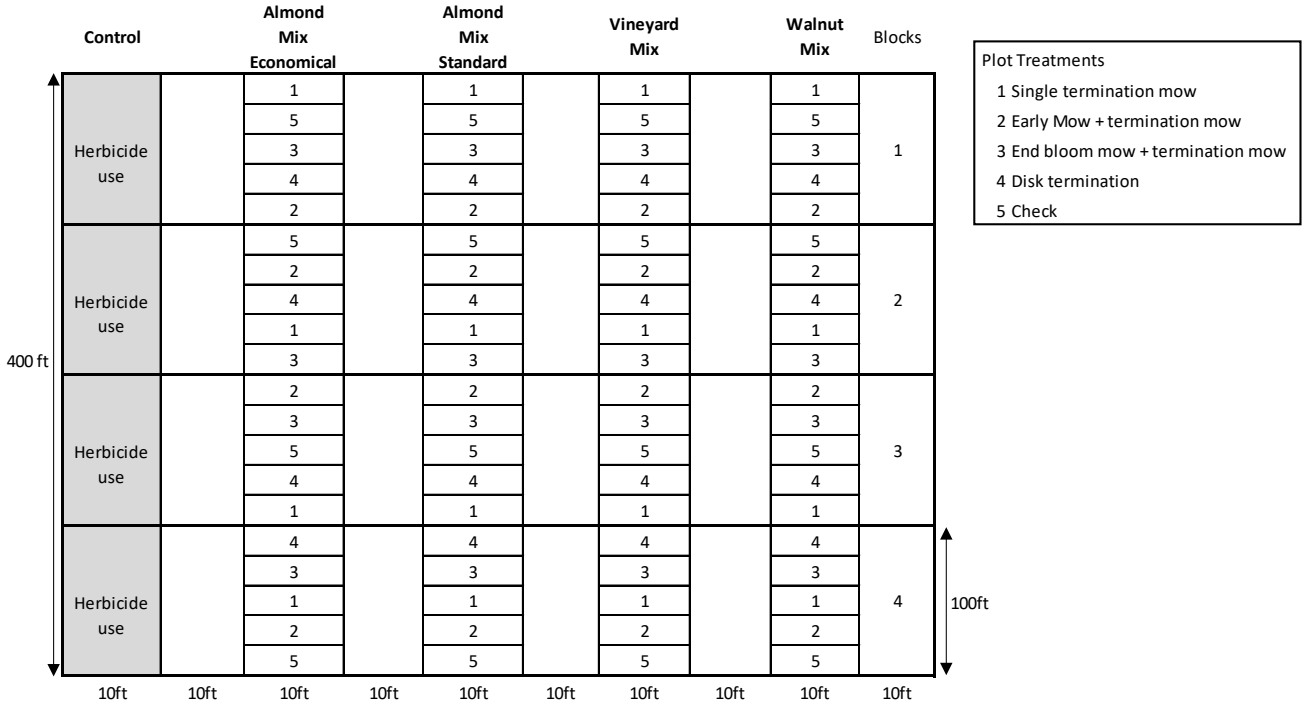

Figure 2. Plot map of insectary cover crop mix trial at the Lockeford CAPMC.

Table 2. Timing of management treatments on the insectary cover crop mixes trial at the CAPMC.

Treatments	Insectary Cover Crop Mix Treatment Timing				
Managemend and Termination Methods	**Almond Mix Standard**	**Almond Mix Economical**	**Vineyard Mix**	**Walnut Mix**	**Control (Bare ground)***
Single Termination Mow *(prior to crop harvest)*	mid-July	mid-July	early August	early August	Herbicide
Early Mow + Termination Mow *(reduce frost potential and prior to crop harvest)*	mid-February + mid-July	mid-February + mid-July	late March + early August	late March + early August	Herbicide
End Bloom Mow + Termination Mow *(after cover crop bloom and prior to crop harvest)*	mid-June + mid-July	mid-June + mid-July	mid-June + early August	mid-June + early August	Herbicide
Disc Termination *(prior to crop harvest)*	mid-July	mid-July	early August	early August	Herbicide
Check *(same as Single Termination Mow)*	mid-July	mid-July	early August	early August	Herbicide

*Herbicide applied as needed

Line-point intercept transects were collected every year in February (2018 to 2020) at random locations within each block (50 ft. pretreatment) or plot (20 ft. post treatment) to evaluate mix

composition and ground cover. The transect points were grouped into six categories: seeded forbs, seeded legumes, seeded mix total (seeded forbs plus seeded legumes), weeds, bare ground, or organic matter. 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. Photographs were also taken monthly from established points in each plot to monitor changes in species composition and bloom. Air temperature data was collected annually with temperature sensors mounted at 36 inches in the end bloom mow plus termination mow treatment (3) of the vineyard and two almond mixes as well as the control, to monitor frost potential. Soil health evaluations were based on the NRCS Soil Health Assessment Worksheet and were collected in fall 2019. Evaluations included compaction, structure, aggregate stability, roots and pores, earthworms and other biological activity.

Statistical analysis was completed on all three years of trial evaluations using Statistix 10 (Analytical Software, Tallahassee, FL). Analysis was done 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

Baseline evaluations

Baseline species composition data was collected from all four mixes in early February 2018 using 50 ft. line-point intercept transects within each block to evaluate mix establishment prior to management treatments. Data points were characterized as seeded forbs, seeded legumes, or noted as bare ground or weeds. Seeded mix totals included both seeded forbs and seeded legumes. Average plant height was also collected at this time.

Baseline ground cover data shows that the establishment of the standard commercial almond mix was 23% seeded species (all forbs) and 59% weeds in February 2018 (Table 3, Figure 3), while the economical almond mix was 45% seeded species (40% forbs and 5% legumes) and 50% weeds (Figure 4). The vineyard mix also had much lower establishment of seeded species with 27% seeded species (all forbs) and 61% weeds (Figure 5), while the walnut mix had the best establishment with 76% of the ground cover composed of seeded species (59% forbs and 17% legumes) and only 17% weeds (Figure 6). The walnut mix was also the tallest mix on average at 35 inches due to the bell beans in the mix, while the standard almond mix was the shortest in height at 16 inches. The economical almond mix and the vineyard mix fell in between at 20 inches and 26 inches, respectively.

The poor overall establishment of the seeded species is likely related to the use of broadcast seeding versus direct drilling for trial installation. Seeding rate was below NRCS recommended threshold of 50 seeds per square foot (pure live seed) for a broadcast seeding. There was also strong weed competition. Broadcasting was the only option in this study, due to requirements for seed drill calibration. The establishment results also show that the mixes with a higher percentage of non-native cover crop species and legumes (both the economical almond and walnut mixes) had much better initial establishment. The high initial establishment in these mixes also provided weed competition, in contrast to the mixes that were only composed of forbs (standard almond mix and the vineyard mix).

Table 3. Baseline ground cover percentages of four insectary cover crop mixes in February 2018 at the CAPMC.

February 2018 Evaluation (pretreatment)								
Mix Name	Seeded (lb/ac)	No. Seeds/sq. foot	DAP	Seeded Mix Total (%)[§]	Seeded Forbs (%)[§]	Seeded Legumes (%)[§]	Bare Ground (%)[§]	Weeds (%)[§]
Standard Almond Mix	4	30	97	23.0	23.0	0.0	18.0	59.0
Economical Almond Mix	2	35	97	45.0	40.0	5.0	5.0	50.0
Vineyard Mix	11	35	97	26.5	26.5	0.0	12.5	61.0
Walnut Mix	67	30	97	76.5	59.0	17.5	7.0	16.5
Mean				42.8	37.1	5.6	10.6	46.6
SD[#]				24.7	18.1	8.2	13.6	21.3

[#]Standard deviation

[§]Ground Cover (derived from transects) rated as a visual estimate by transectof the percentage of ground covered by the seeded mix, weeds, or bare ground.

Seeded mixes are the sum of seeded forbs and seeded legumes.

No. = number, sq. = square, lb/ac = pounds/acre; DAP = Days After Planting

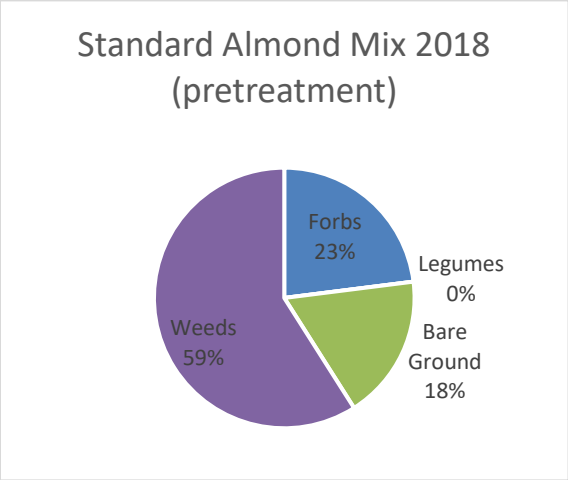

Figure 3. Baseline percent ground cover in standard almond mix collected in February2018.

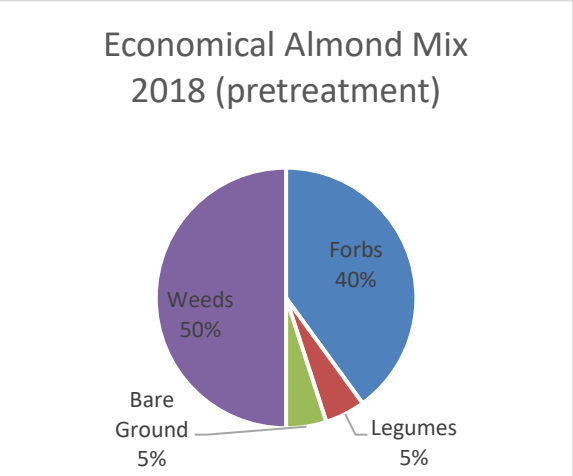

Figure 4. Baseline percent ground cover in economical almond mix collected in February 2018.

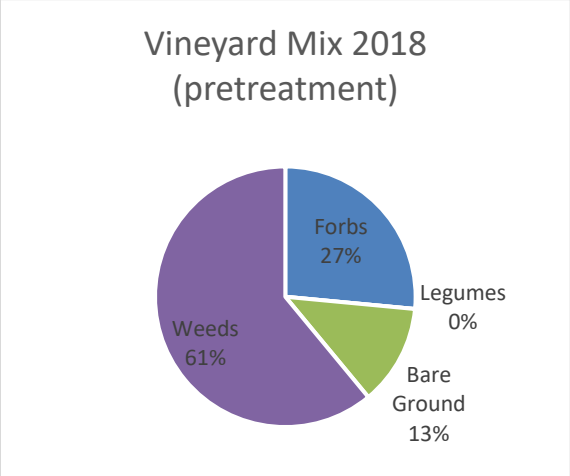

Figure 5. Baseline percent ground cover in vineyard mix collected in February 2018.

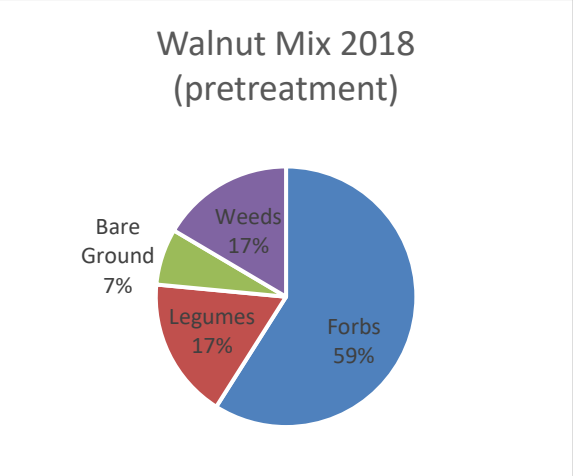

Figure 6. Baseline percent ground cover in walnut mix collected in February2018.

Standard Almond Mix

In the standard almond mix block, observations after the first year of treatments (February 2019), showed similar percentages of seeded forb ground cover across treatments, the majority of which were California poppies (Table 4). The average plant height was 6 inches tall across all treatments. The percentage of bare ground was much higher in the disked plots (30%) and included some volunteer legumes (4%) versus low bare ground percentage in the mowed plots (1%) with no volunteer legumes (Figures 7 and 8). Weeds showed higher ground cover percentage in the mowed plots (68%) versus the disked plot treatments (44%). The disking treatment likely brought up legume seed that germinated with the winter rains, while the mowing treatments favored the weed seed already present in the soil surface. In July 2019, California poppies were the only planted species observed in the plots.

Table 4. Standard almond mix ground cover percentages by management treatments in February 2019 at the CAPMC.

Standard Almond Mix - February 2019 Evaluation				
Management Type	Seeded Mix/ Seeded Forbs (%)[§]	Legumes (%)[§]	Bare Ground (%)[§]	Weeds (%)[§]
Mow[¥]	31.5	0.0	1.0	67.5
Disk Termination[£]	22.5	3.8	30.0	43.8
Mean	27.0	1.9	15.5	55.6
SD[#]	6.3	5.3	16.2	16.8

[#]Standard deviation

[¥]Mow = 1 pass with flail mower (2/14/18; 3/28/18; 7/9/18).

[£]Disk termination = 6 passes with a disk (7/11/2018).

[§]Ground Cover (derived from transects) rated as a visual estimate of the percentage of ground covered by the planted mix, weeds, or bareground from transects.

Seeded mix is made up of only forbs.

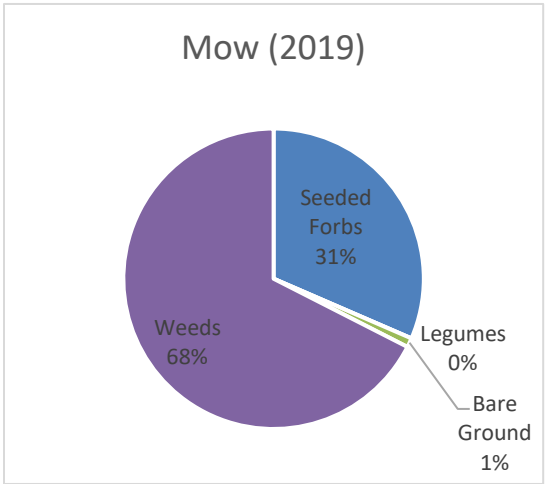

Figure 7. Percent ground cover in standard almond mix mowed treatment plots collected in February 2019.

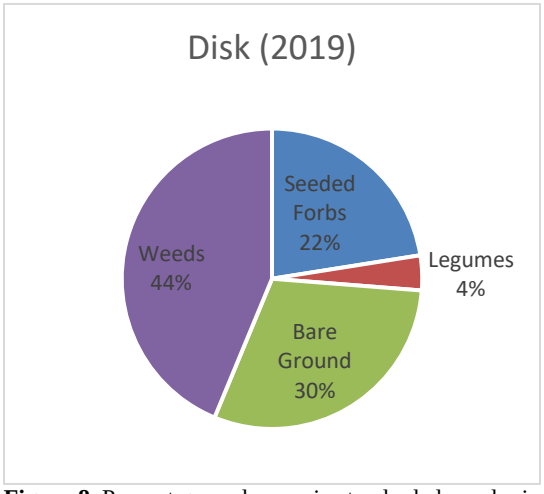

Figure 8. Percent ground cover in standard almond mix disked treatment plots collected in February 2019.

During the final year of treatment (February 2020), seeded forbs had similar ground cover percentages across treatments (18-27%), with the disk termination treatment having the highest percentage (27%) and the end of bloom mow plus termination mow treatment having the lowest (18%) (Table 5). The only planted forb species that persisted in the final year were California poppies. The disk termination treatment also showed a higher percentage of bare ground (5%) and legume ground cover (9%) and had the lowest organic matter cover on the surface (1%) compared to any of the mow treatments (Figure 12). The percentage of ground cover by weeds was the highest in the end of bloom mow plus termination mow plots (75%), but very similar across other treatments (59%) (Figure 11).

The results after three years of ground cover evaluations indicate that the species present in this mix will decline over time, no matter what management type is used. The maximum percentage of seeded species after three years was 28% and all were California poppies. These results also indicate that an early mow at almond bloom, will not drastically reduce the number of planted forb species present. However, a late mow after the cover crop mix has bloomed will favor a higher percentage of weeds by allowing them to reseed.

Table 5. Standard almond mix ground cover percentages by four management treatments in February 2020 at the CAPMC.

Standard Almond Mix - February 2020 Evaluation							
Management Type	Treatment Date(s) 2018	Treatment Date(s) 2019	Seeded Mix/ Seeded Forbs (%)[§]	Legumes (%)[§]	Bare Ground (%)[§]	Weeds (%)[§]	Organic Matter (%)[§]
Single Termination Mow[¥]	7/9/2018	7/16/2019	25.0	0.6	1.9	59.4	13.1
Early Mow[ᶜ] + Termination Mow[¥]	2/14/18; 7/9/2018	2/21/19; 7/16/19	26.3	0.0	2.5	58.8	12.5
End Bloom Mow[ᶜ] + Termination Mow[¥]	6/18/18; 7/9/2018	6/17/19; 7/16/19	17.5	0.0	1.3	75.0	6.3
Disk Termination[£]	7/11/2018	7/18/2019	27.5	8.8	5.0	57.5	1.3
Mean			24.3	2.0	2.5	62.0	9.3
SD[#]			13.0	4.7	4.4	15.8	8.8

[#]Standard deviation

[ᶜ]Early & End Bloom Mow = 1 pass with flail mower.

[¥]Termination mow = 2 passes with flail mower.

[£]Disk termination = 6 passes with a disk.

[§]Ground Cover (derived from transects) rated as a visual estimate of the percentage of ground covered by the planted mix, weeds, or bare ground.

Seeded mix is made up of only forbs.

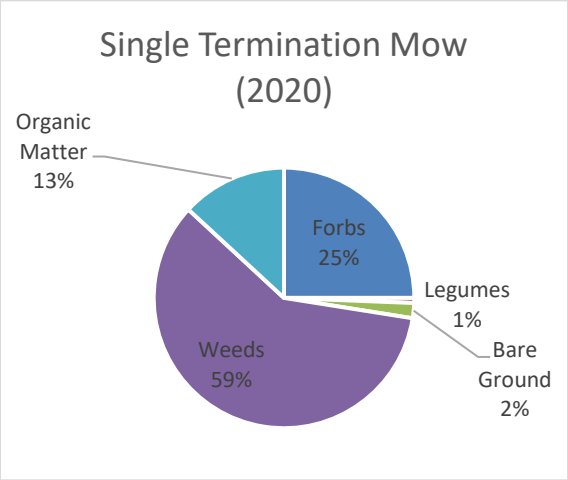

Figure 9. Percent ground cover in standard almond mix single terminations mow treatment plots collected in February2020.

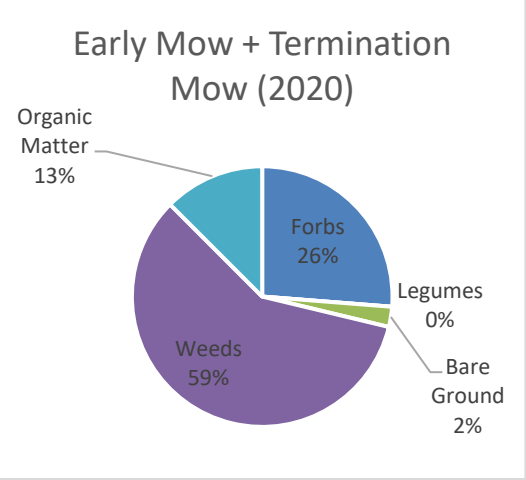

Figure 10. Percent ground cover in standard almond mix early mow plus terminations mow treatment plots collected in February 2020.

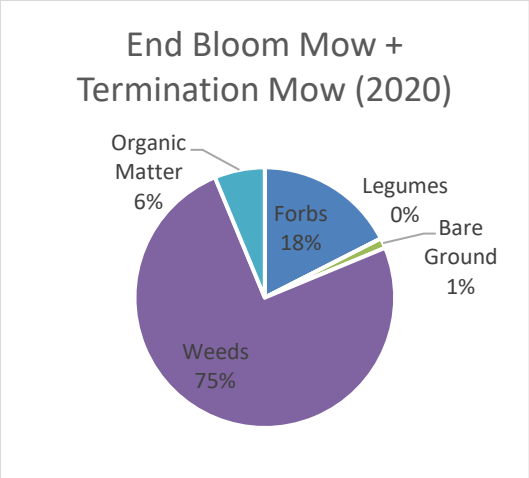

Figure 11. Percent ground cover in standard almond mix end of bloom mow plus terminations mow treatment plots collected in February 2020.

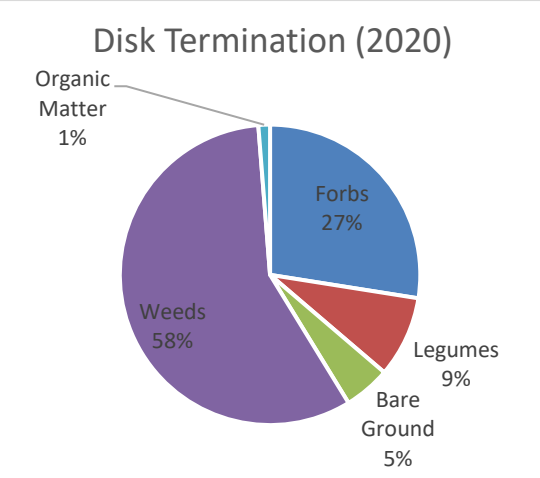

Figure 12. Percent ground cover in standard almond mix disk termination treatment plots collected in February 2020.

Figure 13. Standard almond mix block (top) and close up (bottom) photos March 2018 (left) and April 2019 (right). In 2018, the plants expressed include California poppy and baby blue eyes, as well as weedy grasses and shepherd's purse. In 2019, the ground cover was made up of annual grasses and California poppy.

Economical Almond Mix

In the economical almond mix block, the first year after treatment (2019) resulted in similar ground cover of total seeded species between mow (71%) and disked (85%) treatments (Table 6). After one year, the planted forb species present in February across both mow and disked treatments included California poppy, Chinese houses, flax, white mustard and tillage radish while planted legumes included common vetch and crimson clover. The average height of the cover crop mix was about 17 inches across all treatments. Disked treatments had a slightly higher percentage of legumes (66%) and bare ground (6%) compared to mowed plots (54% legumes, 1% bare ground) (Figure 14 and 15). However, a higher percentage of ground cover in the mowed treatments was made up of weeds (27%) when compared to the disked plots (9%). Disking appears to favor the legume cover crop seed by placing it deeper in the soil. This allows the cover crop to compete better and buries the weed seed, unlike the mowed treatments. In July 2019, California poppies were the only planted species observed in the plots.

Table 6. Economical almond mix ground cover percentages by two management treatments in February 2019 at the CAPMC.

Economical Almond Mix - February 2019 Evaluation						
Management Type	Seeded Mix Total (%)[§]	Seeded Forbs (%)[§]	Seeded Legumes (%)[§]	Bare Ground (%)[§]	Weeds (%)[§]	Organic Matter (%)[§]
Mow[¥]	71.0	17.0	54.0	1.5 b*	27.0	0.5
Disk Termination[£]	85.0	18.8	66.3	6.3 a	8.8	0.0
Mean	78.0	17.9	60.1	3.9	17.9	0.3
SD[#]	19.8	22.7	31.5	3.1	20.2	0.7

[#]Standard deviation

*Means in columns followed by the same letters are not significantly different at $P<0.05$.

[¥]Mow = 1 pass with flail mower (2/14/18; 7/9/18) .

[£]Disk termination = 6 passes with a disk (7/11/2018).

[§]Ground Cover (derived from transects) rated as a visual estimate of the percentage of ground covered by the seeded mix, weeds, or bare ground.

Seeded mixes are the sum of seeded forbs and seeded legumes.

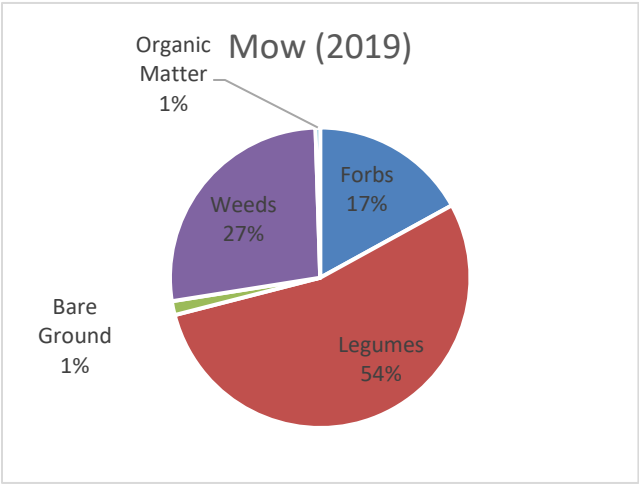

Figure 14. Percent ground cover in economical almond mix mowed treatment plots collected in February 2019.

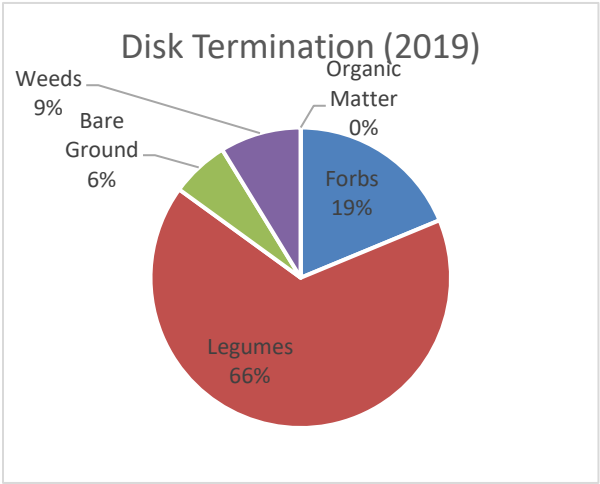

Figure 15. Percent ground cover in economical almond mix disked treatment plots collected in February 2019.

In the final year, significant differences (P<0.05) were seen across treatments in the percentage of ground covered by total seeded species and weeds in the economical almond mix (Table 7). Seeded species present during the February 2020 evaluation included California poppies, white mustard, crimson clover and common vetch. The disking treatment had a significantly higher number of total seeded species (53%) than both the single termination mow treatment (21%) and the end of bloom mow + termination mow treatment (15%). The disking treatment also had significantly fewer weeds covering the ground (44%) compared to the single termination mow treatment (73%) and the end of bloom mow + termination mow treatment (80%). Surprisingly, the highest percentage of seeded forbs and legumes were found in the disk treatment (Figure 19), while the highest percentage of bare ground and weeds were seen in the end of bloom mow + termination mow treatment (Figure 18). Finally, the early mow + termination mow treatment had the highest percentage of organic matter on the surface (Figure 17).

After evaluating the economical cover crop mix for three years, the results indicate that the disking treatment favors cover crop species (especially legume species), likely due to the seed placement and better seed to soil contact. The early mow + termination mow treatment also had a high number of seeded species. These results also indicate that an early mow at almond bloom for frost protection or disking later in the season can actually help maintain a higher number of seeded species. However, a late mow can increase the percentage of weeds that go to seed and can favor a higher weed population during the following years.

Table 7. Economical almond mix ground cover percentages by four management treatments in February 2020 at the CAPMC.

Economical Almond Mix - February 2020 Evaluation

Management Type	Treatment Date(s) 2018	Treatment Date(s) 2019	Seeded Mix Total (%)[§]	Seeded Forbs (%)[§]	Seeded Legumes (%)[§]	Bare Ground (%)[§]	Weeds (%)[§]	Organic Matter (%)[§]
Single Termination Mow[¥]	7/9/2018	7/16/2019	21.3 b*	15.6	5.6	1.9	73.1 a	3.8
Early Mow[c] + Termination Mow[¥]	2/14/18; 7/9/2018	2/21/19; 7/16/19	28.8 ab	22.5	6.3	2.5	61.3 ab	7.5
End Bloom Mow[c] + Termination Mow[¥]	6/18/18; 7/9/2018	6/17/19; 7/16/19	15.0 b	5.0	10.0	5.0	80.0 a	0.0
Disk Termination[£]	7/11/2018	7/18/2019	52.5 a	28.8	23.8	1.3	43.8 b	2.5
Mean			27.8	17.5	10.3	2.5	66.3	3.5
SD[#]			17.7	15.3	12.3	3.4	18.4	6.3

[#]Standard deviation

*Means in columns followed by the same letters are not significantly different at P <0.05.

[c]Early & End Bloom Mow = 1 pass with flail mower.

[¥]Termination mow = 2 passes with flail mower.

[£]Disk termination = 6 passes with a disk.

[§]Ground Cover (derived from transects) rated as a visual estimate of the percentage of ground covered by the seeded mix, weeds, or bare ground.

Seeded mixes are the sum of seeded forbs and seeded legumes.

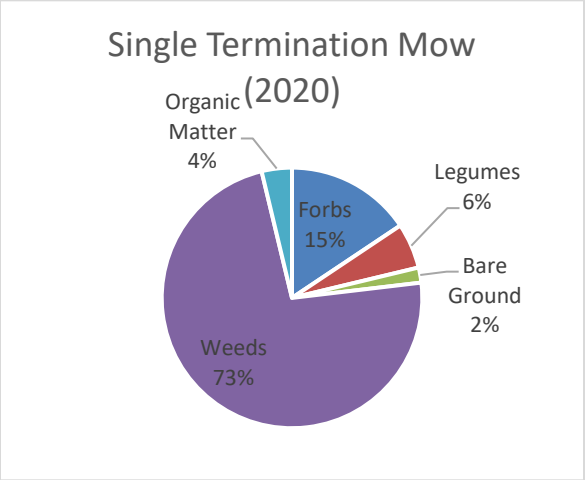

Figure 16. Percent ground cover in economical almond mix single terminations mow treatment plots collected in February 2020.

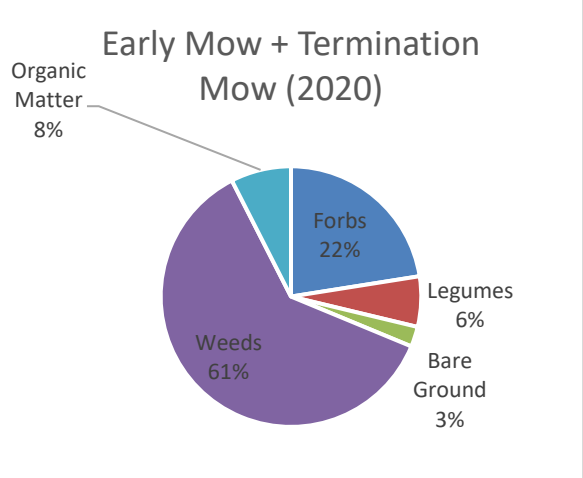

Figure 17. Percent ground cover in economical almond mix early mow plus terminations mow treatment plots collected in February 2020.

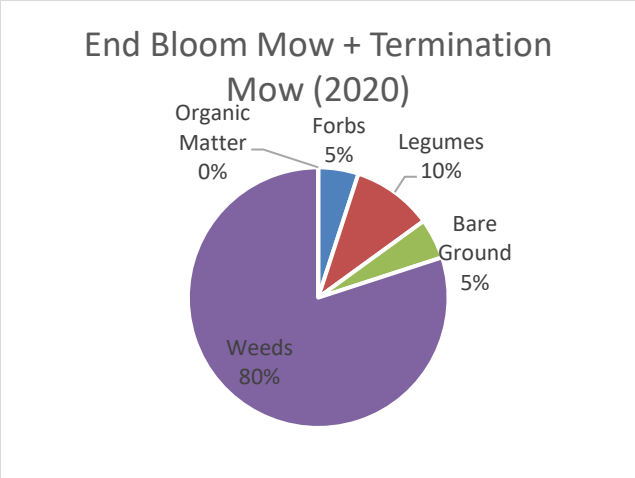

Figure 18. Percent ground cover in economical almond mix end of bloom mow plus terminations mow treatment plots collected in February 2020.

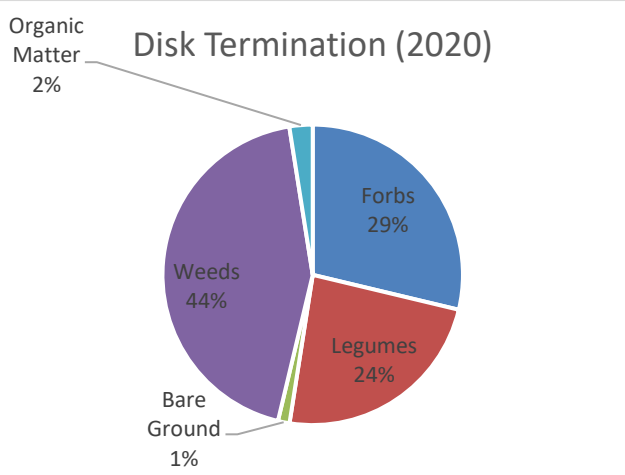

Figure 19. Percent ground cover in economical almond mix disk termination treatment plots collected in February2020.

Figure 20. Economical almond mix block (top) and close up (bottom) photos March 2018 (left) and April 2019 (right). In 2018, the plants expressed include baby blue eyes, flax, radish, mustard and clover, as well as a few weedy grasses and shepherd's purse. In 2019, the ground cover was made up of radish, mustard, vetch, annual grasses and California poppy.

Vineyard Mix

In the vineyard mix block, observations after the first year of treatments (February 2019), showed the same ground cover percentage of seeded forbs across both mow and disking treatments (32-34%) (Table 8). The planted forbs observed included baby blue eyes, California poppy, English marigold, flax, yarrow and tillage radish. The average height of the mix was 10 inches tall across all treatments. The percentage of bare ground was higher in the disked plots (8%) than in the mowed plots (1%) (Figures 21 and 22). Weeds were also similar between mowed (63%) and disked plots (58%) with over 50% as ground cover. In July 2019, seeded species observed in the plots included birdsfoot trefoil, California brome, California poppy, English marigold, gumplant, yarrow and tillage radish.

Table 8. Vineyard mix ground cover percentage by two management treatments in February 2019 at the CAPMC.

Vineyard Mix - February 2019 Evaluation				
Management Type	Seeded Mix/ Seeded Forbs (%)[§]	Bare Ground (%)[§]	Weeds (%)[§]	Organic Matter (%)[§]
Mow[¥]	34.5	1.0	63.0	1.5
Disk Termination[£]	32.5	10.0	57.5	0.0
Mean	33.5	5.5	60.3	0.8
SD[#]	4.2	5.7	5.4	2.1

[#]Standard deviation

*Means in columns followed by the same letters are not significantly different at $P<0.05$.

[¥]Mow = 1 pass with flail mower (3/26/18; 8/1/18) .

[£]Disk termination = 6 passes with a disk (8/3/2018).

[§]Ground Cover (derived from transects) rated as a visual estimate of the percentage of ground covered by the seeded mix, weeds, or bare ground.

Seeded mix is made up of only seeded forbs.

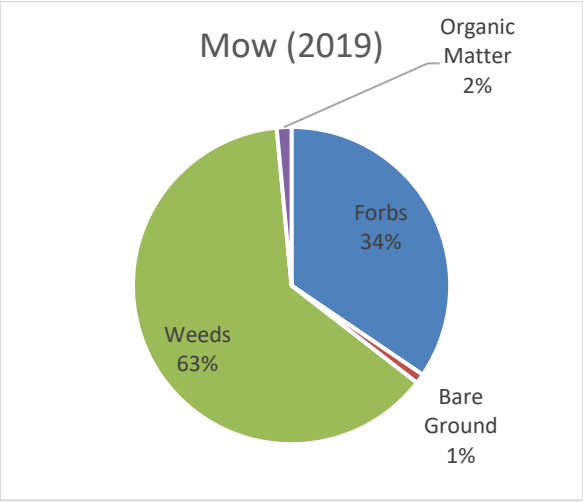

Figure 21. Percent ground cover in vineyard mix mow treatment plots collected in February 2019.

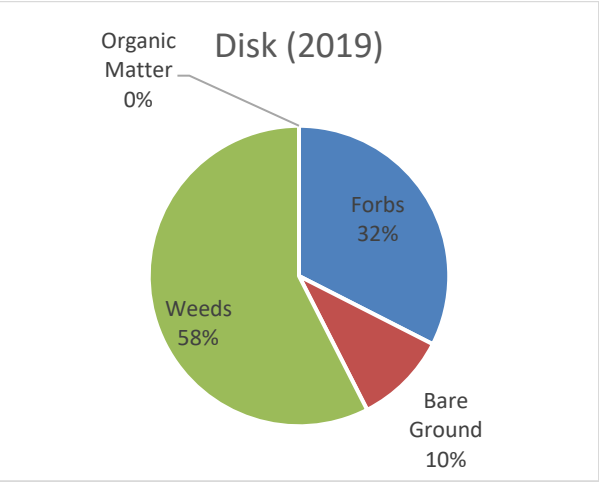

Figure 22. Percent ground cover in vineyard mix disked treatment plots collected in February 2019.

During the final year of treatment (February 2020), no significant differences were seen across

treatments (Table 9). Seeded species observed in the plots in early February included California poppy, English marigold and gumplant. Numerical trends in the data show that the early mow + termination mow had the highest percentage of seeded species (40%) and organic matter (9%) (Figure 24). Alternatively, the end bloom mow + termination mow had the lowest percentage of seeded species (17%) and the highest percentage of weeds (78%) (Figure 25). The disk treatment had the highest percentage of bare ground (5%) compared to any of the mow treatments (Figure 26).

Results after three years of evaluations indicate that the end bloom mow + termination mow is not a good management choice for this mix. An early mow + termination mow, single termination mow, or even disking will result in more seeded forbs and fewer weeds. These results also indicate that an early mow at bud break for frost protection, will not result in a reduced number of seeded forb species, compared to the other treatments. However, a late mow, after the cover crop mix has bloomed, can increase the percentage of weeds present by allowing them to repeatedly set seed and outcompete the seeded species in this forb mix.

Table 9. Vineyard mix ground cover percentage by four management treatments February 2020 at the CAPMC.

Vineyard Mix - February 2020 Evaluation						
Management Type	Treatment Date(s) 2018	Treatment Date(s) 2019	Seeded Mix/ Seeded Forbs (%)[§]	Bare Ground (%)[§]	Weeds (%)[§]	Organic Matter (%)[§]
Single Termination Mow[¥]	8/1/2018	7/31/2019	33.8	1.9	57.5	6.9
Early Mow[¢] + Termination Mow[¥]	3/26/2018; 8/1/18	3/29/19; 7/31/19	40.0	3.8	47.5	8.8
End Bloom Mow[¢] + Termination Mow[¥]	6/18/18; 8/1/2018	6/17/19; 7/31/19	17.5	2.5	77.7	2.5
Disk Termination[£]	8/3/2018	7/31/2019	27.5	5.0	65.0	2.5
Mean			30.5	3.0	61.0	5.5
SD[#]			16.1	3.8	18.0	7.1

[#]Standard deviation

[¢]Early & End Bloom Mow = 1 pass with flail mower.

[¥]Termination mow = 2 passes with flail mower.

[£]Disk termination = 6 passes with a disk.

[§]Ground Cover (derived from transects) rated as a visual estimate of the percentage of ground covered by the planted mix, weeds, or bare ground. Seeded mix is made up of only forbs.

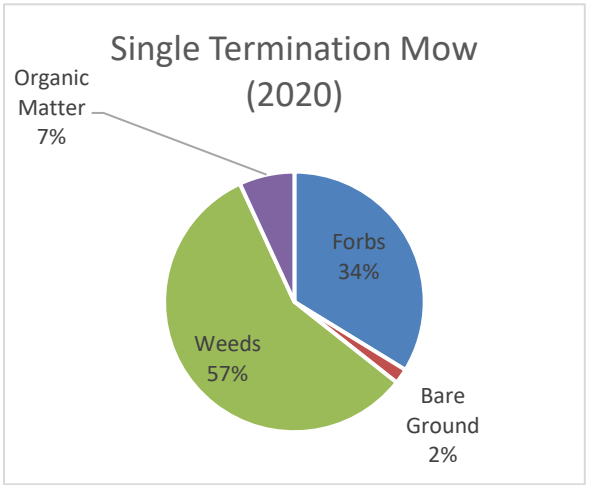

Figure 23. Percent ground cover in vineyard mix single terminations mow treatment plots collected in February 2020.

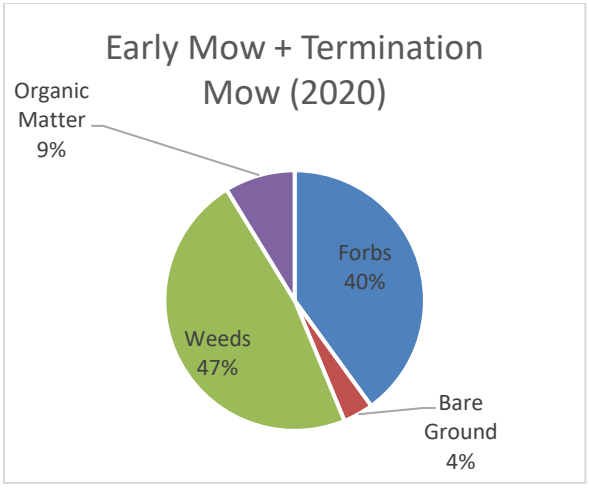

Figure 24. Percent ground cover in vineyard mix early mow plus terminations mow treatment plots collected in February 2020.

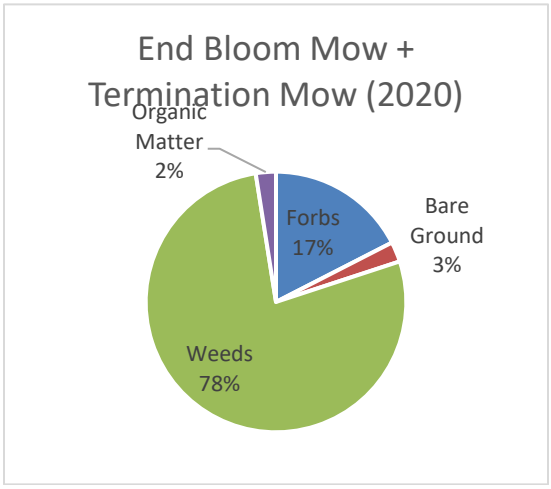

Figure 25. Percent ground cover in vineyard mix end of bloom mow plus terminations mow treatment plots collected in February 2020.

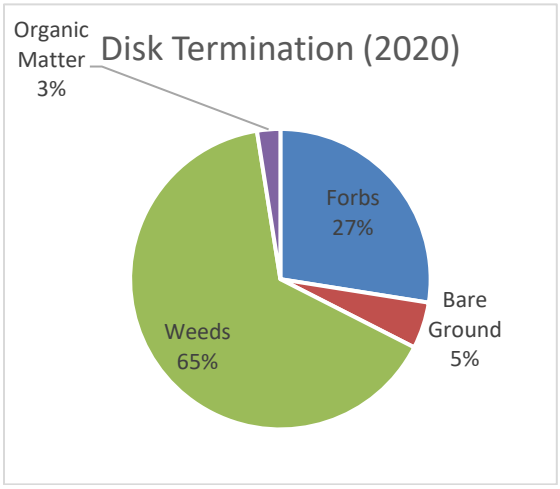

Figure 26. Percent ground cover in vineyard mix disk termination treatment plots collected in February 2020.

Figure 27. Vineyard mix block (top) and close up (bottom) photos March 2018 (left) and April 2019 (right). In 2018, the plants expressed include baby blue eyes, radish, flax, English marigold as well as shepherd's purse. In 2019, the ground cover was made up of annual grasses, California poppy and a few English marigold.

Walnut Mix

In the walnut mix block, first year evaluations resulted in similar ground cover of total seeded species between mowed (67%) and disked (70%) treatments (Table 10). Planted forb species present in February 2019 included California poppy, English marigold, and white mustard, while

planted legumes included common vetch, crimson clover, bell bean and field pea. The average height of the cover crop mix was about 7 inches across all treatments. Mowed treatments had a significantly higher percentage of forbs (12%) than disked plots (1%) (Figure 28 and 29). Disked treatments had a slightly higher percentage of ground cover as legumes (69%) and bare ground (5%) compared to mowed plots (54% legumes, 2% bare ground). Also, the percentages of weed ground cover were very similar between both mowed (29%) and disked (25%) treatments. In July 2019, California poppy and English marigold were the only planted species observed in the plots.

Table 10. Walnut mix ground cover percentages by two management treatments in February 2019 at the CAPMC.

Walnut Mix - Febuary 2019 Evaluation

Management Type	Seeded Mix Total (%)[§]	Seeded Forbs (%)[§]	Seeded Legumes (%)[§]	Bare Ground (%)[§]	Weeds (%)[§]	Organic Matter (%)[§]
Mow[¥]	67.0	12.5 a*	54.5	2.5	29.0	1.5
Disk Termination[£]	70.0	1.3 b	68.8	5.0	25.0	0.0
Mean	68.5	6.9	61.6	3.8	27.0	0.8
Std. dev[#]	18.0	8.3	22.6	5.2	13.6	2.1

[#]Standard deviation

*Means in columns followed by the same letters are not significantly different at $P<0.05$.

[¥]Mow = 1 pass with flail mower (3/26/18; 8/1/18) .

[£]Disk termination = 6 passes with a disk (8/3/2018).

[§]Ground Cover (derived from transects) rated as a visual estimate of the percentage of ground covered by the seeded mix, weeds, or bare ground.

Seeded mixes are the sum of seeded forbs and seeded legumes.

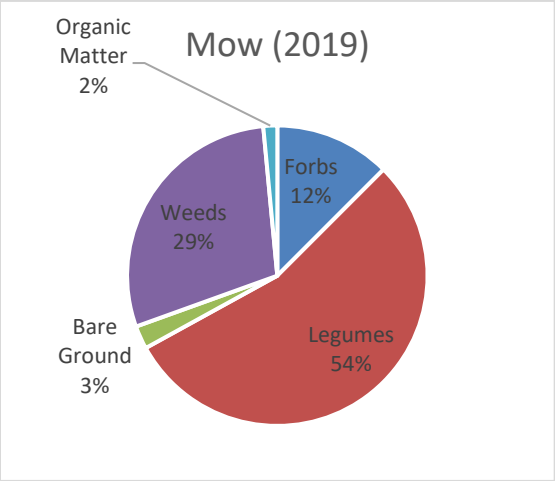

Figure 28. Percent ground cover in walnut mix mow treatment plots collected in February 2019.

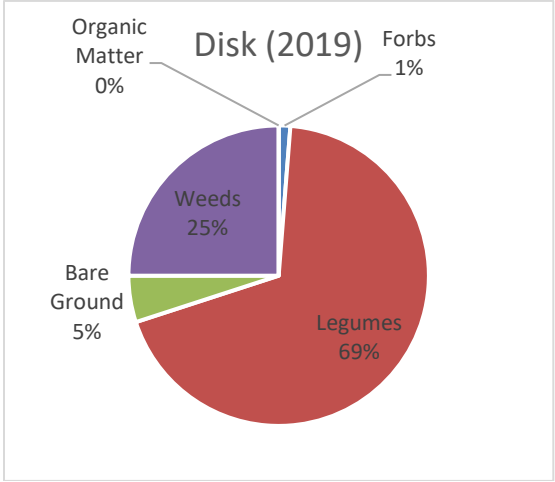

Figure 29. Percent ground cover in walnut mix diked treatment plots collected in February 2019.

The final year, significant differences ($P<0.05$) were seen across treatments in the percentage of ground covered by total seeded species (Table 11). Seeded species present during the February 2020 evaluation included California poppies, English marigold, white mustard, crimson clover, bell bean and common vetch. The disking treatment had a significantly higher number of total seeded species (53%) than the single termination mow treatment (18%) (Figures 30 and 33). The disking treatment

also had a higher percentage of legumes (35%) and bare ground (11%) compared to any of the mow treatments. The highest percentage of seeded forbs were found in the early mow + termination mow treatment (26%) (Figure 31), while the highest percentage of weeds were seen in the single termination mow treatment (73%) (Figure 30). The end bloom mow + termination mow also had a high percentage of weeds (68%) and surprisingly, the lowest percentage of forbs across treatments (9%) (Figure 32).

After three years of evaluating the walnut cover crop mix, results indicate that the disking treatment favors legume cover crop species (similar to the economic almond mix) and suppresses weeds. This is likely due to the seed placement and better seed to soil contact of the legumes, while burying the weed seed. The early mow + termination mow treatment also seemed to favor seeded forb species. However, a late mow, such as the end bloom mow + termination mow or the single termination mow can favor weed species and actually increase the percentage of weeds present. These results also indicate that the best management practices for encouraging reseeding of this mix would be an early mow or disking later in the season to maintain a higher number of planted species and suppress weeds.

Table 11. Walnut mix ground cover percentages by four management treatments in February 2020 at the CAPMC.

Walnut Mix - February 2020 Evaluation								
Management Type	Treatment Date(s) 2018	Treatment Date(s) 2019	Seeded Mix Total (%)[§]	Seeded Forbs (%)[§]	Seeded Legumes (%)[§]	Bare Ground (%)[§]	Weeds (%)[§]	Organic Matter (%)[§]
Single Termination Mow[¥]	8/1/2018	7/31/2019	18.1 b*	15.0	3.1	2.5	73.1	6.3
Early Mow[c] + Termination Mow[¥]	3/26/2018; 8/1/18	3/29/19; 7/31/19	37.5 ab	26.3	11.3	5.0	55.0	2.5
End Bloom Mow[c] + Termination Mow[¥]	6/18/18; 8/1/2018	6/17/19; 7/31/19	21.3 ab	8.8	12.5	5.0	67.5	6.3
Disk Termination[£]	8/3/2018	7/31/2019	52.5 a	17.5	35.0	11.3	36.3	0.0
Mean			29.5	16.5	13.0	5.3	61.0	4.3
SD[#]			21.9	16.6	17.8	6.6	24.3	7.3

[#]Standard deviation

*Means in columns followed by the same letters are not significantly different at $P<0.05$.

[c]Early & End Bloom Mow = 1 pass with flail mower.

[¥]Termination mow = 2 passes with flail mower.

[£]Disk termination= 6 passes with a disk.

[§]Ground Cover (derived from transects) rated as a visual estimate of the percentage of ground covered by the seeded mix, weeds, or bare ground.

Seeded mixes are the sum of seeded forbs and seeded legumes.

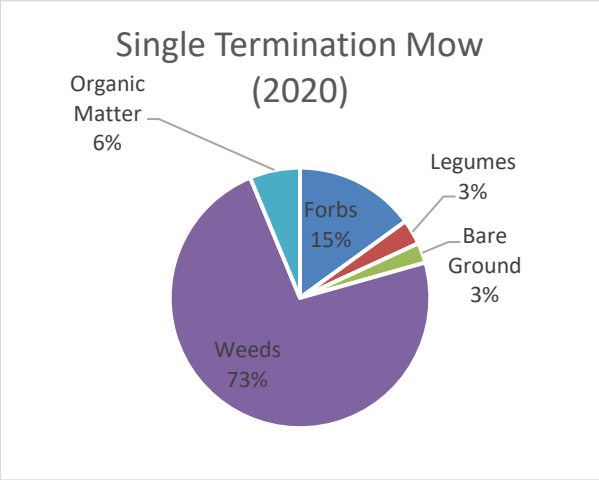

Figure 30. Percent ground cover in walnut mix single terminations mow treatment plots collected in February 2020.

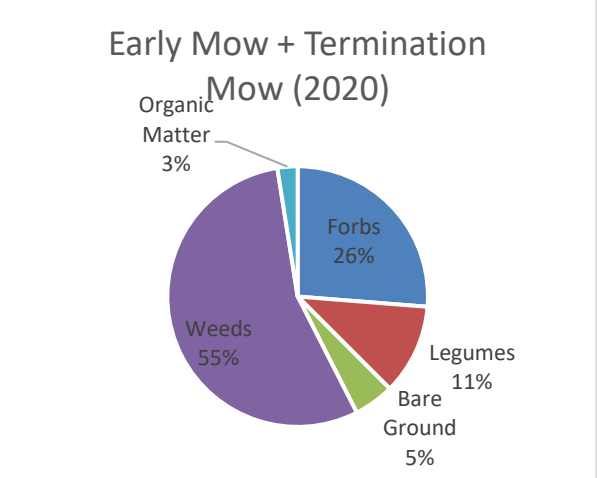

Figure 31. Percent ground cover in walnut mix early mow plus terminations mow treatment plots collected in February 2020.

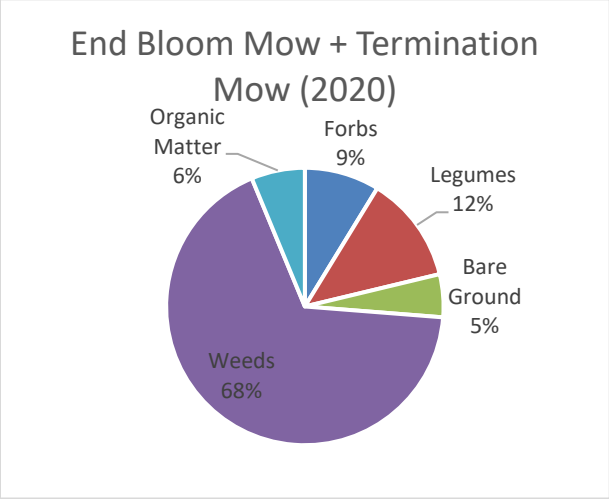

Figure 32. Percent ground cover in walnut mix end of bloom mow plus terminations mow treatment plots collected in February 2020.

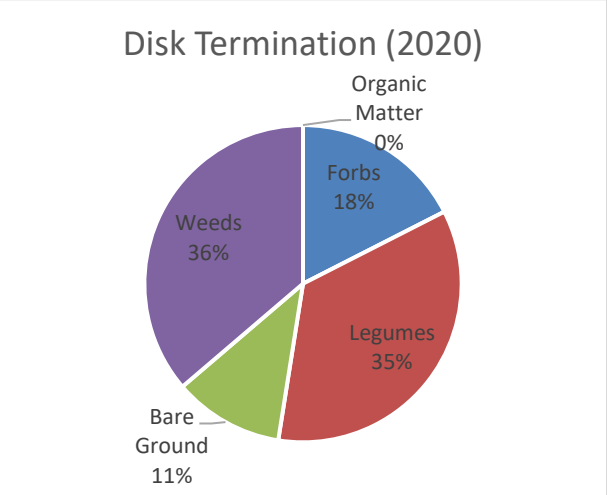

Figure 33. Percent ground cover in walnut mix disk termination treatment plots collected in February 2020.

Figure 34. Walnut mix block (top) and close up (bottom) photos March 2018 (left) and April 2019 (right). In 2018, the plants expressed included mustard, radish, flax, bell bean and vetch. In 2019, the ground cover was made up of bell bean, weedy annual grasses and California poppy.

Air Temperature

To monitor frost potential, air temperature sensors were placed in the end bloom mow plus termination mow treatment of the vineyard and two almond mixes, as well as in the control block. The number of frost days was determined as days where the air temperature dropped to 32°F degrees or below after February 15th for the almond mixes (coinciding with almond bloom) and after March 20th (bud break in the Lodi area) for the vineyard mix. Results show that the number of frost days are more dependent on year to year variation, rather than mix type or management (Table 12). The almond mixes had two to three more frost days than the control in 2018, and the vineyard mix only had one more frost day than the control at the 3-foot height. Unfortunately, the control block temperature sensor malfunctioned during 2019 and the data was lost for that year.

Table 12. Number of frost days in 2018 and 2019 at the CAPMC.

No. of Days Air Temp ≤32° after bloom/budbreak*	Almond Mix Standard[#]	Almond Mix Economical[#]	Vineyard Mix[#]	Control (Bare ground)[¥]
2018	28	29	8	26/7
2019	12	15	2	N/A

*Non replicated. Collected from end of bloom mow plus termination mow treatment.

[#]Assume almond bloom was February 15th and vine budbreak was March 20th.

[¥]Control is almond bloom/vine budbreak dates.

CONCLUSION

Different management treatments had clear effects on the species of plants present in the four insectary cover crop mixes evaluated over the three years of this trial. The forb species in the standard almond mix declined over time, no matter what the management. However, a late mow after the cover crop mix has bloomed, allowed weeds to reseed causing the forbs in the mix to get outcompeted quickly. An early mow + termination mow or single termination mow for the vineyard mix, maintained higher populations of seeded forbs and fewer weeds. In the economic almond and walnut cover crop mixes , disking seemed to favor and increase percentages of planted legume species likely due to seed placement and better seed to soil contact, while the early mow + termination treatment encouraged higher percentages of the forbs. Across all four mixes, the end bloom mow + termination treatments had the highest weed incidence and encouraged weeds to reseed over three years of evaluations. Overall, maintaining desirable species year after year is a challenge due to weed competition. The maximum percentage of seeded species present after 3 years was only about 50% in the economic almond and walnut mixes, 40% in the vineyard mix and less than 30% in the standard almond mix, showing that over time the planted species will decline and become outcompeted by weeds. Re-establishment of cover crop species may be required more frequently than previously thought in order to maintain higher populations of desirable species for attracting beneficial insects.

LITERATURE CITED

Blaauw, B. R., and R. Isaacs. 2014. Flower Plantings Increase Wild Bee Abundance and the Pollination Services Provided to a Pollination-Dependent Crop. J. Appl. Ecol. 51: 890–898.

Carvalheiro, L. G., R. Veldtman, A. G. Shenkute, G. B. Tesfay, C.W.W. Pirk, J. S. Donaldson, and S. W. Nicolson, 2011. Natural and Within-Farmland Biodiversity Enhances Crop Productivity. Ecology Letters. 14: 251–259.

Clark, A., 2007. Managing Cover Crops Profitably, Third Edition. Sustainable Agriculture Research and Education (SARE) program handbook series, book 9. College Park, MD.

DeVincentis, A.J., S. Sandoval, E.M. Bruno, A. Leavitt, A. Gomes, S. Rice and D. Zaccaria. 2020. Using cost benefit analysis to understand adoption of winter cover cropping in California's specialty crop systems. Journal of Environmental Management 261: https://doi.org/10.1016/j.jenvman.2020.110205. Accessed12/3/2020

Fiedler, A.K., D. A. Landis, S.D. Wratten. 2008. Maximizing ecosystem services from conservation biological control: The role of habitat management. Biological Control 45:254–271.

Garibaldi, L. A., L. G. Carvalheiro, S. D. Leonhardt, M. A. Aizen, B. R. Blaauw, R. Isaacs, M. Kuhlmann, D. Kleijn, A. M. Klein, C. Kremen, et al, 2014. From Research to Action: Enhancing Crop Yield through Wild Pollinators. Frontiers in Ecology and the Environment. 12: 439–447.

Ingels, C.A., R. L., Bugg, G. T. McGouty and L. P. Christensen, 2002. Cover Cropping in Vineyards: A Growers Handbook. University of California, Agriculture and Natural Resources.

Kay Cruz, J., M. Vaughan, and K. Bolte, 2019. Insectary Cover Cropping in California: Specifications and Technical Guidance. The Xerces Society for Invertebrate Conservation. https://www.xerces.org/publications/guidelines/insectary-cover-cropping-in-california. Accessed 2/23/2021.

Klein, A. M., C. Brittain, S. D. Hendrix, R. Thorp, N. M. Williams, and C. Kremen, 2012. Wild Pollination Services to California Almond Rely on Seminatural Habitat. J. of Appl. Ecol. 49: 723–732.

Lindow, S.E. 1983. The role of bacterial ice nucleation in frost injury to plants. Ann, Rev Plant Phytopathology.21:363-384.

Liu, A., Ma, B.L., Bomke, A.A., 2005. Effects of cover crops on soil aggregate stability, total organic carbon, and polysaccharides. Soil Sci. Soc. Am. J. 69, 2041–2048.

Magdoff, F., Van Es, H., Network, S.A., 2000. Building Soils for Better Crops, 2nd ed. Sustainable Agriculture Network, University of California.

M'Gonigle, L. K., L. C. Ponisio, K. Cutler, and C. Kremen, 2015. Habitat Restoration Promotes Pollinator Persistence and Colonization in Intensively Managed Agriculture. Ecological Applications. 25: 1557-1565.

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.

Mitchell, J.P., A. Shrestha, & S. Irmak. 2015. Trade-offs between winter cover crop production and soil water depletion in the San Joaquin Valley, California. Soil and Water Conservation. 70(6):430-440.

Morandin, L. A., R. F. Long, and C. Kremen, 2016. Pest Control and Pollination Cost–Benefit Analysis of Hedgerow Restoration in a Simplified Agricultural Landscape. J. Economic Entomology, 109(3):1020-1027. DOI: 10.1093/jee/tow086.

Soil Health Institute, 2019. Progress Report: Adoption of Soil Health Systems Based on Data from the 2017 U.S. Census of Agriculture. https://soilhealthinstitute.org/wp-content/uploads/2019/07/Soil-Health-Census-Report.pdf. Accessed December 4, 2020.

USDA NASS. 2016. State Agriculture review, California. https://www.nass.usda.gov/Quick_Stats/Ag_Overview/stateOverview.php?state=CALIFORNIA (Accessed 8/10/2017).

or contact USDA through the Federal Relay Service at (800) 877-8339. Additionally, program information may be made available in languages other than English.

To file a program discrimination complaint, complete the USDA Program Discrimination Complaint Form, AD-3027, found online at How to File a Program Discrimination Complaint and at any USDA office or write a letter addressed to USDA and provide in the letter all of the information requested in the form. To request a copy of the complaint form, call (866) 632-9992. Submit your completed form or letter to USDA by: (1) mail: U.S. Department of Agriculture, Office of the Assistant Secretary for Civil Rights, 1400 Independence Avenue, SW, Washington, D.C. 20250-9410; (2) fax: (202) 690-7442; or (3) email: program.intake@usda.gov.

USDA is an equal opportunity provider, employer, and lender.