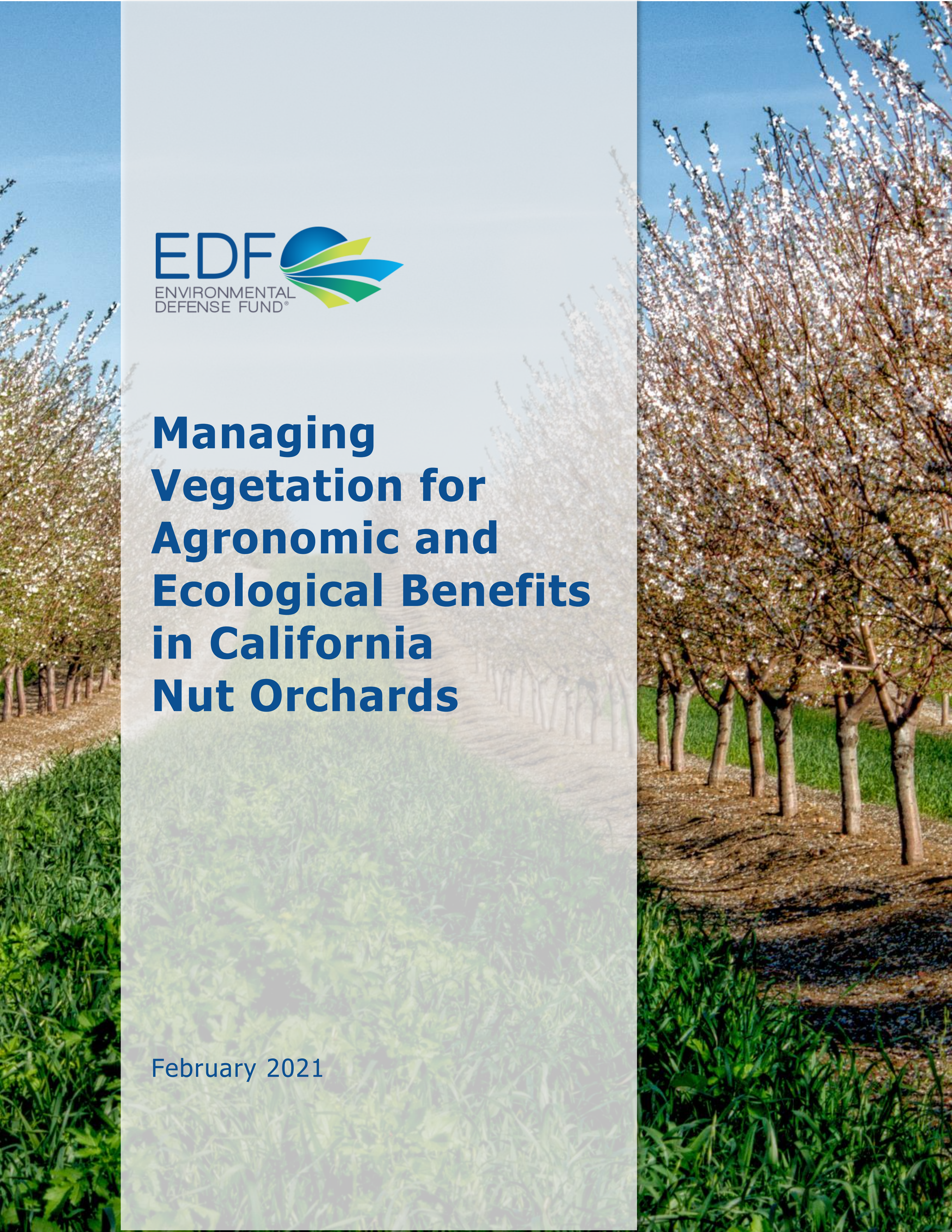

Managing Vegetation for Agronomic and Ecological Benefits in California Nut Orchards

February 2021

Acknowledgements

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INTRODUCTION

Permanent crops, like vineyards and orchards, are the fastest growing category of agricultural production in California's Central Valley, totaling over 3 million acres (USDA, 2019). Tree nuts alone — including almonds, pistachios and walnuts — account for over $9 billion in production value (CDFA, 2019). It is standard orchard practice to rely on intensive nutrient inputs and chemical pest management to ensure crop success, even though these practices significantly degrade the environment, impact human health, and reduce biodiversity and available habitat for native insects and pollinators.

EDF and partners in the agricultural industry recognize the need for a more resilient agricultural system in the Central Valley — one that is both profitable and sustainable. EDF is launching a strategy for California agriculture industries to operationalize resilience in underutilized spaces as a good business practice. The challenge is that working lands resilience is multi-disciplinary and requires scientific research that integrates dual agronomic and ecological goals. Traditional research typically focuses on only a single aspect of resilience and fails to leverage a multi-disciplinary approach for creating a resilient landscape in a changing climate. EDF aims to broaden these research goals to better understand both agronomic and ecological benefits and then put these new resilience strategies into practice across the Central Valley. For example, EDF's Orchards Alive project is demonstrating how two pecan orchards that typically keep orchard floors bare can be transformed to provide valuable monarch and pollinator habitat, attract beneficial insects, improve soil health and create a myriad of other co-benefits through the establishment of a cover crop rich with native wildflowers.

The purpose of this report is to inform a regional strategy for managing vegetation in California nut orchards for agronomic benefits and ecosystem services, with a focus on pest management. Strategic cover crop planting is a smart investment in ecosystem services that have defined economic value such as pest management for lower costs and slowed chemical resistance and improved soil health for better crop production, nutrient availability and disease resistance. Creating a connected network of permanent and seasonal native vegetation within Central Valley nut orchards can increase these ecosystem services, the economic value of which is often underappreciated. Regional efforts at scale also have the potential to help prevent Endangered Species Act listings and recover declining species.

This report compiles and communicates findings from best available scientific research and integrated pest management (IPM) practices. In doing so, we provide a clearer understanding of the starting-point context, drivers and needs for the tree nut sectors in California. Specifically, this report provides

- An overview on the state of research related to managing vegetation in tree nut orchards in California, including specific ecosystem service benefits and projected climate change impacts.
- A summary of influences on grower decision-making regarding conservation practices, with a focus on grower perceptions, concerns and knowledge gaps.
- Key considerations for managing vegetation in tree nut orchards, including selecting the right plant species and other technical guidance.
- Opportunities and constraints for integrating vegetation in California tree nut sectors.
- Recommendations for future research and large-scale applications on commercial orchards to move toward broader-scale implementation.

Importantly, while there are many agronomic and ecological benefits that can be gained from managing vegetation, this practice is not a panacea. Conservation practices such as cover crops and hedgerows are meant to complement, and not replace, conventional orchard management practices. Conventional inputs should be used as a secondary option and implemented in a way that reduces environmental impacts. Beyond integrating managed vegetation, more integrated pest management practices to consider in orchard management are discussed in Appendix A. Crop-Specific Information.

STATE OF RESEARCH: MANAGED VEGETATION IN NUT ORCHARDS

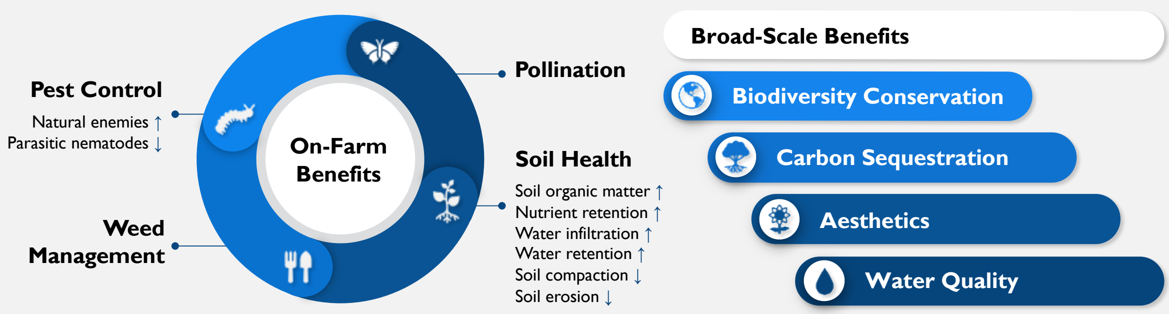
Western growers are increasingly considering human and environmental health in land management decisions, consequently their use of broad-spectrum pesticides is decreasing (Farrar et al., 2016). While there is growing adoption of IPM practices in the western U.S., adoption is not universal. Increasing grower adoption of conservation practices requires a deeper understanding of the ecosystem services, economic value and technical methods related to these practices. Further, growers continue to face new challenges, such a changing climate and increased pest pressures. While it is critical to consider projected climate change impacts in any land management scenario, this is particularly important for orchards due to their relatively long lifetimes.

What is Managed Vegetation?

There are many options for increasing vegetation on agricultural landscapes. Throughout this report, **"managed vegetation"** refers to vegetation planted and managed by growers for agronomic and ecological benefits. Managed vegetation does not necessarily need to be native, but using native vegetation will maximize conservation benefits. The focus in this report is primarily on cover crops with a secondary focus on hedgerows. There are many additional options for managing beneficial vegetation in orchards that are not covered in this report, such as with windbreaks, riparian buffers and alley cropping.

What are the Benefits?

Managed vegetation is a smart investment in on-farm ecosystem services, such as pest control, pollination, weed management and soil health. There are also broad-scale benefits of managed vegetation such as improved biodiversity conservation, increase in soil organic mattter, aesthetics and water quality.



This section provides information on 1) scientific literature and case studies focused on the ecosystem services and economic value of managing vegetation in nut orchards, and 2) the implications of climate change on California nut orchard management. Additional information on the most relevant studies referenced can be found in Appendix B. Annotated Bibliography.

Ecosystem Services and Business Value of Managed Vegetation

Agricultural productivity relies on services provided by natural ecosystems, including pollination, pest control, soil maintenance and weed suppression (Power, 2010). Increasing managed vegetation on agricultural landscapes, including through planting cover crops, can enhance these valuable ecosystem services, providing multifaceted benefits to both farmers and biodiversity (Power, 2010).

Incorporating managed vegetation in nut orchards can help boost pest control, enhance pollination benefits, increase soil water infiltration and retention, suppress weeds and sequester carbon. There are also benefits to soil health, including increased organic matter, reduced compaction and erosion, and enhanced nutrient retention. There are also potential disease resistance benefits to stimulating a more diverse and robust soil microbial community (Vukicevich, 2016), which is currently being studied by USDA ARS. By implementing these practices, growers can also contribute to additional, broad-scale benefits such as increasing water quality, soil organic matter and wildlife biodiversity. Increasing ecosystem services can boost crop yields and reduce the need for expensive pesticides, allowing landowners to increase business value while also contributing to sustainability. However, benefits from ecosystem services are difficult to quantify. Understanding the ecological and agronomic value of the ecosystem services provided and quantifying across socio-ecological contexts is important for broadening adoption of these conservation practices.

Nut orchards are dynamic systems, with unique temporal and spatial opportunities for integrating native vegetation. Orchard floors are typically left bare, presenting a great opportunity for managing vegetation as cover crops. Native vegetation can be maintained seasonally, or in the years it takes for orchards to reach full maturity. Available research on ecosystem services and agronomic benefits focuses on four specific areas — 1) pest control, 2) pollination, 3) soil health, and 4) weed management.

Pest Control

High pesticide use negatively impacts not only soil (Imfeld & Vuilleumier, 2012), water (Amweg et al., 2005), wild insects (Attwood et al., 2008) and birds (Mineau & Whiteside, 2006), but also human health (Larsen et al., 2017; Gatto et al., 2009; Gunier et al., 2017). Though exposure is ubiquitous in the United States, farm workers and people living in agricultural regions face higher pesticide exposure and poisoning, creating an issue of environmental injustice (Alavanja, 2009; Pfeifer, 2016). Keeping farms profitable is important for local communities, economies and culture; however, decreasing pesticide use is necessary to work toward improved worker safety and equity. Managing vegetation on agricultural landscapes, such as with cover crops or hedgerows, can decrease the need for pesticide use, creating lasting economic, environmental and health benefits.

Beneficial Insects

Enhancing wild natural enemies to suppress pests with managed vegetation provides a way to reduce pesticide use without sacrificing crop yield (Jonsson et al., 2008). Increasing an agricultural landscape's complexity, such as managing vegetation, can enhance populations of beneficial insects (otherwise known as pests' "natural enemies"). This benefit is well documented; a 2011 meta-analysis of 46 studies demonstrated that increased natural habitat enhanced natural enemy presence (Chaplin-Kramer et al., 2011). Cultural practices to mitigate pest damage include decreasing pesticide use and decreasing dust, both of which cover crops can help accomplish (UC IPM, n.d.). However, there is still a lot we do not understand (see Research Recommendations), so tailoring efforts to each site and grower and testing different management designs is important (Crézé et al., 2019).

The impact of managed vegetation on beneficial insects has been well demonstrated in California's Central Valley. Hedgerows of strategically-chosen perennial shrubs and native grasses attract more beneficial insects than pests (Morandin et al., 2011). However, unmanaged areas are prone to infestation by non-native annual weeds, which harbor more pests than native vegetation. A grower concern is that managed vegetation can harbor pest populations (Garbach & Long, 2017). However, some plant species can increase natural enemies more than pest populations, highlighting the importance of strategic plant species selection (see Selecting Plant Species).

Benefits from enhancing pest control have also been demonstrated specifically for California tree nut orchards. Managing vegetation in almond orchards promotes pest control of navel orangeworm, a primary almond pest (Eilers & Klein, 2009). Additionally, beneficial insects abundance is higher and crop pest abundance is lower in walnut orchards with hedgerows compared to those left bare or with resident vegetation (Long et al., 2017). Placement can also matter; beneficial insects attracted to vegetation will move up to 250 feet on walnut and almond orchards (Long et al., 1998).

The role natural enemies play in pest control is particularly important on farms that experience secondary pest outbreaks. Secondary pest outbreaks occur when intensive pesticide use depletes the natural enemies that typically keep a pest under control, resulting in increased pest populations. In almond orchards, intensive pesticide use for pests including the peach twig borer, scales or the navel orangeworm, can cause secondary outbreaks of mites (Zalom et al., 2001). Mite outbreaks are typically later in the season, and exacerbated by dust created by many of the management and harvest operations associated with almond production. Further, even if the insecticide does not decimate the natural enemy populations, residues can impact natural enemies' reproduction and behavior and decrease their pest control abilities (Dreistadt, 2014). To sustain the pest control benefits from natural enemy populations, it is important to reduce broad-spectrum pesticides whenever possible. For example, spraying for spider mites and San Jose scale pest outbreaks may only be necessary in conventional almond orchards, but not organic or low-input almond orchards (Hendricks, 1995).

Nematode Suppression

In addition to providing pest control for pests on orchard trees, some cover crops can suppress nematode pests in the orchard soil. While beneficial nematodes can provide services for an orchard, plant-parasitic nematodes can cause plant damage and transmit disease. The residues of some plant species, such as brassicas (i.e. rapeseed, black mustard seed), sorghum and French marigold, have biofumigant properties which suppress parasitic nematodes (Dutta et al., 2019). However, different plant species impact different nematode species in different ways, thus it is important to understand the farm's specific nematode pressures (Crézé et al., 2019; Dutta et al., 2019). While biofumigants from cover crops are not as strong as conventional fumigants, incorporating brassica residues in soils can be integrated with other pest management strategies to decrease nematode pressures and environmental impacts.

Importantly, biofumigation is not the only way that managed vegetation suppresses nematode pests. Increasing organic matter in the soil creates habitat for a more vibrant soil ecology, which can include parasites and predators of plant parasitic nematodes.

Birds and Bats

Birds and bats are also important insect predators and maintaining their presence on agricultural landscapes can boost pest control. Because their diets and feeding time vary, birds and bats complement each other in pest control activities (DuFour, 2000). Like invertebrate natural enemies, vertebrates are more likely to be on complex landscapes, such as those with integrated vegetation, than on simple landscapes, such as monocultures. For example, bird predation on codling moth larvae can significantly reduce pest pressures in walnut orchards that include managed vegetation (Heath & Long, 2019). The most simple, homogenous agricultural landscapes can benefit from increasing bird and bat pest control the most. Bat activity is 61% higher on organic farms, and foraging activity is 84% higher on organic farms compared to conventional farms (Wickramasinghe et al., 2003).

Ensuring Pest Control Benefits

While there is considerable opportunity for increasing pest control with managed vegetation, not all farmers succeed. Tscharntke et al. (2016) describes the five following hypotheses for why managed habitat may fail to enhance biological control (Tscharntke et al., 2016), each is followed by a potential resolution. These scenarios highlight that the impacts of managed vegetation for supporting beneficial insects can differ depending on the type of crop, insects, habitat, management regime and landscape type. However, strategic management, such as by decreasing pesticide use, implementing habitat patches, and replacing invasive with native plant species, can help improve pest control effectiveness (Tscharntke et al., 2016).

Natural habitat and biological pest control: Five hypotheses for when managed habitat does not enhance biocontrol (Tscharntke et al., 2016). Subset of table from Tscharntke et al (2016) with potential resolutions added.

HYPOTHESIS	POTENTIAL RESOLUTION
1. Pests do not have effective natural enemies in the region. Pest density may be driven by other factors such as environmental conditions, crop susceptibility, agricultural practices and area.	▪ Survey existing pest and beneficial insect community to inform strategy. ▪ Implement other cultural practices to manage pests (see Appendix A).
2. Managed vegetation is a greater source of pests than natural enemies. Natural habitats can provide a suitable environment for pest species.	▪ Strategically choose plant species (see Selecting Plant Species). ▪ Manage weeds effectively.
3. Cash crops provide more important resources for natural enemies than managed vegetation does. Natural enemies may not receive all their resources from managed vegetation, and they may be more influenced by neighboring crops.	▪ Strategically choose plant species (see Selecting Plant Species) ▪ Consider increasing natural habitat and the associated benefits and costs.
4. Managed vegetation does not provide large enough enemy populations for pest control. Managed vegetation must be large and proximate enough to farms to increase enemy abundance.	▪ Consider increasing natural habitat and the associated benefits and costs. ▪ Ensure natural habitat is in close proximity to crops.
5. Agricultural practices counteract natural enemy establishment in managed vegetation. Pesticide spraying and low crop diversity may negatively impact natural enemies and support pests, regardless of managed vegetation available.	▪ Combine managed vegetation with other IPM practices to decrease pesticide use. ▪ Replace broad-spectrum pesticides with targeted pesticides.

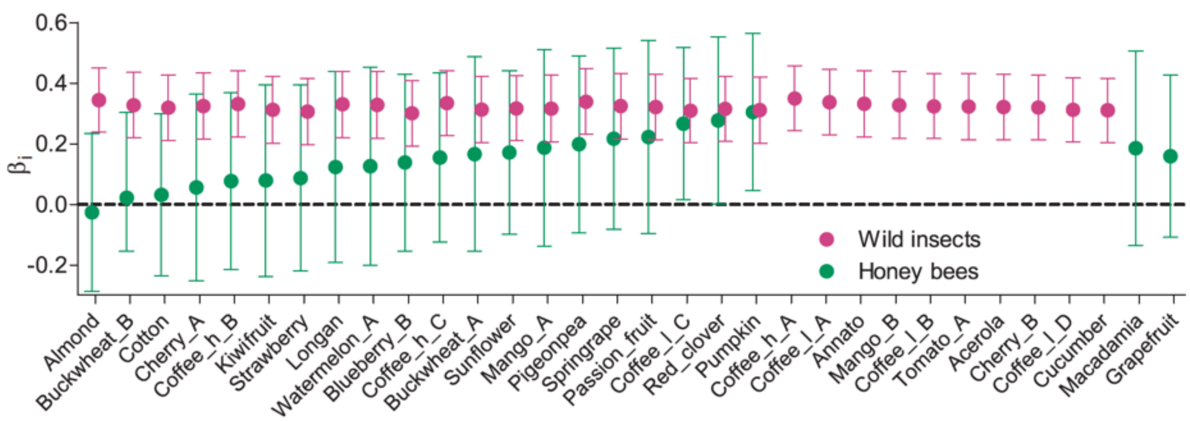
Pollination

Global reliance on pollinators for agricultural production is well known (Losey & Vaughan, 2006). Intensive, simplified agricultural landscapes often have little surrounding habitat, which has led to a loss of biodiversity and valuable ecosystem services. Increasing global food demand will likely exacerbate this trend towards agricultural intensification in the tree nut and other sectors. Finding ways to increase crop yields while also supporting biodiversity is necessary to sustain agricultural production.

Crop production in almond orchards relies on pollinators. Increasing natural habitat on the agricultural landscape, such as by planting wildflowers in cover crops or hedgerows, can increase pollination services from wild pollinators and increase fruit set (Klein et al., 2012). Planting nectar and pollen resources is a valuable strategy for attracting pollinators because they can be designed to fit various cropping systems and landscapes and can also support other beneficial insects, increase soil and water protection, and enhance orchard aesthetics (Sidhu & Joshi, 2016; Wratten et al., 2012). Managed vegetation is essential in maintaining native pollinator diversity, particularly of less common species (Morandin et al., 2013).

Conventional U.S. agriculture relies on the European honey bee for pollination; however, demand for pollination is growing faster than honey bee stocks (Aizen & Harder, 2009). Wild insects are more effective pollinators than honey bees, and wild pollinators can supplement or possibly replace honey bees on farms with integrated habitat. A global study of over 40 crop systems demonstrated that wild insect visitation increased fruit set twice as much as honey bee visitation (Garibaldi et al., 2013). Almonds saw a relatively large increase in fruit set with wild bee visitation and minimal to no benefits to fruit set from honey bee visitation (Garibaldi et al., 2013). Similarly, a study in California almond orchards found wild bee species richness and visitation to be associated with increased fruit set in almond orchards, but did not find a similar increase from honey bee visitation (Klein et al., 2012). Honey bees are not a viable replacement for wild bees, and wild pollinators are also necessary to maximize pollination benefits.

The presence of wild bees can increase honey bees' productivity, producing synergistic effects for pollination services. Honey bee movement and pollination effectiveness is higher in almond orchards with wild bees than in those without (Brittain et al., 2013). Possible explanations include that honey bees may avoid flowers with scent marks left by wild bees or that wild bees may deplete flower resources, forcing the honey bees to increase their movement. Further, wildflower plots do not compete with almond flowers for honey bee visitation (Lundin et al., 2017).



Wild insect visitation increases fruit set more than honey bee visitation in over 40 crop systems. β represents the impact of visitation by wild insects (pink) or honey bees (green) on fruit set. The difference between wild insects and honey bees was the greatest for almonds of all crops studied (Garibaldi et al., 2013).

Soil Health

A fundamental benefit of integrating vegetation on agricultural lands is increased soil health and subsequently, boosted crop yield, quality and resiliance. Soil health improvements can include increased soil organic matter and fertility, which in turn enhances nutrient and water retention and develops soil structure, providing improved water infiltration and reducing soil compaction and erosion. Boosts to soil health, including improved aggregate stability and water infiltration, are possible in California almond orchards in less than two seasons (Crézé et al., 2019), while improvements in soil organic matter are uncertain. Increased soil health may in turn increase cover crop productivity, creating a positive feedback loop for cover crop growth. This cycle is important to consider because even if initial impacts from cover crop implementation are not substantial, they may increase over time (Crézé et al., 2019).

Managing vegetation can increase net accumulation of soil carbon and soil organic matter if organic inputs are sustained, improving nutrient retention and reducing greenhouse gases. Increased soil organic matter from vegetation can act as a buffer that absorbs nutrients so they are released more steadily during the growing season (Jarvis-Shean & Lightle, 2019). Organic management, including the use of cover crops, increases soil carbon content in California orchards (Suddick et al., 2013).

Cover crops increase soil microbial abundance and diversity which can positively impact carbon, nitrogen and phosphorus cycling (Castellano-Hinojosa & Strauss, 2020). Both cover crops and enhanced soil carbon have been demonstrated to promote soil microbial biomass abundance and community complexity. Microbes associated with soil and plant surfaces can serve as a preliminary mode of plant defense via production of antibiotive and antifungal compounds and competitive displacement of plant pathogens. Further, enhanced plant nutrient availability and growth promotion imparted by soil microbes can support healthy and robust orchard trees.

Impacts to soil health will depend on the selected plant species selected. Cover crops that include legumes can provide an alternative source of nitrogen, offsetting the need for synthetic fertilizers. Plants with deep taproots and extensive root systems, like cereals and grasses, are beneficial in reducing soil compaction and nutrient management because they can penetrate compacted soil layers, returning nutrients to the topsoil and improving soil permeability (Van Sambeek, 2017). Changes in soil health can occur quickly with higher diversity in seed mixtures, offering multiple beneficial plant traints (Van Sambeek, 2017), as well as with single species cover crops, which may be simpler for grower management (Florence & McGuire, 2020). See Selecting Plant Species for more information on plant species' impacts on soil health.

Weed Management

Weeds present a challenge during crop growth due to competition effects that can lead to crop yield losses. Herbicides are typically used to suppress weeds; however, herbicides have negative impacts on the environment and in herbicide-resistant weeds can develop. Cover crops can provide an alternative weed suppression strategy. Weed suppression provided by cover crops is comparable to chemical and mechanical weed control methods (Osipitan et al., 2018). Weed suppressing characteristics, such as biomass productivity and residue persistence, are more important than the specific cover crop species (Osipitan et al., 2018).

Lastly, managed vegetation may provide benefits to air quality. The sweeping and pick-up process in almonds contributes substantially to particulate matter air pollution (Baticados, 2019). If the previous benefits of managed vegetation are more broadly realized, off-ground harvest may be desirable and move the industry away from management practices that contribute to soil loss and air pollution. However, more research is needed (see Research Recommendations).

Climate Change Impacts

California's climate has already changed considerably and will continue changing (Pathak et al., 2018). There is urgency to increase resilience in California agriculture and reduce vulnerability to climate change impacts such as warmer temperatures and more frequent extreme weather events. Nut crops are among California's most valuable agricultural products (CDFA, 2019), and because orchards are a long-term investment, consideration of projected climate change impacts is especially important. Climate change in the next 20 to 30 years is important to consider for current crops and is especially important in planning for new orchards (Lobell & Field, 2011). Climate change stressors that threaten nut orchards include temperature changes, reduced irrigation water supply, and increased pest and disease outbreaks (Luedeling et al., 2009, 2011).

Nut orchards require cool temperatures in the winter for regular crop development. Not meeting the required chilling requirements can temporally extend blooming time, reducing crop yield and quality. Asynchronous flowering is particularly problematic in orchards that require overlap between male and female flowering, like pistachios and walnuts, because it can reduce pollination. For all nut orchards, unfulfilled chilling requirements can result in varying crop sizes and maturity stages at the time of harvest, decreasing value and increasing costs (Luedeling et al., 2009).

Winter warming is expected to decrease winter chill in California, rendering current regions used for crops that require cold temperatures unsuitable for future use (Luedeling et al., 2009). Impacts will be greatest on crops that require a high number of chilling hours. Almonds have low chill requirements, whereas pistachios and walnuts have higher requirements. By 2080, the majority of the Central Valley may be unsuitable for orchards with high chill requirements, including pistachios and walnuts (Luedeling et al., 2009). In almonds and walnuts, however, increased spring and summer temperatures may result in increased yield, potentially offsetting decreases from winter warming (Lobell & Field, 2011).

Climate Change Impacts on California Tree Nuts

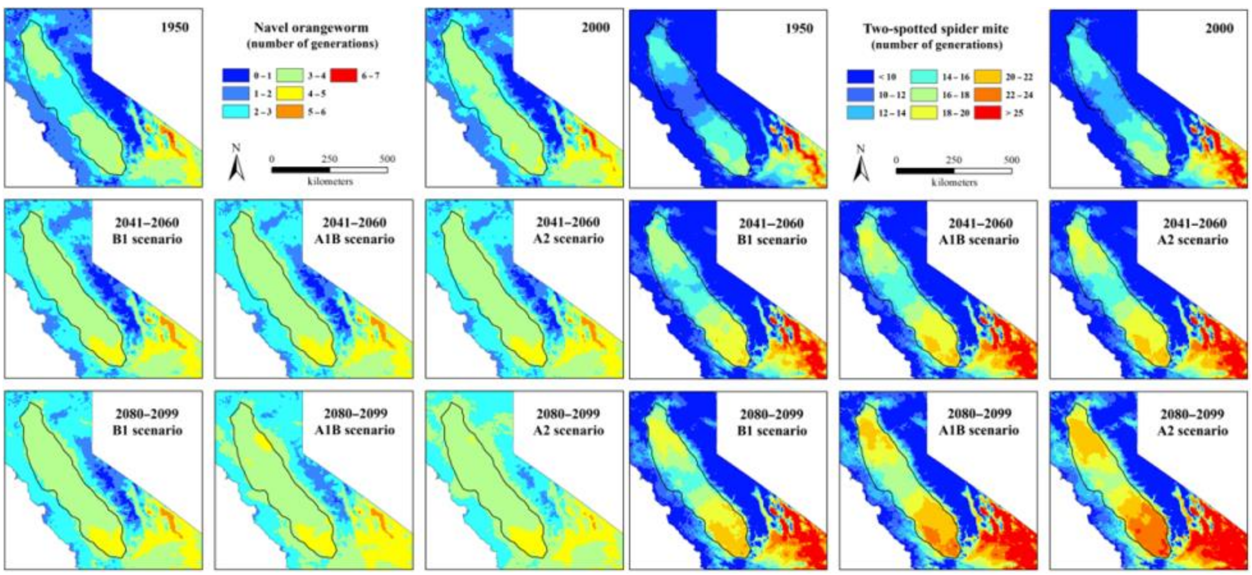
There is urgency to increase resilience in California agriculture and reduce vulnerability to climate change impacts. Because orchards are a long-term investment, consideration of projected climate change impacts is especially important. The table below summarizes the scientific literature regarding impacts from changing temperature on California tree nuts (Kerr et al., 2018).

Summary of literature review on temperature relationships of California specialty crop (Kerr et al., 2018). Subset of table from Kerr et al. (2018) limited to relevant crops and information. Pecans were not included in the review.

CROP	TEMPERATURE RELATIONSHIPS
Almond	Lower chilling requirements (200-400 hours), thus may remain productive in many parts of the Central Valley (Luedeling et al., 2009), but winter fog loss is an important unknown (Baldocchi & Waller, 2014).
Pistachio	High chilling requirements (800-900 hours); Central Valley may no longer be suitable by late century (Luedeling et al., 2009) unless lower-chill cultivars are developed (Kallsen et al., 2009).
Walnut	High chilling requirements (800-1,000 hours); which may no longer be attainable in Central Valley by mid- to late century (Lobell et al., 2006; Luedeling et al., 2009), also sensitive to heat during fruit-set in late spring (Baldocchi & Wong, 2008).

Climate change will also impact pest pressures. Primary nut orchard pests are expected to increase under climate change projections (Luedeling et al., 2011). Those studied include navel orangeworm (almond, walnut, and pistachio pest; see figure below), codling moth (walnut), two-spotted spider mite (almond, walnut, and pistachio; see figure below), and European red mite (almond, walnut). See Appendix A. Crop-Specific Information for natural enemies and cultural practices that can help mitigate these pests, which may be increasingly important under climate change.

Climate change can indirectly impact pest pressures as well. For example, increased insecticide applications necessary for some pests due to climate change may disrupt biological control and increase the likelihood of secondary pest outbreaks from other pests. Interactions among pests may also play a role. For example, navel orangeworms may use entry holes made by codling moths to infest walnuts, so an increase in codling moths may increase navel orangeworms as well (UC IPM, n.d.). Additionally, pests may start appearing sooner and persisting later in the season, impacting orchards at times that have not traditionally been subject to pest pressures and requiring modifications to current management practices (Luedeling et al., 2011).



Projected pest pressure from navel orangeworm and two-spotted spider mite, pests to almond, pistachio, and walnut, in the Central Valley under several climate scenarios (Luedeling et al., 2011).

GROWER DECISION-MAKING

Given the multitude of potential benefits from increasing managed vegetation on farms, why aren't these practices more widely adopted? While the constraints are obvious for some farmers, the rationale for others may be more nuanced and related to a lack of available information, real and perceived barriers, and misaligned communication networks. This section summarizes factors that influence grower decision-making around adoption of conservation practices.

Grower Perceptions

Growers' perceived benefits and concerns regarding conservation practices highly influence adoption. Surveys of western growers demonstrate that perceived benefits include attracting bees, attracting natural enemies, improving farm aesthetics, increasing wildlife, decreasing reliance on pesticides, reducing production costs, environmental protection, improved worker safety and human health, yield improvement, and income diversification (Brodt et al., 2019; Garbach & Long, 2017; Goldberger & Lehrer, 2016). Primary concerns include maintaining a clean floor for harvest, weeds, rodents, equipment limitations, insect pests, regulations, crop diseases and costs. Perceptions vary between growers that have adopted conservation practices and those that have not (Garbach & Long, 2017; see text box below).

Perceived Benefits & Concerns of Field Edge Plantings

A survey of 109 landowners in the Sacramento Valley determined the top perceived potential benefits and concerns of field edge plantings (Garbach & Long, 2017). Factors were rated differently by adopters and non-adopters. For example, growers that did not adopt conservation features (non-adopters) did not rate the benefits of natural enemies as a primary benefit, yet adopters did. Increased communication and case studies of the pest control benefits from managed vegetation may help close this gap.

Top Perceived Benefits		Top Perceived Concerns	
Adopters	*Non-Adopters*	*Adopters*	*Non-Adopters*
1. Bees	**1. Erosion control**	**1. Costs**	**1. Weeds**
2. Natural enemies	**2. Wildlife**	**2. Lack of time**	**2. Rodents**
3. Aesthetics	3. Bees	3. Weeds	3. Limited equipment
4. Wildlife	4. Water quality	4. Limited equipment	4. Insect pests
5. Erosion control	5. Soil health	5. Farm investment	5. Regulations

Addressing Grower Concerns

Many perceived barriers can be overcome through increased communication with growers. Primary concerns from grower interviews and EDF's applied experience include that managed vegetation 1) will harbor pests, 2) will compete with crops for water or nutrients, 3) is too costly to be viable, 4) will compete with crops for pollinators, 5) will increase frost risk, and 6) will attract rodents and jeopardize food safety. In the following table, we provide more information about methods and case studies for overcoming these perceived barriers. Below, we also provide more detailed information on three of these issues — cost, food safety and frost risk.

Potential resolutions and case studies for perceived barriers to managing vegetation.

PERCEIVED BARRIER	RESOLUTION	CASE STUDY
Managed vegetation will harbor and enhance pest populations	**Thoughtfully select plant species**. Replacing weedy edges with native plant species can increase beneficial insect abundance more than pest abundance. *See Pest Control in Ecosystem Services*	A study in Yolo County demonstrated that replacing weedy edges with native plants can increase beneficial insect abundance more than pest insect abundance (Morandin et al., 2011).
Managed vegetation will compete with crops for water or nutrients	**Be strategic about timing, location and plant species**. Space cover crops away from trees in the interrow middles to decrease competition for nutrients. Consider winter cover crops to avoid water constraints in the summer. *See Timing in Key Considerations*	A study in California almond orchards demonstrated that cover crops maintained from October to April have low additional water usage and can be primarily rain-fed (Crézé et al., 2019).
Managed vegetation costs too much to be viable	**Leverage cost-share programs and understand the financial benefits from ecosystem services**. There are long-term direct benefits from managing vegetation, and the return on investment time can be decreased with government incentives like cost-share programs. *See Implementation Cost (below) and Funding and Incentives Resources*	A study in Yolo County demonstrated that when considering pollination benefits and insecticide savings from pest control, the return on investment time for a typical hedgerow planting is 7 years, and a cost shares allow for a quicker return time (Morandin et al., 2016).
Managed vegetation will compete with crops for pollinator visits	**Use wildflower plantings to increase crop pollinator visits**. Increasing habitat increases flower visitation and fruit set. Additionally, native bees and honey bees can work synergistically, increasing overall pollination effectiveness. *See Pollination in Ecosystem Services*	A study in Kern County demonstrated that honey bee visitation to wildflower plots did not decrease honey bee visitation in the neighboring almond orchards (Lundin et al., 2017). Further, honey bee pollination effectiveness is actually higher in almond orchards with wild bees (Brittain et al., 2013).
Managed vegetation will increase frost risk	**Recognize that frost risk is not likely to increase, or mow if necessary**. Cover cropping is likely to alter the surrounding microclimate; however, the effect may not impact a tree crop's frost risk. Mowing when low temperatures are expected can also mitigate risk. *See Frost Risk (below)*	A study on cover crops in California almond orchards did not experience increased frost risk. While cover crops did buffer top soil temperatures, there were no changes in temperature above three feet (Crézé et al., 2019).
Managed vegetation will attract rodents	**Recognize that that increasing managed vegetation does not increase rodents or pathogens**. Rodents are prevalent in crops regardless of edge habitat, and pathogens may be more likely to increase in farms where noncrop vegetation is removed. *See Attracting Rodents (below)*	A study in California walnut orchards demonstrated that while rodent presence is higher in hedgerows than conventional field edges, hedgerows do not increase rodent presence in orchards (Sellers et al., 2016). Additionally, managed vegetation is not associated with *E. coli* or *Salmonella* prevalence (Karp et al., 2015).

Implementation Cost

A large barrier to adoption is the immediate startup cost. Managed vegetation provides benefits to a wide range of people, but growers predominantly bear the costs (Lonsdorf et al., 2020). High costs are one of the most frequently mentioned constraints to managing vegetation even among farmers familiar with cost-share programs (Brodt et al., 2009).

While there are substantial direct and indirect benefits from increasing managed vegetation, up-front costs can be significant, and growers may not begin to see benefits for years. A cost-benefit analysis in California almond orchards demonstrated that winter cover crops can be profitable in the long-term, with net profit in 10 to 15 years (DeVincentis et al., 2020). Estimates for the long-term profits were dependent on the extent of irrigation savings, climate change and access to financial subsidies. Growers that benefitted the most included those with flexible contractual obligations, the ability to wait for the long-term benefits, and the ability to closely manage cover crops. Experiments at scale are needed to find ways to decrease these costs (see Research Recommendations).

Costs and benefits associated with winter cover crops in Central Valley almond orchards (DeVincentis et al., 2020).

Direct Costs	Indirect Costs	Direct Benefits	Indirect Benefits
▪ Seed ▪ Planting (labor) ▪ Termination (labor)	▪ Harvest complications ▪ Machinery depreciation ▪ Opportunity cost of time spent learning	▪ Increased yield ▪ Soil erosion control ▪ Nutrient cycling ▪ Weed control ▪ Fungi colonization ▪ Discounted beehives	▪ Increased soil organic matter ▪ Reduced surface water runoff

A common thread among grower decision-making studies is an emphasis on the importance of incentives and cost-share programs in lowering the barriers to implementation and encouraging conservation practice adoption (Brodt et al., 2009; Cullen et al., 2008; DeVincentis et al., 2020; Morandin et al., 2016). However, cover crop adoption remains low in California, despite widespread cost-share programs. Increasing grower knowledge and familiarity with available cost-share programs may help increase adoption. Additionally, potential policy changes that could decrease costs include subsidies for ecosystem and social services through agricultural mitigation practices (DeVincentis et al., 2020). Conservation districts can also offer discounted or free equipment rentals to lower barriers. For existing incentives programs in California, see Funding and Incentives Resources.

Attracting Rodents

Grower concerns that managed vegetation on a farm can increase rodent abundance and threaten food safety has accelerated habitat loss in California (Gennet et al., 2013). However, increased vegetation does not actually increase pathogen prevalence. Managed vegetation is not associated with *E. coli* or *Salmonella* prevalence; alternatively, pathogen prevalence can increase when managed vegetation is removed (Karp et al., 2015). Increasing pest pressure from rodents is an additional concern. However, a case study in California walnut orchards demonstrated that while hedgerows may increase rodents compared to conventional field edges, they do not increase rodents in the orchards (Sellers et al., 2016).

Frost Risk

A concern around cover crop implementation is that alterations to the microclimate will increase frost risk. However, a preliminary study on cover crops in California almond orchards did not find that the cover crops increased frost risk. While cover crops did buffer top soil temperatures, there were no changes in temperature above three feet (Crézé et al., 2019). Frost risk therefore may not be an issue relevant to orchards in California; however, these preliminary results are only based on one season of data and further research is needed. Concerned growers can mow when frost is expected to ensure that frost risk does not increase.

Other Factors Influencing Adoption

In addition to the considerations already mentioned, factors influencing adoption may include trialability (whether on-farm trials are possible prior to larger implementation), access to equipment, complicated management practices, diverse irrigation requirements and timing of different activities (Brodt et al., 2009; Cullen et al., 2008; Goldberger & Lehrer, 2016). Some farmers are more likely to adopt conservation-oriented practices than others. Orchard growers that use these practices are more likely to have more orchard experience, have larger, more diversified operations, have certified organic farms, and frequently consider environmental impacts in decision-making (Goldberger & Lehrer, 2016).

Grower Knowledge Gaps

Increased and targeted communication can overcome knowledge barriers. Surveys and interviews of growers that engage in conservation practices, including almond and walnut growers, reveal grower knowledge gaps (Brodt et al., 2009, 2019). Knowledge gaps primarily fall into two categories: systems design issues and ecosystem service quantification.

Knowledge Gaps in Systems Design

- Ideal plant species for varying objectives, including for weed control, to allow for picking up nuts during harvest, and to function for pastoral use.
- Importance of native versus non-native species.
- Strategies for managing diverse tree species.
- Effects on tree root growth and architecture.
- Impacts to microclimate.
- How to balance different irrigation regimes, including tradeoffs of water use.

Knowledge Gaps in Quantifying Ecosystem Services

- Carbon sequestration potential.
- Impacts to crop quality and plant nutrition.
- Capacity to buffer farms from weather extremes.
- Impacts on input needs and use efficiency.

Communication Networks

Technical learning, such as through outreach and extension, is critical for adoption of conservation practices. However, technical learning alone is likely not sufficient as social and cultural factors also play a role (Garbach & Long, 2017). To strategically increase adoption, it is important to understand the social dynamics necessary to support scientifically-informed innovation (Cullen et al., 2008).

The most important roles in growers' communication networks are agencies that provide technical support and fellow landholders (Garbach & Long, 2017). Socially influential growers working with agencies can effectively build community support for conservation practices and growers who act as champions for on-farm research and demonstration projects can influence high adoption rates (Brodt et al., 2009). In addition to technical learning support, expanding peer-to-peer communication can to increase adoption of conservation practices.

Pest control advisors (PCAs) and certified crop advisors (CCAs) also play a key role in decision-making. Lack of recommendation by pest management consultants is a top barrier to implementing on-farm conservation features (Goldberger & Lehrer, 2016). Growers rely on advisors for IPM decision-making, specifically regarding insect and mite pests and diseases (Brodt et al., 2005). Increasing grower access to PCAs and CCAs who are informed about the benefits of managed vegetation, such as through training, can help increase adoption.

While the research above emphasizes the influence of communication networks, it is important to recognize this is just one part of a multi-faceted approach to broad-scale adoption with no single solution. Supply chain interventions and agricultural lending programs for resilient agriculture (see EDF's Financing Resilient Agriculture) are additional ways to increase grower adoption not specifically discussed. See Research Recommendations for additional factors and knowledge gaps.

KEY CONSIDERATIONS

Research can lead the way and influential growers can increase support, but how can practices grow to scale? There must be clear alignment around recommendations for equipment, timing, adequate monitoring, and other technical specifications. Further, the logistics regarding planting, monitoring and maintaining beneficial vegetation need to be accessible and achievable for growers in orchards of various sizes and locations in order to grow to scale.

There are many options for managing vegetation on agricultural landscapes. While the following considerations are generally applicable across practices, the primary focus here is on cover crops with a secondary focus on hedgerows. However, there are many other options for agronomically and ecologically beneficial management in orchards, such as windbreaks, riparian buffers and alley cropping.

The following are considerations for plant species and timing to inform strategies for managing vegetation in nut orchards. These considerations will vary on a site-specific basis, depending on grower objectives, tree nut crop, current irrigation and management systems, and climatic region. Additionally, see Technical Planting Guidance for detailed technical guidance regarding planting cover crops.

Selecting Plant Species

To increase the chance of success, it is important to consider pedoclimatic conditions and the ecology of desired insects, timing of bloom, weather, irrigation system and water availability, shade tolerance and cropping system. Different plant species will impact the orchard in different ways and, although there is a great amount of overlap, the ideal strategy will depend on site-specific characteristics and each grower's objectives.

Primary objectives for integrating managed vegetation on an orchard will likely include increasing pollinator habitat, pest control, soil health, or weed management (Jarvis-Shean & Lightle, 2019). Plant species can be selected accordingly. Most orchards are likely to have a combination of objectives, so a variety of diverse plant species is ideal. An excellent resource for selecting regionally-specific plant species is the NRCS California eVegGuide. See additional resources in Appendix C. Key Resources.

Selecting plant species based on primary objectives. Adapted from Jarvis-Shean & Lightle (2019). Hollow stars (☆) denote moderate benefit and filled stars (★) denote maximum benefit.

	 BRASSICAS	 WILDFLOWERS	 LEGUMES	 GRASSES
Pollinator habitat	★	★	★	
Pest control	★	★	★	☆
Soil health	☆	☆	★	★
Weed management	☆	☆	★	★

To Increase Pollinator Habitat

Attracting wild pollinators may be a goal for almond growers (see Pollination), as almond orchards depend on cross-pollination whereas walnut and pistachio orchards are wind pollinated. Timing is particularly important to consider because almond bloom is earlier than that for most orchards. For this reason, brassicas (mustards) are the best to reap the benefits of wild pollinators, because few other plants flower as early. If supporting pollinators after almond bloom is desired, other wildflowers are beneficial as well. Native wildflowers, such as phacelia species, should be prioritized for maximum conservation benefits. Learn more about the benefits from managed vegetation in Pollination.

To Increase Pest Control

The ideal plant species for pest control benefits vary (DuFour, 2000); however, there is a great amount of overlap. Ideal plant species provide beneficial insects with a food source, such as with nectar, pollen, extrafloral nectaries, or other insect species. Generally, plants with small, nectar-rich flowers are best for supporting natural enemy populations without attracting additional pests. These beneficial species can include those in the carrot, mustard, sunflower, mint, or buckwheat families (DuFour, 2000). Legumes can be beneficial as well, such as vetch, cowpea, and clovers. Mustards also have parasitic nematode suppressing properties which can assist farms facing nematode pressures (see Nematode Suppression).

Planting a mixture of species that bloom in succession can attract beneficial insects for longer periods or fill in potential gaps (DuFour, 2000). Beneficial insect movement from the cover crop to main crop is sometimes associated with the cover crop's post-bloom period. In this case, mowing the cover crops in alternate strips can facilitate their movement while maintaining some habitat (DuFour, 2000). Learn more about the benefits from managing vegetation in Pest Control.

Orchards Alive

Orchards Alive, a pilot project funded by the Wildlife Conservation Board and implemented by EDF and partners, is demonstrating how transforming the bare ground of pecan orchards into pollinator habitat can benefit native wildlife while sustaining crop productivity. Orchards Alive is already yielding positive results. Initial monitoring results document avoided pesticide use as a result of beneficial insects effectively controlling aphid outbreaks. See Case Study: EDF's Orchards Alive for more information.

Persian clover and crimson clover on a participating Orchards Alive pecan orchard. Photo: Rex Dufour, NCAT

To Increase Soil Health

Growing any plants in the orchard middles is more beneficial to soil health than bare soil (Jarvis-Shean & Lightle, 2019). However, some species will provide increased or more specific benefits over others. Cover crops can greatly benefit soil health over time by increasing soil organic matter, reducing soil erosion, reducing soil compaction, increasing water infiltration and retention, and regulating nutrients and other aspects of fertility (salinity or pH, for example).

Nutrient management benefits from cover crops depends on the plant species composition. Legumes can add nitrogen to the system, decreasing the need for fertilizers and reducing costs. The amount of nitrogen contributed to the orchard depends on the cover crop biomass, the types and amounts of legumes contained, and the orchard management practices. However, because cover crops are not grown in the tree line, it's not entirely clear whether cover crops reduce nitrogen needs for the trees. Further, the nitrogen release from the cover crop needs to be synchronized with tree nitrogen demand. Determining the timing and amount of nitrogen update in mature orchards is paramount to develop integrated nitrogen management strategies and it remains a key knowledge gap (see Research Recommendations).

Plants with deep taproots and extensive root systems, like cereals and grasses, are beneficial in soil compaction and nutrient management because they penetrate compacted soil layers, returning nutrients to the topsoil and improving permeability (Van Sambeek, 2017). Increasing overall soil organic matter with increased vegetation can act as a buffer that absorbs nutrients so they are released more steadily during the growing season (Jarvis-Shean & Lightle, 2019). Changes in soil health will occur more quickly with higher diversity in the seed mixtures (Van Sambeek, 2017). Learn more about the benefits to soil health from managing vegetation in Soil Health.

To Increase Weed Management

Cover crops can outcompete weeds for water, nutrients and light. Important weed suppressing characteristics include rapid growth rates and high biomass productivity, such as in buckwheats and legumes (Schonbeck, 2020; Osipitan et al., 2018). Some plant species, such as cereals and grains, also produce phytoxic compounds which suppress weeds. Biofumigant properties in brassicas that suppress parasitic nematodes can also work to suppress weeds (Van Sambeek, 2017). Learn more about these benefits in Weed Management.

Timing

Maintaining cover crops through the growing season is likely to provide the greatest benefits to wild insects, pest control and soil health. However, there are tradeoffs to consider, include timing of orchard management practices and seasonal water usage. In determining a cover crop strategy, timing will vary depending on each site's orchard management practices, irrigation systems and water demand.

Alternate Row Mowing

If the cover crop grows too tall to manage, an option is to alternatively mow every other row. Alternate row mowing can extend the cover crop bloom time, maintaining pest control benefits by providing beneficial insects refuge and resources in unmowed rows. This method has proven successful on pecan orchards in EDF's Orchards Alive.

For Water Usage

In California, water is often a limiting factor. Cover crops may increase water demand (Prichard et al., 1989); however, recent reports suggest that benefits may offset the demand (DeVincentis, 2020). Cover crops improve infiltration, retention and re-distribution of soil water, which can improve water management conditions and reduce irrigation needs (DeVincentis, 2020; Grant et al., 2006). There are not differences in soil moisture between cover cropped and bare fields, meaning that Central Valley growers can likely adopt cover crops without changing their current irrigation practices. (DeVincentis, 2020).

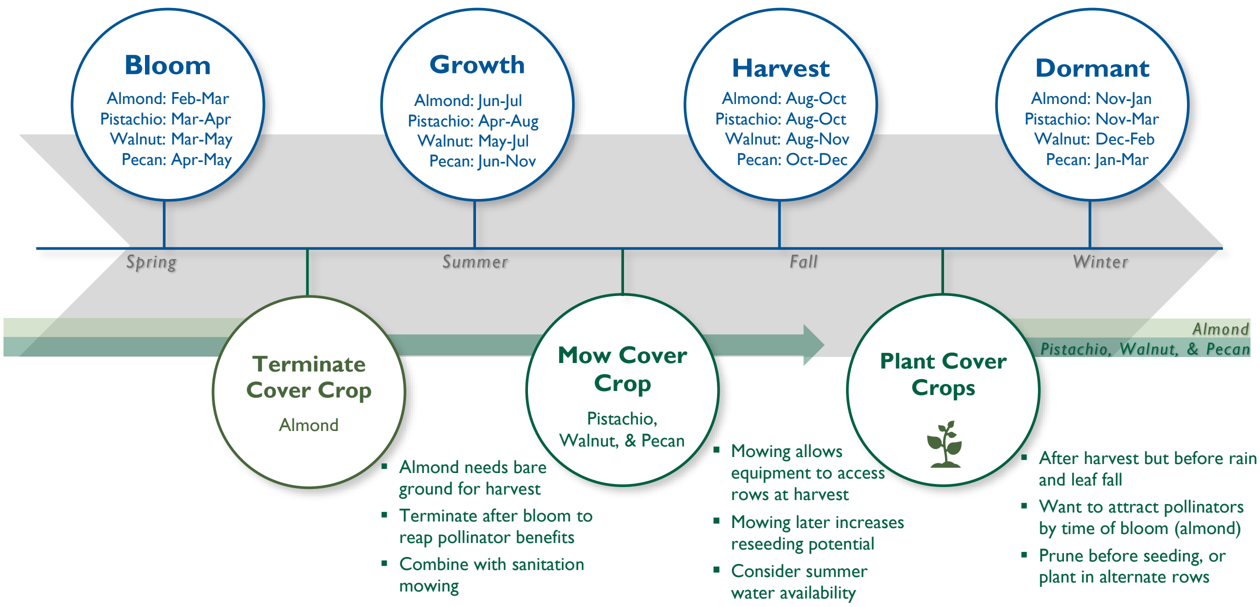
Water usage also depends on plant species and growth which regulates evapotranspirative demand. Some cover crops like cowpeas, millet and medics use less water than those with high water usage, like alfalfa or rye (Van Sambeek, 2017). Water usage will also be site- and crop- specific. For example, cover crop water use may be lower in walnut than in almond orchards because of greater shading of the orchard floor (Grant et al., 2006). Differences vary regionally, as the Sacramento Valley and San Joaquin Valley face difference water constraints. Maintaining cover crops during winter and terminating in spring can minimize water competition, particularly in the San Joaquin Valley where water is a larger constraint.

Impacts to water usage will also depend on current irrigation practices. Rainfed winter cover crops seeded in fall and terminated in spring can usually be grown without full-coverage irrigation depending on the region, as removal is before the typical irrigation season begins (Grant et al., 2006). However, if cover crops are present throughout the year, full-coverage sprinkler or flood irrigation will provide for ideal crop growth and longevity (Grant et al., 2006).

For Orchard Management

Cover crops can hinder management practices that require machinery traversing the interrow middles, such as sanitation for mummy nuts, pruning and harvesting. However, it is possible to work around these issues by strategically timing management practices.

Below is a potential timeline for managing cover crops with considerations related to orchard management, followed by specific considerations for seeding and terminating.



A potential timeline for implementing cover crops for mature almond, pistachio, walnut and pecan orchards.

Seeding

There is a specific time window in which cover crop seeding should occur to minimize impacts to orchard management. Seeding should happen after harvest and after pruning to not hinder equipment and picking up the nuts, yet before the first rain and before the leaves fall, to avoid rain and leaf litter interrupting seed establishment (Hasey & Cady, 2016). Additionally, if rain occurs prior to cover crop seeding, weeds can establish early and outcompete cover crop establishment. If it is not possible to prune quickly after harvest, another option is to plant the cover crops in alternate tree rows. This will minimize disruption to seed germination and allow the machinery to easily traverse in the rows the cover crops are not planted in, while still accruing benefits in the cover cropped rows. For almond orchards to reap the benefits of attracting wild pollinators, it is important to plant cover crops early enough for the cover crop bloom to coincide with tail end bloom. Selecting plant species that bloom early, such as brassicas and phacelia, in addition to seeding soon after harvest, can increase the benefits from pollinators.

Terminating

Leaving the plants intact for as long as possible throughout the growing season will allow for a longer bloom, boosting pest control benefits and increasing the success of reseeding (Bugg & Waddington, 1994; *Seeds for Bees*, n.d.). However, deciding when to remove the cover crop requires a balance of maximizing biomass production and the need to conserve soil moisture for the nut trees (Grant et al., 2006) and to maintain a mowed (pistachio, walnut) or bare (almond) soil for harvesting. Terminating the cover crops in the spring by mechanical or chemical mowing allows enough time for the floor to be completely bare during harvest, a common concern among almond growers (Crézé et al., 2019). Orchard sanitation, or destroying mummy nuts for mitigating damage from navel orangeworms, can be combined with mowing the cover crop in the spring. A case study in California almond orchards demonstrated that cover crops will not get in the way of management practices if pruning occurs before cover crop seeding (after harvest) and sanitation occurs after cover crop termination (after bloom) (Crézé et al., 2019).

Maintaining cover crops in the summer will likely increase benefits for pest control and soil health, but may increase competition with the trees for water and nutrients (Bugg et al., 1991; Van Sambeek, 2017). This tradeoff should be considered, particularly in orchards with high summer water constraints. If there is a desire to extend the cover crop season, irrigation needs to be provided. If feasible, another terminantion method to consider is grazing by a small ruminant which also provides soil health benefits.

Technical Planting Guidance

Instructions for implementing cover crops will vary depending on each site and the plant species selected. The following are broad recommendations and options to get started. Unless stated otherwise, this information is adapted from the guidance provided in UC ANR's Planting a Cover Crop (Hasey & Cady, 2016) and Project *Apis m.* Seeds for Bees (*Seeds for Bees*, n.d.).

Ground Preparation, Seeding and Termination

The steps necessary for ground preparation are dependent on the current soil health and seeding equipment. Regardless of the method used, a flat, level surface is necessary. The best method for planting is direct seeding with a no-till drill, and most soil conditions are conducive for drill planting without needing ground preparation. Seeding is also possible using a broadcaster or grain drill. Ground preparation is likely necessary if seeding with a broadcaster or grain drill, unless the soil is already loose or sandy. If the ground is made up of heavy or clay soils, first work up the soil with a disk or harrow to create a fine seed bed. Seeds should be buried in the top quarter- to half-inch of soil. After broadcasting, cover the seed by using a ring roller or dragging a piece of chain-link fence behind an ATV or tractor.

Cover crops are planted in orchard interrow middles to avoid competition, and the tree rows are typically kept free of vegetation by tilling or using herbicides (Grant et al., 2006). Plant the cover crops as widely as possible without risking damage to tree roots during equipment use for cultivation, seeding and mowing practices to maximize benefits. Also consider the width of equipment when determining the width of planted middles, as seeding the width of your mower can increase efficiency (Grant et al., 2006). Most years, fall and winter rainfall can be sufficient for germination and winter growth in regions with low to moderate water constraints. However, some irrigation may be necessary to better synchronize blooms, in years with light rainfall, if maintaining vegetation year-round, or in regions with high water constraints.

To terminate the cover crops, disk or mow them as late as possible to encourage regrowth the following year from reseeding. An herbicide treatment applied at or before seeding can be helpful in preventing weed competition; however, some types of herbicide residue can inhibit cover crop growth and even with herbicide use there are plant residues that must be removed for a bare soil. Disking the cover crop into a biologically active soil is a solution for eliminating plant residues.

Other Considerations

To maximize pest control and pollinator benefits from incorporating managed vegetation and to protect wild insects, it is important to not spray insecticides, especially neonictinoids, on the flowering plants (Lee-Mader et al., 2015). If spraying is necessary, it is vital to mow and remove flowers at least 24 hours before spraying to decrease impacts to beneficial insects.

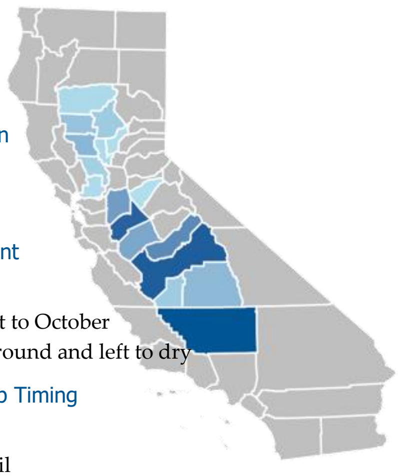
Equipment constraints can be a limitation of managing vegetation. No-till and grain drill rentals may be available from equipment suppliers and input suppliers. Broadcast seeders are less available, though another, possibly more challenging options is to use a fertilizer spreader. Other, more creative options include using a large belly grinder on a pickup truck tailgate or even a battery-powered ant bait spreader mounted on an ATV (Parsons, 2020).

OPPORTUNITIES AND CONSTRAINTS IN CALIFORNIA TREE NUTS

Managing vegetation in tree nut orchards has on-farm and broad-scale benefits. However, each tree nut sector faces a unique set of opportunities and challenges regarding integrating beneficial vegetation. This section provides crop-specific considerations for implementing cover crops on California almond, walnut, pistachio, and pecan orchards, and the following case study demonstrates cover crops in practice on California almond orchards.

More detailed information regarding orchard management, pest pressures, and IPM opportunities for each crop can be found in Appendix A. Crop-Specific Information.

Almond



California Production

- 1,180,000 acres
- $5,468,040,000

Orchard Management

- Cross pollinated
- Harvest is August to October
- Nuts shaken to ground and left to dry

Potential Cover Crop Timing

- Seed in October
- Terminate in April

Key Counties

Kern, Fresno, Stanislaus, Madera, San Joaquin, Merced, Colusa, Tulare, Glenn, Butte, Kings, Yolo, Tehama, Sutter, Solano, Yuba, and Calaveras Counties

Pistachio

California Production

- 288,000 acres
- $2,615,550,000

Orchard Management

- Wind pollinated
- Harvest is August to October
- Nuts shaken from tree and captured

Potential Cover Crop Timing

- Seed in October
- Mow in August, may reseed

Key Counties

Kern, Fresno, Tulare, Madera, and Kings Counties

Walnut

California Production

- 365,000 acres
- $878,800,000

Orchard Management

- Wind pollinated
- Harvest is August to November
- Nuts shaken to ground and swept

Potential Cover Crop Timing

- Seed in November
- Closely mow in July, may reseed

Key Counties

Tulare, San Joaquin, Butte, Stanislaus, Sutter, Glenn, Tehama, Colusa, Kings, Yuba, Yolo, Solano, Placer, Lake, Calaveras, and Amador Counties

Pecan

California Production

- 3,500 acres
- $7,400,000

Orchard Management

- Wind pollinated
- Harvest is October to December
- Nuts shaken from tree and swept

Potential Cover Crop Timing

- Seed in October
- Mow to turf in mid-September prior to harvest.

Key Counties

Pecans are not a leading commodity in any California counties.

California production of four tree nuts. Acres for almond (CDFA, 2020), pistachio (ACP, 2020), and walnut (USDA, 2020) reflect 2019 bearing acreage. Pecan bearing acreage, total production value for all crops, and production value maps of key counties production for all crops reflect 2018 statistics (CDFA, 2019).

Almonds

There are over one million acres dedicated to almond production in California, providing ample opportunity for creating environmental benefits. Further, almonds rely on pollinators, allowing direct economic opportunity to increase crop yield with cover crops that include wildflowers. Almonds also have the most available research regarding the benefits of cover crops that can be leveraged in alternative orchard management designs (see Almond Cover Crop Case Study).

Almond orchard management presents some challenges to cover crop adoption; however, none that cannot be overcome. Almonds are typically left on the orchard floor for around 10 days to dry. This requires a the orchard floor to be completely bare before harvest to ensure no moisture is introduced and there are no residues in the crop. Additionally, early almond bloom is earlier than the bloom of most plants, so plant selection is important to ensure pollinator benefits. Lastly, incorporating cover crops on all nut orchards mentioned might require adoption to the typical orchard management schedules, such as for sanitation and pruning but can be relatively easily accommodated (see Timing).

Pistachios

California pistachio production generates over $2 billion and is rapidly expanding with a 64% increase between 2018 and 2019 with 400,000 acres projected by 2026 (CDFA, 2019; Missiaen, 2019). This expansion provides ample opportunity to strategically work with growers on new orchards. Additionally, pistachios use substantially less water than almonds (Marvinney et al., 2014), so transitions from almond to pistachio production may not be uncommon given increasing water usage constraints. However, pistachios are more vulnerable to climate change (Luedeling et al., 2009; see Climate Change Impacts), so increasing orchard resilience is necessary to avoid financial risk during this period of rapid expansion.

During harvest, pistachios are captured during shaking and do not contact the orchard floor. Floor preparation for harvest is thus less important than for other tree nuts, allowing flexibility for vegetation in the interrow middles. It is likely possible to maintain cover crops through the growing season if water is not a large constraint; however, there is very little relevant research in pistachio orchards. While this provides opportunity for new research to lead the way, there may be unforeseen complications.

Walnuts

Managing vegetation in walnut orchards is not a new practice. Historically the focus has been on improving soil health and weed suppression (Grant et al., 2006). Walnuts are quickly swept after being shaken from the tree. Therefore, is important for the orchard floor to be closely mowed to ensure effective sweeping but the floor does not need to be completely bare. Water is less likely to be a constraint in walnuts than in almonds or pistachios because walnuts typically grow in northern, wetter regions and because the orchards are typically more shaded.

Walnuts are harvested relatively late, leaving only a short window for planting cover crops between harvest and the first rain. However, strategic timing for planting and occasional mowing for management activities should allow reseeding annual cover crops to persist in walnut orchards.

Pecans

Pecans have relatively low barriers to cover crop implementation. Pecan orchards rarely have pest pressures from navel orangeworm or ants, so sanitation (mummy nut removal) is not necessary. Additionally, pecan orchards are more likely to use high volume irrigation which can provide water for cover crops without additional cost. Cover crops can be maintained for the growing season, with limited mowings to preserve flowering resources, and mowed shortly before harvest. There is very little research regarding managed vegetation in California pecan orchards. However, EDF is leading the way with Orchards Alive.

Case Study: EDF's Orchards Alive in California Pecan Orchards

Orchards Alive, a pilot project funded by the Wildlife Conservation Board and implemented by EDF and partners, is demonstrating how transforming the bare ground of pecan orchards into pollinator habitat can benefit native wildlife while sustaining crop productivity. This project aims to:

- **Develop a custom cover crop species mix and management regime** to benefit native pollinators in maturing pecan orchards, while improving soil health and incorporating an ecological pest management approach.
- **Work with landowners** to implement this management regime in two pecan orchards.
- **Measure habitat outcomes** and project success using EDF's Habitat Quantification Tool.
- **Share results** with other orchard managers, agricultural groups and policymakers to create opportunities to scale.

Two farms in the Sacramento Valley have committed to planting a cover crop mix that includes native wildflowers on 325 total acres of pecan orchards, providing highly productive nectar and pollen resources for native bees and butterflies. EDF and partners are monitoring and evaluating the sites for plant diversity, habitat functionality for the monarch butterfly, pest pressure and abundance of beneficial insects and native pollinators. Soil health and soil organic matter content will also be monitored, allowing for a holistic evaluation of impacts above and below the orchard floor. Over the 2.5-years of project implementation, EDF and partners will also conduct outreach to develop scaling opportunities for the project approach. Participating landowners have agreed to maintain habitat benefits by managing cover crops and a hedgerow for a minumum of five years. During that time, they will carry out an active ecological pest management strategy that minimizes pesticide exposure risks for monarchs, other pollinators, and beneficial insects.

Orchards Alive is already yielding positive results. Initial monitoring results document avoided pesticide use as a result of beneficial insects effectively controlling aphid outbreaks. The project is an innovative approach, grounded in science and vetted for compatibility with pecan orchard operations by licensed pest control advisors and pecan orchard managers. Successful pollinator habitat projects could help scale up this technique and vastly increase the amount of pollinator habitat in the Central Valley and across the state. This approach will pave the way for the integration of multi-benefit pollinator habitat into pecan orchards at a large scale. Preliminary results from this project were included in proposals for research on cover crops, soil health, and disease suppression in perennial agricultural systems.

Cover crops integrated in a Orchards Alive participating pecan orchard, where plant species are providing valuable resources for native pollinators while sustaining crop productivity. Photo shows Crimson clover (red), phacelia (blue), CA poppy (orange) and white clover (lower left).
Photo: Rex Dufour, NCAT

Photo credit: Cynthia Crézé and Dr. Kent Daane, UC Davis Almond Cover Crop Lab

Case Study: Cover Crop Systems for California Almond Orchards

Exploring benefits and tradeoffs to inform management (Crézé et al., 2019)

A team of researchers from UC Davis and UC Cooperative Extension is examining the benefits and tradeoffs of implementing cover crops in almond orchards. Their research foci include soil health, water use, frost damage risk, soil-borne pest suppression, weed suppression, navel orangeworm pest control, pollination, orchard management, and grower practices and adoption. This project is ongoing and only preliminary results are currently available.

The study includes three commercial almond orchards across a precipitation gradient in Tehama, Merced, and Kern Counties. They are testing two seed mixes: a soil mix (legumes, brassicas and grass) and a pollinator mix (primarily brassicas). They maintained the cover crops from October to April.

Agronomic benefits

- *Increased yield.* Both mixes resulted in higher almond yields after one year when compared to bare soil and to resident vegetation.
- *Improved soil health*. Improved aggregate stability and water infiltration for all sites and both mixes. A heavily impacted orchard benefited the most from soil health benefits.
- *Nematode suppression*. The impact depended on both the plant and the nematode species.
- *Weed suppression*. Both mixes reduced winter weed populations more than standard herbicides.

Orchard management implications

- *Successful harvest*. The cover crop termination post-bloom resulted in no cover crop residues at the time of harvest. The clean orchard floor allowed for typical harvest operations.
- *Successful sanitation*. Cover crops did not interfere with sanitation and could even improve equipment access. Navel orangeworm pressure was similar in bare and cover cropped orchards.
- *No change in frost risk*. Cover crop did buffer temperatures in the topsoil, but air temperatures over three feet did not change. This impact is not well understood and if growers are concerned about frost risk, an option is to mow when frost is expected.

The researchers emphasize the importance for cover crop management to be site-specific depending on the grower's objectives and the regional climate. Additionally, they state that cover crops are a long-term investment, and benefits may not be visible until after several years. While only preliminary, these results justify optimism for increasing cover crop implementation on California almond orchards.

More information about this study can be found at UC Davis's Almond Cover Crop Project Overview.

CONCLUSION

Recommendations for Research and Field Scale Experimentation

While there is increasing interest in the benefits of managed vegetation, there is still much that we do not know. The majority of research on managing vegetation on agricultural landscapes has focused on annual cash crops, with little focus on conservation benefits. Additionally, research is often conducted as small-scale, controlled experiments. It can be challenging to translate the promising results from this research into field scale applications with growers and influence broader industry adoption.

Below, we provide recommendations for future research and field-scale experimentation that would inform study design to fill knowledge gaps regarding managed vegetation in tree crops. This experimentation is needed to create a cohesive, multi-sector tree crop resilience strategy.

On-Farm Benefits

- **Benefits of managing native versus nonnative plant species**. While planting native species will likely have greater conservation benefits, the difference in on-farm benefits is less understood. Growers have expressed that this is a knowledge gap for them as well (Brodt et al., 2019).
- **Impact of natural enemy populations on crop pests, crop quality and crop yield**. It is well documented that vegetation increases natural enemies (Chaplin-Kramer et al., 2011); but the corresponding benefits are less researched. For example, Chaplin-Kramer et al. (2011) analyzed 46 related studies and found that only 3 studies measured the impacts on crop quality and yield.
- **Contribution to crop quality and plant nutrition**. Cover crops provide benefits for soil health, but the influence of those benefits to crop quality and nutritional density, and the resulting reduction in fertilizer inputs, is less well understood. Understanding benefits may help growers decrease costs and enable price premiums.
- **Strategies for using cover crops for pastoral use**. Growers desire strategies for using cover crops in nut orchards for pastoral use, such as cattle pasture or sheep fodder (Brodt et al., 2019).
- **Strategies for extending cover crop season and supporting reseeding for reduced long term cost**. If a grower can allow enough time for a cover crop to go to seed, they can decrease the costs from repeated annual plantings. Experimentation regarding the length of the cover crop season, as well as related cost-benefit analyses, are needed.
- **Timing and amount of nitrogen uptake in mature orchards**. Because cover crops are not grown in the tree line, it's not entirely clear whether cover crops reduce nitrogen needs for the trees. Further, the nitrogen release from the cover crop needs to be synchronized with tree nitrogen demand. Determining the timing and amount of nitrogen update in mature orchards is paramount to develop integrated nitrogen management strategies and it remains a key knowledge gap.
- **Impacts on air quality.** Traditional harvesting in almonds contributes to particulate matter air pollution (Baticados, 2019). Improvements to soil structure from cover crops may reduce soil loss and air pollution during the pick-up process, but this area is in need of research.

Grower Concerns and Decision-Making

- **Cost-benefit analyses**. While some cost-benefit analyses have been conducted (DeVincentis et al., 2020; Morandin et al., 2016), further understanding of economic tradeoffs, ecosystem services value, strategies for decreasing costs (i.e. reseeding), and impacts of cost-share programs is necessary.

- **Impacts on frost risk.** Because cover crops may buffer temperature, growers are concerned about increased frost risk. While preliminary results demonstrate that temperature changes may not be sufficient to influence frost risk in orchards (Crézé et al., 2019), further research is needed.
- **Specific impacts on water use.** Depending on the irrigation system, plant species, climatic region and annual weather, cover crops may or may not require additional water inputs. Recent research demonstrates benefits to water infiltration and retention from cover crops can offset greater water demand (DeVincentis, 2020). However, specific guidance around the ideal conditions to limit need for additional water inputs is needed.
- **Potential for collaboration with PCA and CCAs to spread information on the benefits of managed vegetation**. Each PCA and CCA's background and training could influence their recommendations. Research is needed to understand the potential value for PCA and CCA training, specifically on the management of beneficial vegetation, in increasing grower adoption.

Broad-Scale Sustainability

- **Carbon sequestration potential.** Increasing vegetation on a farm will increase carbon sequestration (Poeplau & Don, 2015), which allows broad-scale benefits. Detailed quantification of these benefits could be useful to growers, particularly if they are able to benefit from carbon sequestration such as through a carbon trading network (Suddick et al., 2013). Further research is needed to determine the longevity of carbon storage in the tree nut orchard context.
- **Capacity to buffer farms from erratic weather extremes**. While it is not well understood, there is potential for cover crops to increase resilience to climate change by acting as a buffer to temperature and precipitation changes. Understanding these benefits may increase adoption.
- **Impacts of climate change on beneficial insects**. Climate change is likely to increase crop pests (Luedeling et al., 2011), but more research is needed regarding the impacts on natural enemies.
- **Regional impact of cover crops on native insect populations.** On a broad scale, increased vegetation has the potential to support insect populations. Further understanding would be beneficial to conservation planning, especially for insects known to be in decline like native bees.
- **Impacts to water table recharge.** Research regarding whether cover crops increase water table recharge could be important for improving water usage, particularly in the context of SGMA.

Crop-Specific Case Studies

- **Case studies on pistachio orchards.** Studies regarding the impacts of incorporating vegetation on pistachio orchards are lacking. Given pistachio's rapid expansion in California (CDFA, 2019; Missiaen, 2019), case studies in the near future could encourage adoption on new orchards.

Call to Action

Increasing resilience for Central Valley orchards requires a new strategy — one that pairs small-scale, highly-controlled experiments with field-scale application and research on working farms. Many of the benefits outlined in this report compound when coordinated among landowners in a local region. Ideally, on-farm research will develop a network of multi-disciplinary experiments to inform regional biological infrastructure strategies to establish a more resilient landscape.

While relying on scientific evidence is critical, research studies may not always play a key role in grower decision-making. Instead, prioritizing communication efforts, particularly peer-to-peer communication via farmer demonstrations, may more heavily influence grower adoption of conservation practices. Additionally, the up-front costs of managing vegetation may decrease economic sustainability and act as a barrier to interested growers. Further effort is needed to expand the variety of mechanisms available to finance restoration beyond the traditional state and federal cost-share programs, and ensure growers have access to relevant knowledge and resources. Lastly, alternative methods to increase broad-scale adoption are needed, such as engaging the supply chain in actively experimenting with and pursuing integrated orchard management.

Lastly, practitioners should be encouraged to learn as they go. Waiting for perfect information will lead to lost opportunities for creating on-the-ground conservation benefits. While research continues, there is enough evidence to know that efforts in managing vegetation in tree crops are a low risk strategy that will deliver some level of agronomic and ecological benefits. Applied research will enable learning while also improving the soil microbiome, increasing water retention and nutrient cycling, long term soil carbon storage potential, contributing to better worker safety and health by reducing pesticide use, and creating habitat to support biodiversity across the region.

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APPENDIX A. CROP-SPECIFIC INFORMATION

Almonds

Almonds are California's third leading commodity crop and top leading export, generating over $5.5 billion in production value. California is responsible for the entirety of domestic production and 78% of worldwide production (CDFA, 2019). With over one million acres of California almond production, there is ample opportunity for creating significant environmental benefits by integrating conservation features.

California almonds are not projected to be substantially impacted by temperature changes due to climate change. This is due to their relatively low requirements for chilling hours and because harm to yield from winter warming may be counteracted by an increase in yield from summer and spring warming (Luedeling et al., 2009; Lobell & Field, 2011). However, pest pressures are likely to increase with climate change, so increasing resilience should remain a priority (Luedeling et al., 2011). More information is in Climate Change Impacts.

Almonds can greatly benefit from pollination services by managing vegetation. Managed vegetation can increase wild pollinators, leading to increases in crop yield (Brittain et al., 2013; Klein et al., 2012). These benefits are further explored in Pollination and Appendix B. Annotated Bibliography.

Increasing communication regarding benefits from ecosystem services may increase adoption of conservation practices on almond orchards. Given the reliance of growers on advisors, such as PCAs and CCAs for pest management decisions (Brodt et al., 2005), appropriate biological strategies need to be better incorporated into their expertise and services.

Almonds are a leading commodity in Kern, Fresno, Stanislaus, Madera, San Joaquin, Merced, Colusa, Tulare, Glenn, Butte, Kings, Yolo, Tehama, Sutter, Solano, Yuba, and Calaveras Counties.

CALIFORNIA ALMOND FAST FACTS

Acreage	1,181,000 acres[1]
Production value	$5,468,040,000[2]
% US production	100%[2]
Pollination	Cross-pollinated
Harvest	Nuts shaken to ground
Climate change impacts	Temp changes: low[3] Pest pressure: high[4]

[1] 2019 bearing acreage (CDFA, 2020)
[2] Data for 2018 (CDFA, 2019)
[2] (Luedeling et al., 2009; Lobell & Field, 2011)
[3] (Luedeling et al., 2011)

Orchard Management

Orchard floor preparation and harvest

Orchard floor management is extremely important to almond growers because the crop is picked up from the soil surface after being shaken from the trees (Mosz, 2002a). The need for bare soil during summer is likely the primary perceived constraint to incorporating cover crops in almond orchards. However, there are many benefits to gain from maintaining cover crops from fall to spring, or possibly year-round in young trees that don't require harvest. While mowing to prepare the orchard floor for harvest typically begins in February (Mosz, 2002a), a study in Merced County demonstrated it is possible to delay mowing until May, June, or even July in some organic and low-input orchards (Hendricks, 1995).

Almonds are harvested using a shaker, causing the nuts to fall to the orchard floor. After the nuts fall to the floor, they are allowed to dry for seven to fourteen days (Mosz, 2002a). Drying is important for efficient removal from the shell; almonds are picked up quickly when they are dry to avoid exposure to moisture, fungus, and insects (Kader, 2013). Then, mechanical sweepers move the nuts into rows that are gathered by a pickup machine.

The sweeping and pick-up process contribute substantially to particulate matter air pollution (Baticados, 2019). Thus, improvements to soil structure from cover crops may reduce soil loss and air pollution during the pick-up process, but this area is in need of research (see Research Recommendations). Any benefits assigned to cover crops and their prolonged inclusion in orchards may also encourage off-ground harvest and drying methods within the industry, offering additional benefits to air quality.

Irrigation

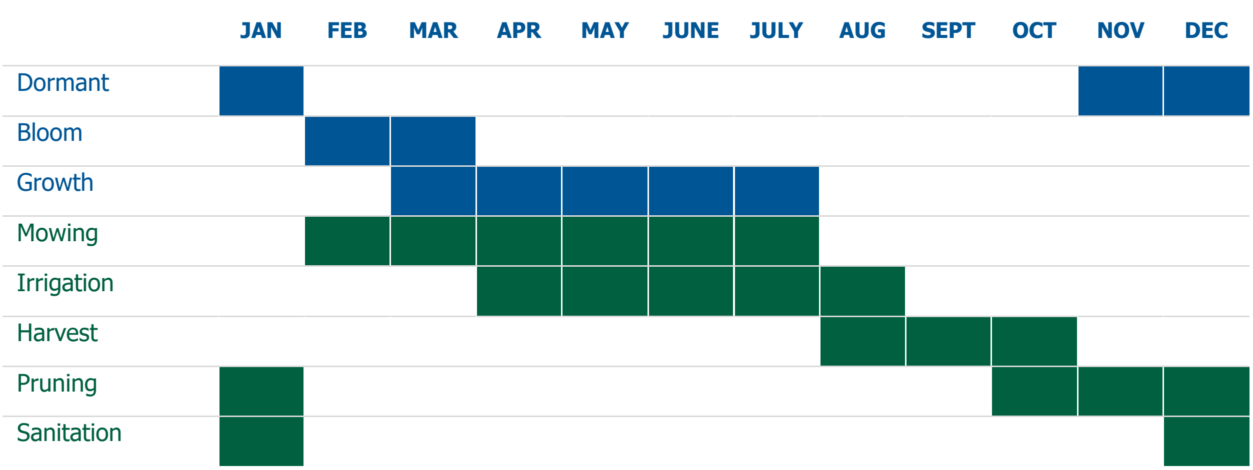
Most California almond orchards use low-volume irrigation systems, such as microirrigation or dripline systems which provide water to a narrow tree berm (Lepsch et al., 2019). Low-volume irrigation systems are not very amenable to cover crops compared to flood irrigation. Water constraints in the summer may make it difficult to maintain cover crops without additional irrigation water usage.

Due to differences in climate, management practices may vary between the Sacramento and San Joaquin Valleys. Orchards with flood irrigation, which may be more common in regions with greater water availability, may be more amenable to integrating cover crops, particularly if an objective is to manage cover crops into the late spring or early summer.

Sanitation

To mitigate yield losses from navel orangeworm, almond's primary pest, it is necessary to "sanitize" the orchard, or destroy and remove mummy nuts after harvest. Sanitation is typically conducted in winter with a shaker and flail mower (Mosz, 2002a), so the need to prepare row middles for sanitation may be interrupt cover crop germination. However, it is possible to sanitize prior to cover crop planting or to combine cover crop mowing with mummy nut flail mowing (Parsons, 2020). Further, navel orangeworm sanitation may be less necessary on orchards with cover crops because the cover crops increase mummy nut decomposition (Bugg & Waddington, 1994). High levels of biological control may decrease need for sanitation as well (Hendricks, 1995).

Almond timeline in a conventional orchard, adapted from USDA Regional IPM Centers' *Almond Timeline* (Mosz, 2002a). Blue represents crop stages and green represents worker activities.



Pest Pressures & IPM Opportunities

Managing vegetation in almond orchards is not likely to eliminate the need for pesticides, and it may not work for all farmers. However, these practices can be a valuable part of an integrated pest management strategy, including biological, cultural and chemical pest control practices. The focus of this section is on cultural practices that are mindful of pest and natural enemy ecology and can increase the effectiveness of pest management strategies. Primary almond pests in California include navel orangeworm (*Amyelois transitella*), peach twig borer (*Anarsia lineatella*), scales, mites and ants. Unless stated otherwise, the following information is adapted from UC IPM's Pest Management Guidelines (UC IPM, n.d.) and USDA Regional IPM Centers' *Almond Timeline* (Mosz, 2002a). Further, the following tables summarize pests, pesticides, common natural enemies and beneficial plant species to attract them.

Using key takeaways from a 6-year study on almond orchards in Merced County, Hendricks (1995) describes steps to decreasing pesticide use with IPM practices, including the following.

1. Eliminate in-season insecticide sprays with proper winter sanitation.
2. Establish a good cover crop and, when necessary, mow middles alternately.
3. Monitor pests very carefully and avoid using disruptive insecticide sprays.
4. Harvest promptly.

ALMOND PRIMARY PESTS	NATURAL ENEMIES
Navel Orangeworm Navel orangeworm is almond's primary pest, responsible for most almond rejects at harvest. Nuts that have fallen to the ground provide navel orangeworm with overwintering sites; mitigating navel orangeworm can be done with effective sanitation practices that quickly remove or destroy nuts on orchard floors after harvest. A study in Kern County demonstrated that navel orangeworm damage can be brought below 2% by reducing nut mummies in trees and on the ground before spring (Higbee & Siegel, 2009). Cover crops also aid in decomposing unharvested almonds, decreasing the availability of navel orangeworm overwintering sites (Bugg & Waddington, 1994). Further, a study in Merced County almond orchards demonstrated that with effective biological control, sanitation for navel orangeworm may not be necessary (Hendricks, 1995). Navel orangeworm occurrence may also increase with peach twig borer abundance because navel orangeworm larvae may enter kernels damaged by peach twig borer. Effective management of peach twig borer may also help manage navel orangeworm.	▪ Bigeyed bugs ▪ Damsel bugs ▪ Minute pirate bugs ▪ Lacewings ▪ Spiders ▪ Tachinid flies ▪ Wasps
Peach Twig Borer Peach twig borers feed on shoots and nuts. There are no known cultural practices to decrease peach twig borer damage, so insecticides are often necessary.	▪ Damsel bugs ▪ Soldier beetles ▪ Tachinid flies ▪ Wasps ▪ Spiders

Scales Two scales infest almond orchards as primary pests: the San Jose scale and the European fruit lecanium. The San Jose scale decreases tree nut production and can even kill trees. Cultural practices to mitigate damage from the San Jose scale include decreasing pesticide use and decreasing dust, both of which cover crops can help accomplish. The San Jose scale is typically kept under control by natural enemies in orchards that avoid intensive pesticide use during the growing season, so scale populations can actually increase with pesticide use. To avoid unnecessary pesticide use for the European fruit lecanium, it is important to be aware of impacts from the weather. European fruit lecaniums are often controlled by the combination of natural enemies and summer temperatures consistently over 100°F. Additionally, low winter mortality due to mild temperatures can permit a buildup of scale numbers.	▪ Minute pirate bugs ▪ Lacewings ▪ Beetles ▪ Predatory mites ▪ Wasps
Mites Cultural practices that can mitigate mite damage include decreasing pesticide use and decreasing dust. Dust can interfere with natural enemy activity and increase the risk of spider mite outbreaks. In-season insecticide use of almond orchards for pests including the peach twig borer, scales or the navel orangeworm, can also cause secondary outbreaks (Zalom et al., 2001). This is because broad-spectrum pesticides harm predatory mites, important predators of mites such as the brown mite. Spraying for spider mites and San Jose scales is often necessary in conventional almond orchards, but may not be necessary in organic or low-input almond orchards (Hendricks, 1995).	▪ Bigeyed bugs ▪ Damsel bugs ▪ Lacewings ▪ Minute pirate bugs ▪ Beetles ▪ Predatory mites
Ants In addition to mitigating damage from navel orangeworm, proper orchard sanitation can also help control ants because they rely on nuts that have fallen to the ground as a food source. Damage to almond orchards from southern fire ants increases with number of days that nuts are left on the ground; nuts left for four days can lead to up to 2% damage, whereas nuts left for 21 days can lead to up to 11% damage.	▪ Spiders

Summary of relevant aspects of pest management for almonds in California, including primary pests, natural enemies, and beneficial plants that can attract them. This information is from the UC IPM Pest Management Guidelines for Agricultural Pests (UC IPM, n.d.), NCAT's Farmscaping to Enhance Biological Control: Pest Management Systems Guide (DuFour, 2000), and the NRCS California eVeg Guide. Asterisks denote California native plants.

INVERTEBRATE PESTS

Ants
- Pavement ant
- Southern fire ant
- Red imported fire ant

Beetles
- American plum borer
- Peach twig borer
- Peachtree borer
- Prune limb borer
- Tenlined June beetle

Bugs
- Leaffooted bug
- Stink bugs
  - Green stink bug
  - Redshouldered stink bug
  - Uhler stink bug

Caterpillars
- Forest tent caterpillar
- Navel orangeworm
- Oriental fruit moth

Leafrollers
- Fruittree leafroller
- Obliquebanded leafroller

Mites
- Brown mite
- European red mite
- Peach silver mite
- Spider mites
  - Pacific spider mite
  - Strawberry spider mite
  - Twospotted spider mite

Scales
- European fruit lecanium
- San Jose scale

NATURAL ENEMIES

Beetles
- Lady beetles
- Ground beetles
- Rove beetles
- Tiger beetles
- Sap beetles
- Soldier beetles
- Spider mite destroyers

Bugs
- Assassin bugs
- Bigeyed bugs
- Damsel bugs
- Minute pirate bugs
- Predatory seed bugs

Flies
- Tachinid flies

Lacewings
- Green lacewings
- Brown lacewings

Praying mantids

Predatory thrips
- Sixspotted thrips

Spiders & mites
- Predatory mites
- Spiders

Wasps
- Aphelinid wasps
- Braconid wasps
- Chalcid wasps

BENEFICIAL PLANTS

Buckthorns
Amaranth, buckthorn, California lilacs*

Buckwheats
Common knotweed, California buckwheat*, California lilacs*

Carrot family
Caraway, Queen Anne's lace, dill, angelica*, fennel, tansy, bishop's weed, coriander, chervil, parsley, anise

Cereals & Grasses
Corn, rye, blue wildrye*, purple needle grass*, other grains

Legumes
Berseem clover, subterranean clover, alfalfa, crimson clover, hairy vetch, black locust, hemp sesbania, white clover, cowpea, sweet clover, arroyo lupine*, bull clover*, lacy phacelia*, native lupines*

Mint family
Spearmint

Mustard family
Sweet alyssum, mustard, candy tuft, meadowfoam*

Sunflower family
Native goldenrod*, yarrow*, native coreopsis*, cosmos, sunflower*, dandelion, golden marguerite, tidy tips*, daisies, marigold

Other Native Wildflowers
California poppy*, mountain pride*, ithuriel's spear*, baby-blue-eyes*, native milkweeds*

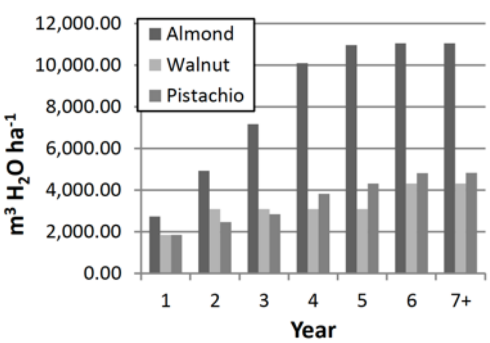
Summary of pesticides used in California almond orchards, affected groups, and toxicity to natural enemies. Adapted from the UC IPM Pest Management Guidelines for Agricultural Pests (UC IPM, n.d.): Relative Toxicities of Pesticides Used in Almonds to Natural Enemies and Honey Bees. Toxicities reflect the most conservative (i.e. highest) toxicity level to predatory mites, general predators, and parasites.

PESTICIDE	**SELECTIVITY**	**AFFECTED GROUPS**	**TOXICITY**
Abamectin - Clinch	▪ Narrow	▪ Ants	▪ Low
Metaflumizone	▪ Narrow	▪ Ants	▪ Low
Methoprene	▪ Narrow	▪ Ants	▪ Low
Pyriproxyfen – Esteem	▪ Narrow	▪ Ants	▪ Low
Diflubenzuron	▪ Narrow	▪ Caterpillars	▪ High
Bacillus thuringiensis	▪ Narrow	▪ Caterpillars	▪ Low
Methoxyfenozide	▪ Narrow	▪ Caterpillars	▪ Low
Chlorantraniliprole	▪ Narrow	▪ Caterpillars	▪ Medium
Emamectin benzoate	▪ Narrow	▪ Caterpillars	▪ Unknown
Spinetoram	▪ Narrow	▪ Caterpillars, aphids, scales	▪ High
Spinosad	▪ Narrow	▪ Caterpillars, aphids, scales	▪ High
Clothianidin*	▪ Broad	▪ Caterpillars, leaffooted bugs, stink bugs	▪ High
Petroleum oils	▪ Broad	▪ Exposed insects, mites	▪ Low
Bifenthrin	▪ Broad	▪ Insects and mites	▪ High
Carbaryl	▪ Broad	▪ Insects and mites	▪ High
Chlorpyrifos - in season	▪ Broad	▪ Insects and mites	▪ High
Cyfluthrin	▪ Broad	▪ Insects and mites	▪ High
Diazinon	▪ Broad	▪ Insects and mites	▪ High
Esfenvalerate	▪ Broad	▪ Insects and mites	▪ High
Fenpropathrin	▪ Broad	▪ Insects and mites	▪ High
Phosmet	▪ Broad	▪ Insects and mites	▪ High
Chlorpyrifos - dormant	▪ Broad	▪ Insects and mites	▪ Medium
Clofentezine	▪ Narrow	▪ Mites	▪ High
Bifenazate	▪ Narrow	▪ Mites	▪ Low
Hexythiazox	▪ Narrow	▪ Mites	▪ Low
Acequinocyl	▪ Narrow	▪ Mites	▪ Unknown
Etoxazole	▪ Narrow	▪ Mites	▪ Unknown
Spirodiclofen	▪ Narrow	▪ Mites	▪ Unknown
Abamectin – Agri-Mek	▪ Moderate	▪ Mites and leafminers	▪ High
Fenpyroximate	▪ Narrow	▪ Mites and some insects	▪ High
Sulfur	▪ Narrow	▪ Mites and thrips	▪ High
Fenbutatin oxide	▪ Narrow	▪ Pest mites	▪ Low
Proparigite	▪ Narrow	▪ Pest mites	▪ Medium
Lambda-cyhalothrin	▪ Broad	▪ Plant bugs, beetles, caterpillars	▪ High
Pyriproxyfen – Seize	▪ Narrow	▪ Scales and beetles	▪ High
Buprofezin	▪ Narrow	▪ Sucking insects and beetles	▪ High

Pistachios

Pistachios are California's sixth leading commodity crop and second leading export, generating over $2 billion in production value (CDFA, 2019). Pistachio production is rapidly expanding, with a 64% increase between 2018 and 2019 (CDFA, 2019) and 400,000 acres projected by 2026 (Missiaen, 2019). The current expansion provides an excellent opportunity to strategically work with growers to integrate agronomic and ecological benefits on new orchards.

Water is often limiting in California and, considering new legal obligations under the Sustainable Groundwater Management Act (SGMA) and increased frequency of droughts and heat waves due to climate change, pressures to decrease water usage are likely to increase. A benefit of increased pistachio production is the relatively low water requirement, particularly compared to almonds (Marvinney et al., 2014; see figure below). Some argue that due to pistachio's lower water requirement, longer lifespan, and higher resistance to drought, seeing almond orchards replaced by pistachio orchards will not be uncommon (Schapiro, 2019).



Variation in irrigation water by year and crop (Marvinney et al., 2014).

Pistachios are a leading commodity in Kern, Fresno, Tulare, Madera, and Kings Counties.

CALIFORNIA PISTACHIO FAST FACTS

Acreage	288,000 acres[1]
Production value	$2,615,550,000[2]
% US production	100%[2]
Pollination	Wind pollinated
Harvest	Nuts captured
Climate change impacts	Temp changes: high[3] Pest pressure: high[4]

[1] 2019 bearing acreage (ACP, 2020)
[2] Production value data for 2018 (CDFA, 2019)
[3] (Luedeling et al., 2009; Lobell & Field, 2011)
[4] (Luedeling et al., 2011)

Recent models project that California pistachios may be substantially impacted by climate change. Regions in California where winter chill meets pistachio's high requirements may no longer exist by 2080 (Luedeling et al., 2009). Additionally, pest pressures are likely to increase for several primary pests (Luedeling et al., 2011). Increasing resilience should be a priority.

Orchard Management

The following information is adapted from USDA Regional IPM Centers' *Pistachio Timeline* (Mosz, 2002b).

Orchard Floor Preparation and Harvest

Orchard floor preparation is not as large of a concern as it is for almonds and walnuts, because pistachios do not fall to the floor during harvest. However, orchard floor management is still important for weed control and to allow equipment in the interrow middles. Tillage and herbicide applications are typically used to keep interrow middles clean. Typically, a shaker with a catching frame is used to dislodge and capture the nuts. In young orchards, the nuts are hand harvested because the trees are more sensitive to shaking.

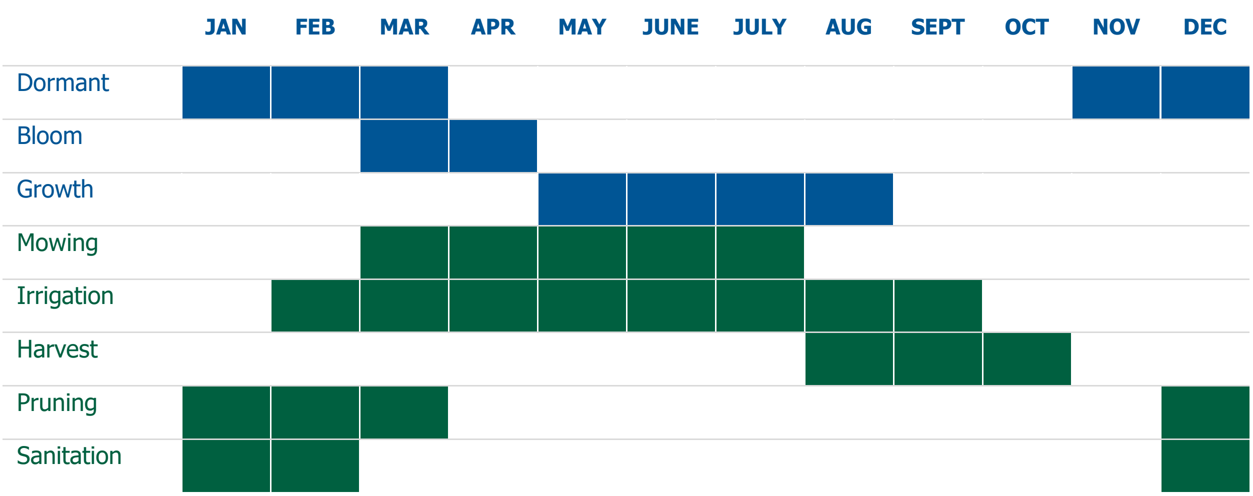
Irrigation

Low-volume irrigation systems, such as drip and micro-sprinkler irrigation, are used in most pistachio orchards. Low-volume irrigation systems are not very amenable to cover crops compared to flood or sprinkler irrigation. Water constraints in the summer may make it difficult to maintain cover crops without additional irrigation water usage.

Sanitation

Removal of mummy nuts is important for management of the navel orangeworm. Sanitation occurs well after harvest in the dormant season to allow greater maturity and increase the ease of removal. Trees are mechanically shaken, but unlike harvest, the nuts fall to the ground. In some orchards and conditions, nuts are allowed to rot, but in others, the nuts must be destroyed. Cover crops may interfere with sanitation; however, this is avoidable by shifting the typical sanitation schedule to outside of the time cover crops are maintained (i.e. after harvest but before cover crop seeding) or by mowing prior to sanitation.

Pistachio timeline in a conventional orchard, adapted from USDA Regional IPM Centers' *Pistachio Timeline* (Mosz, 2002b). Blue represents crop stages and green represents worker activities.



Pest Pressures & IPM Opportunities

Cultural practices that are mindful of pest and natural enemy ecology can increase the effectiveness of pest management strategies in pistachio orchards. Primary pistachio pests in California include navel orangeworm (*Amyelois transitella*), obliquebanded leafroller (*Choristoneura rosaceana*), citrus flat mite (*Brevipalpus lewisi*), plant bugs and soft scales. Unless stated otherwise, the following information is adapted from UC IPM's Pest Management Guidelines (UC IPM, n.d.) and USDA Regional IPM Centers' *Pistachio Timeline* (Mosz, 2002b). Further, the following tables summarize pests, pesticides, common natural enemies and beneficial plant species to attract them.

PISTACHIO PRIMARY PESTS	NATURAL ENEMIES
Navel Orangeworm Navel orangeworm in pistachios can lead to crop losses and aflatoxin contamination. Nuts that have fallen to the ground provide navel orangeworm with overwintering sites; mitigating navel orangeworm can be done with effective sanitation practices that quickly remove or destroy nuts on orchard floors after harvest. Kernels decompose more quickly in moisture, so it is important to sanitize before the first rain. Cover crops or grasses in interrow middles can also increase moisture and aid in decomposition, decreasing availability of overwintering sites. Managing pests that increase the number of mummy nuts, such as the citrus flat mite, can also aid in decreasing mummy nut availability. It is also possible that navel orangeworm populations increase in orchards with obliquebanded leafroller infestations. Harvest date and proximate almond orchards may also influence damage from navel orangeworm. In the San Joaquin Valley, nuts harvested earlier (late August to early September) have lower levels of damage compared to those harvested later. Navel orangeworm in pistachio orchards may originate in adjacent almond orchards. Reduction efforts for pistachio should include reduction efforts in nearby almond orchards as well (Andrews & Barnes, 1982).	▪ Bigeyed bugs ▪ Damsel bugs ▪ Minute pirate bugs ▪ Lacewings ▪ Spiders ▪ Tachinid flies ▪ Wasps
Obliquebanded Leafroller Obliquebanded leafroller reduces crop yield by causing defoliation and stem damage. There are not cultural practices known to effectively decrease obliquebanded leafrollers, but there are effective, low-risk pesticides such as *Bacillus thuringiensis* (Bt).	▪ Bigeyed bugs ▪ Damsel bugs ▪ Minute pirate bugs ▪ Lacewings ▪ Spiders ▪ Tachinid flies ▪ Wasps
Soft Scales Soft scales produce honeydew which can increase mold growth and decrease photosynthesis. Scales are typically kept under control by natural enemies. However, permethrin treatments for other pests decreases the prevalence of natural enemy populations, resulting in an increase in scale populations. While decreasing pesticide use can help manage scales, there are also options for effective biological controls, such as with the release of *Metaphycus* parasitic wasps, and dormant oil sprays.	▪ Minute pirate bugs ▪ Lacewings ▪ Beetles ▪ Predatory mites ▪ Wasps
Citrus Flat Mite Citrus flat mites cause damage to nuts and stems. Damaged nuts remain on the trees as mummy nuts, increasing the number of overwintering sites for navel orangeworm. There are not cultural practices known to effectively decrease citrus flat mites. Sulfur is an organic option; however, sulfur can be toxic to natural enemy populations.	▪ Bigeyed bugs ▪ Damsel bugs ▪ Lacewings ▪ Minute pirate bugs ▪ Beetles ▪ Predatory mites

Plant Bugs

Plant bugs feed on orchard vegetation, then move to the orchard trees when other vegetation dries out. Thus, strategic species selection and management of managed vegetation is important to control plant bugs. Mowing ground cover before orchard bloom can also reduce populations. Natural enemies may also effectively control plant bug pests.

- Assassin bugs
- Bigeyed bugs
- Lacewings
- Damsel bigs
- Spiders

Summary of relevant aspects of pest management for pistachios in California, including primary pests, natural enemies, and beneficial plants that can attract them. This information is from the UC IPM Pest Management Guidelines for Agricultural Pests (UC IPM, n.d.), NCAT's Farmscaping to Enhance Biological Control: Pest Management Systems Guide (DuFour, 2000), and the NRCS California eVeg Guide. Asterisks denote California native plants.

INVERTEBRATE PESTS	NATURAL ENEMIES	BENEFICIAL PLANTS
Aphids ▪ Cotton aphid Beetles ▪ Darkling beetles Bugs ▪ False chinch bug ▪ Leaffooted bug ▪ Small plant bugs ▫ California buckeye bug ▫ Calocoris bug ▫ Phytocoris bug ▫ Western tarnished plant bug ▪ Stink bugs ▫ Green plant bug ▫ Green stink bug ▫ Redshouldered stink bug Caterpillars ▪ Navel orangeworm ▪ Western tussock moth Leafrollers ▪ Obliquebanded leafroller Mealybugs ▪ Gill's mealybug ▪ Grape mealybug Mites ▪ Citrus flat mite ▪ Spider mites ▫ Pacific spider mite ▫ Twospotted spider mite Scales ▪ Black scale ▪ Brown soft scale ▪ European fruit lecanium ▪ Frosted scale Wasps ▪ Pistachio seed chalcid	Beetles ▪ Lady beetles ▪ Ground beetles ▪ Mealybug destroyer ▪ Rove beetles ▪ Soldier beetles ▪ Spider mite destroyers Bugs ▪ Assassin bugs ▪ Bigeyed bugs ▪ Damsel bugs ▪ Minute pirate bugs Flies ▪ Aphid midges ▪ Syrphid flies ▪ Tachinid flies Lacewings ▪ Brown lacewings ▪ Dustywings ▪ Green lacewings Praying mantids Predatory thrips ▪ Sixspotted thrips Spiders & mites ▪ Predatory mites ▪ Spiders Wasps ▪ Braconid wasps ▪ Chalcid wasps	Buckthorns Amaranth, buckthorn, California lilacs* Buckwheats Common knotweed, California buckwheat*, California lilacs* Carrot family Caraway, Queen Anne's lace, dill, angelica*, fennel, tansy, bishop's weed, coriander, chervil, parsley, anise Cereals & Grasses Corn, rye, blue wildrye*, purple needle grass*, other grains Legumes Berseem clover, subterranean clover, alfalfa, crimson clover, hairy vetch, black locust, hemp sesbania, white clover, cowpea, sweet clover, arroyo lupine*, bull clover*, lacy phacelia*, native lupines* Mint family Spearmint Mustard family Sweet alyssum, mustard, candy tuft, meadowfoam* Sunflower family Native goldenrod*, yarrow*, native coreopsis*, cosmos, sunflower*, dandelion, golden marguerite, tidy tips*, daisies, marigold Other Native Wildflowers California poppy*, mountain pride*, ithuriel's spear*, baby-blue-eyes*, native milkweeds*

Summary of pesticides used in California pistachio orchards, affected groups, and toxicity to natural enemies. Adapted from the UC IPM Pest Management Guidelines for Agricultural Pests (UC IPM, n.d.): Relative Toxicities of Pesticides Used in Pistachios to Natural Enemies and Honey Bees. Toxicities reflect the most conservative (i.e. highest) toxicity level to predatory mites, general predators, and parasites.

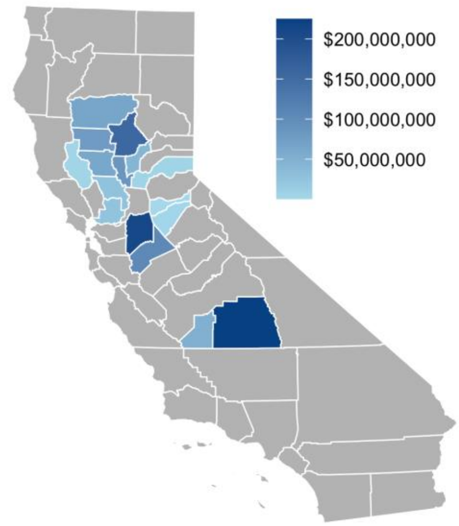
PESTICIDE	SELECTIVITY	AFFECTED GROUPS	TOXICITY
Lambda-cyhalothrin	▪ Broad	▪ Beetles and caterpillars	▪ High
Methoxyfenozide	▪ Narrow	▪ Caterpillars	▪ High
Bacillus thuringiensis	▪ Narrow	▪ Caterpillars	▪ Low
Chlorantraniliprole	▪ Narrow	▪ Caterpillars	▪ Medium
Emamectin benzoate	▪ Narrow	▪ Caterpillars	▪ Unknown
Spinetoram	▪ Narrow	▪ Caterpillars, thrips, whiteflies, aphids, scales, and leafminers	▪ High
Spinosad	▪ Narrow	▪ Caterpillars, thrips, whiteflies, aphids, scales, and leafminers	▪ Medium
Acephate	▪ Broad	▪ Insects and mites	▪ High
Bifenthrin	▪ Broad	▪ Insects and mites	▪ High
Carbaryl	▪ Broad	▪ Insects and mites	▪ High
Cyfluthrin	▪ Broad	▪ Insects and mites	▪ High
Permethrin	▪ Broad	▪ Insects and mites	▪ High
Phosmet	▪ Broad	▪ Insects and mites	▪ High
Spirotetramat	▪ Narrow	▪ Mealybugs and aphids	▪ Low
Fenpyroximate	▪ Narrow	▪ Mites	▪ High
Etoxazole	▪ Narrow	▪ Mites	▪ Medium
Spirodiclofen	▪ Narrow	▪ Mites	▪ Medium
Sulfur	▪ Narrow	▪ Mites and citrus thrips	▪ High
Imidacloprid	▪ Narrow	▪ Sucking insects	▪ High
Pyriproxyfen	▪ Narrow	▪ Sucking insects	▪ High
Fenpropathrin	▪ Narrow	▪ Sucking insects	▪ Unknown
Buprofezin	▪ Narrow	▪ Sucking insects and beetles	▪ High
Acetamiprid	▪ Moderate	▪ Sucking insects and larvae	▪ High

Walnuts

Walnuts are California's 13th leading commodity crop, generating over $800 million in production value (CDFA, 2019).

Recent models project that California walnuts may be substantially impacted by temperature changes due to climate change. Regions in California where winter chill meets walnut's high requirements may no longer exist by 2080 (Luedeling et al., 2009). However, summer and spring warming may increase yields (Lobell & Field, 2011). Additionally, pest pressures are likely to increase (Luedeling et al., 2011). Given walnuts' vulnerability to climate change, increasing resilience should be a priority.

Managing vegetation in walnut orchards is not a new practice. Historically the focus has been on improving soil health and weed suppression, and less on pest control, so plant species utilized reflect those objectives (Grant et al., 2006). However, a 2016 survey found that a large proportion (47%) of California walnut growers use conservation biological control practices, including minimizing pesticide use and enhancing natural enemy habitats. Further research on pest control benefits to walnut orchards may help increase integration of flowering plants in walnut orchards.



Walnuts are a leading commodity in Tulare, San Joaquin, Butte, Stanislaus, Sutter, Glenn, Tehama, Colusa, Kings, Yuba, Yolo, Solano, Placer, Lake, Calaveras, and Amador Counties.

CALIFORNIA WALNUT FAST FACTS

Acreage	365,000 acres[1]
Production value	$878,800,000[2]
% US production	100%[1]
Pollination	Wind pollinated
Harvest	Nuts shaken to ground
Climate change impacts	Temp changes: high[3] Pest pressure: high[4]

[1] 2019 bearing acreage (USDA, 2020)
[2] Production value data for 2018 (CDFA, 2019)
[3] (Luedeling et al., 2009; Lobell & Field, 2011)
[4] (Luedeling et al., 2011)

Orchard Management

The following information is adapted from USDA Regional IPM Centers' *Walnut Timeline* (Mosz, 2002d).

Orchard Floor Preparation and Harvest

Like with almonds, a debris-free orchard floor is important for walnut harvest to avoid incorporating debris when the nuts are swept off the ground (Kader, 2013).

Nuts are removed from the trees with a mechanical shaker then swept into windrows by a mechanical sweeper. Walnuts must be picked up as soon as possible (typically within a day) after harvest to avoid deterioration. Early harvest is important in walnut orchards to decrease crop damage (such as from navel orangeworm and mold), so some growers use a growth regulator to encourage early harvest. There is often a secondary harvest as well. Depending on the time of harvest, there may be only a short time between harvest and leaf fall for walnuts, providing a relatively small window for establishing a cover crop. Planting before leaf fall is important because leaf litter can discourage germination and seedling growth (Grant et al., 2006).

Pruning

Pruning typically occurs during the winter dormant season and the equipment used in pruning operations can disrupt cover crop seed establishment (Grant et al., 2006). During years that pruning occurs, pruning should be done prior to seeding cover crops to avoid damage to the cover crop seedbed or emerging seedlings. Alternatively, if this is not feasible, an option is to plant cover crops in alternate middles and conduct pruning operations and chipping from the unplanted rows (Grant et al., 2006).

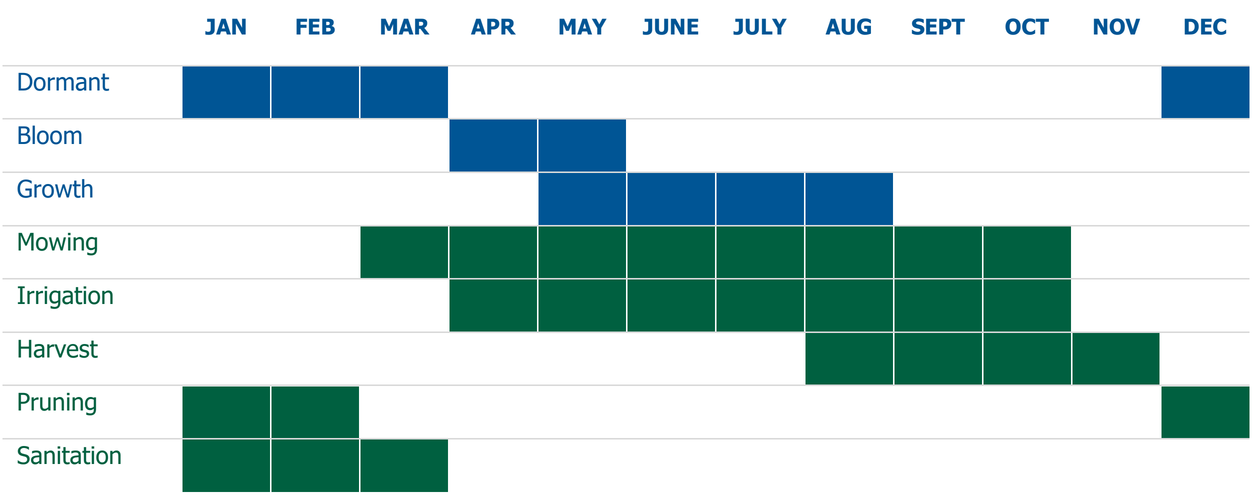
Irrigation

Because the orchard floor is shaded, water use may be lower for cover crops in walnut orchards than in almond orchards (Grant et al., 2006).

Sanitation

Removal of mummy nuts is important for management of the navel orangeworm. Mechanical shakers are used to remove the nuts from the trees, typically after rain or fog when the nuts are heavy. The nuts are mowed to destroy them.

Walnut timeline in a conventional orchard, adapted from USDA Regional IPM Centers' *Walnut Timeline* (Mosz, 2002d). Blue represents crop stages and green represents worker activities.



Pest Pressures & IPM Opportunities

Cultural practices that are mindful of pest and natural enemy ecology can increase the effectiveness of pest management strategies. Primary walnut pests in California include codling moth, navel orangeworm, walnut husk fly, aphids, mites and redhumped caterpillar. Unless stated otherwise, the following information is adapted from UC IPM's Pest Management Guidelines (UC IPM, n.d.) and USDA Regional IPM Centers' *Walnut Timeline* (Mosz, 2002d). Further, the following tables summarizes pests, pesticides, common natural enemies and beneficial plant species.

WALNUT PRIMARY PESTS	**NATURAL ENEMIES**
Codling Moth Codling moths cause significant damage to walnut orchards and can increase damage from navel orangeworm. There are no known effective cultural practices for controlling codling moths. Management options for codling moth include insecticides and pheromone mating disruption. Biological control can help supplement mating disruptants, such as through release of the parasitic wasp *Trichogramma platneri*. Bats have also been shown to be significant natural enemies of codling moths, which fly at night when bats are hunting.	▪ Bigeyed bugs ▪ Damsel bugs ▪ Minute pirate bugs ▪ Lacewings ▪ Spiders ▪ Tachinid flies ▪ Wasps
Navel Orangeworm Walnuts damaged by navel orangeworm are unmarketable. Nuts and waste materials on the ground provide navel orangeworm with overwintering sites; sanitation, decreasing damaged nuts, and harvesting promptly are the best ways to decrease damage. Navel orangeworm only attacks damaged nuts before husk split, so controlling codling moth, walnut husk fly, mites, walnut blight, and sunburn can also decrease navel orangeworm infestations.	▪ True bugs ▪ Lacewings ▪ Spiders ▪ Tachinid flies ▪ Wasps
Walnut Husk Fly Walnut husk fly damage decreases quality, hinders harvest, and can enable navel orangeworm infestation. There are no known effective cultural practices for managing walnut husk fly, but targeting insecticide use is important. Not all orchards need to apply insecticides every year, and when they do, timing is critical.	▪ Predatory mites ▪ Spiders
Aphids Walnut aphids and dusky-veined aphids are two primary walnut pests. Aphids can cause yield and quality losses in walnuts by damaging the leaves and increasing mold. Managed vegetation can increase pest control of aphids by lady beetles (Bugg & Waddington, 1994; Mace & Mills, 2017). Careful management is important because if the vegetation is terminated too early, the beetles will disperse from the orchards and pest control benefits will be lost. Other biological control, such as release of the parasitic wasp *Trioxys pallidus*, can also decrease the need for insecticide use on walnut aphids.	▪ Assassin bugs ▪ Bigeyed bugs ▪ Damsel bugs ▪ Minute pirate bugs ▪ Lacewings ▪ Beetles ▪ Syrphid flies ▪ Spiders ▪ Wasps ▪ Walnut aphid parasite
Mites Mites feed on leaves and produce webbing, causing defoliation and decreases in yield and quality. Damage from mites can also allow navel orangeworm infestations in nuts. Natural enemies typically keep mite populations under control and some mites, such as the European red mite, can support populations of beneficial predatory mites. Reducing dust, such as by managing vegetation or with windbreaks, and decreasing pesticide use can help decrease mite outbreaks.	▪ Bigeyed bugs ▪ Damsel bugs ▪ Lacewings ▪ Minute pirate bugs ▪ Beetles ▪ Predatory mites

Redhumped Caterpillar

Redhumped caterpillars damage walnut trees by skeletonizing leaves. Natural enemies can typically keep redhumped caterpillar populations under control. There are biological control options as well, including through release of *Hyposoter* and *Apanteles* parasitic wasps.

- Bigeyed bugs
- Damsel bugs
- Lacewings
- Spiders
- Tachinid flies
- Wasps

Summary of relevant aspects of pest management for walnuts in California, including primary pests, natural enemies, and beneficial plants that can attract them. This information is from the UC IPM Pest Management Guidelines for Agricultural Pests (UC IPM, n.d.), NCAT's Farmscaping to Enhance Biological Control: Pest Management Systems Guide (DuFour, 2000), and the NRCS California eVeg Guide. Asterisks denote California native plants.

INVERTEBRATE PESTS	NATURAL ENEMIES	BENEFICIAL PLANTS
Aphids ▪ Walnut aphid ▪ Dusky-veined aphid **Beetles** ▪ Pacific flatheaded borer ▪ Walnut twig beetle **Bugs** ▪ False chinch bug **Caterpillars** ▪ Codling moth ▪ Fall webworm ▪ Navel orangeworm ▪ Redhumped caterpillar **Flies** ▪ Walnut husk fly **Leafrollers** ▪ Fruittree leafroller **Mites** ▪ European red mite ▪ Webspinning spider mite **Scales** ▪ European fruit lecanium ▪ Frosted scale ▪ Italian pear scale ▪ San Jose scale ▪ Walnut scale	**Beetles** ▪ Ground beetles ▪ Lady beetles ▪ Leather-winged beetles ▪ Rove beetles ▪ Soldier beetles **Bugs** ▪ Assassin bugs ▪ Bigeyed bugs ▪ Damsel bugs ▪ Minute pirate bugs **Flies** ▪ Aphid midge ▪ Syrphid flies ▪ Tachinid flies **Lacewings** ▪ Brown lacewings ▪ Dustywings ▪ Green lacewings **Praying mantids** **Predatory thrips** ▪ Sixspotted thrips **Spiders** **Wasps** ▪ Braconid wasps ▪ Chalcid wasps ▪ Walnut aphid parasite	**Buckthorns** Amaranth, buckthorn, California lilacs* **Buckwheats** Common knotweed, California buckwheat*, California lilacs* **Carrot family** Caraway, Queen Anne's lace, dill, angelica*, fennel, tansy, bishop's weed, coriander, chervil, parsley, anise **Cereals & Grasses** Corn, rye, blue wildrye*, purple needle grass*, other grains **Legumes** Berseem clover, subterranean clover, alfalfa, crimson clover, hairy vetch, black locust, hemp sesbania, white clover, cowpea, sweet clover, arroyo lupine*, bull clover*, lacy phacelia*, native lupines* **Mint family** Spearmint **Mustard family** Sweet alyssum, mustard, candy tuft, meadowfoam* **Sunflower family** Native goldenrod*, yarrow*, native coreopsis*, cosmos, sunflower*, dandelion, golden marguerite, tidy tips*, daisies, marigold **Other Native Wildflowers** California poppy*, mountain pride*, ithuriel's spear*, baby-blue-eyes*, native milkweeds*

Summary of pesticides used in California walnut orchards, affected groups, and toxicity to natural enemies. Adapted from the UC IPM Pest Management Guidelines for Agricultural Pests (UC IPM, n.d.): Relative Toxicities of Pesticides Used in Walnuts to Natural Enemies and Honey Bees. Toxicities reflect the most conservative (i.e. highest) toxicity level to predatory mites, general predators, and parasites.

PESTICIDE	SELECTIVITY	AFFECTED GROUPS	TOXICITY
Metaflumizone	Narrow	Ants	Unknown
S-methoprene	Narrow	Ants	Unknown
Bacillus thuringiensis	Narrow	Caterpillars	Low
Methoxyfenozide	Narrow	Caterpillars	Low
Chlorantraniliprole	Narrow	Caterpillars	Medium
Emamectin benzoate	Narrow	Caterpillars	Unknown
Spinetoram	Narrow	Caterpillars, aphids, scales	High
Diflubenzuron	Broad	Caterpillars, beetles	High
Cydia pomonella	Narrow	Codling moth	Low
Petroleum oils	Broad	Exposed insects, mites	Low
Rosemary and peppermint oil	Narrow	Exposed insects, mites	Low
Spinosad	Narrow	Husk fly	Unknown
Methyl parathion	Broad	Insects	Medium
Bifenthrin	Broad	Insects and mites	High
Carbaryl	Broad	Insects and mites	High
Cyfluthrin	Broad	Insects and mites	High
Esfenvalerate	Broad	Insects and mites	High
Fenpropathrin	Broad	Insects and mites	High
Malathion	Broad	Insects and mites	High
Permethrin	Broad	Insects and mites	High
Phosmet	Broad	Insects, mites	High
Dicofol	Narrow	Mites	High
Bifenazate	Narrow	Mites	Low
Clofentezine	Narrow	Mites	Low
Hexythiazox	Narrow	Mites	Low
Acequinocyl	Narrow	Mites	Unknown
Etoxazole	Narrow	Mites	Unknown
Spirodiclofen	Narrow	Mites	Unknown
Abamectin	Moderate	Mites and leafminers	High
Fenbutatin oxide	Narrow	Pest mites	Low
Proparigite	Narrow	Pest mites	Medium
Lambda cyhalothrin	Broad	Plant bugs, beetles, caterpillars	High
Pyriproxyfen	Narrow	Scales and beetles	High
Imidacloprid	Narrow	Sucking insects	High
Buprofezin	Narrow	Sucking insects and beetles	High
Acetamiprid	Moderate	Sucking insects and larvae	Unknown

Pecans

With less than 2% of domestic production, there are 5,600 acres of pecan production in California.. As a riparian species native to North America, pecans have the potential to grow as a low input crop that helps to restore riparian ecology. There are indications that acreage is expanding to areas subject to seepage near levees in California. Pecans may be particularly well suited to areas targeted for groundwater recharge given their tolerance to saturated conditions post dormancy.

Pecans are not a leading commodity in any California counties. Participating Orchards Alive farms are located in Colusa and Yolo Counties.

CALIFORNIA PECAN FAST FACTS

Acreage	3,500 acres[1]
Production value	$7,400,000[1]
% US production	1-2%[1]
Pollination	Wind pollinated
Harvest	Nuts shaken to ground

[1] Data for 2018 (CDFA, 2019)

Orchard Management

The following information is adapted from USDA Regional IPM Centers' *Pecan Timeline* (Mosz, 2002c).

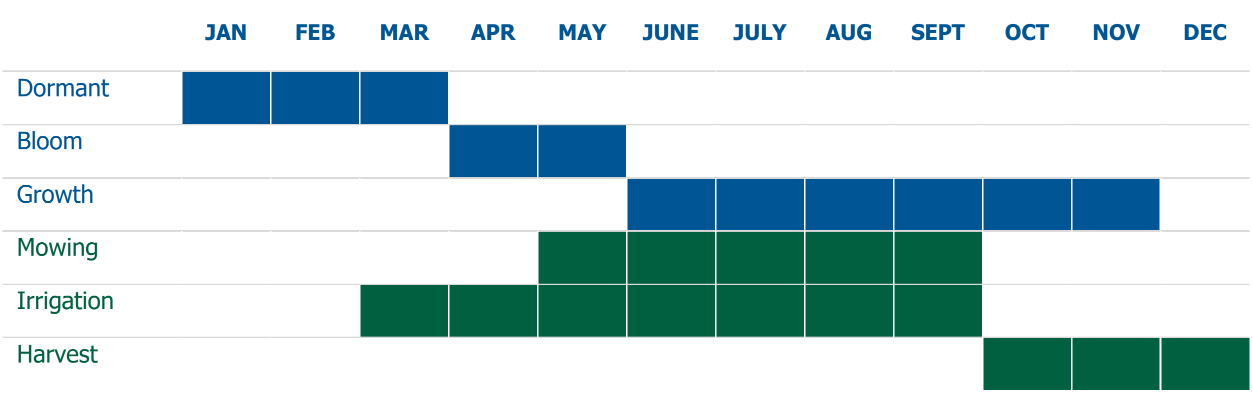
Orchard Floor Preparation and Harvest

A debris-free orchard floor is important for pecan harvest. Orchard floor preparation is similar to that of walnut in that debris (i.e. from pruning or broken limbs) must be removed to allow equipment access, but a completely bare floor is not necessary. Nuts are removed from the trees with a mechanical shaker then swept into windrows by a mechanical sweeper and picked up with a mechanical harvester. Catch frames are used in some orchards. Mowing cover crops before harvest should be sufficient for ensuring the cover crops do not interfere with equipment access.

Irrigation

Low-volume irrigation is the most common nationwide, but high volume irrigation is more common in the west. In native stands, trees grow near natural water supplies so irrigation is not necessary.

Pecan timeline in a conventional western orchard, adapted from USDA Regional IPM Centers' *Pecan Timeline* (Mosz, 2002c). Blue represents crop stages and green represents worker activities.



Pruning	■	■

Pest Pressures & IPM Opportunities

Cultural practices that are mindful of pest and natural enemy ecology can increase the effectiveness of pest management strategies. Aphids are the only major pests in California pecan orchards, though there have been recent reports of naval orange worm infestations in Kern County. Unless stated otherwise, the following information is adapted from UC IPM's Pest Management Guidelines (UC IPM, n.d.) and USDA Regional IPM Centers' *Pecan Timeline* (Mosz, 2002c). Further, table x summarizes pests, pesticides, common natural enemies, and beneficial plant species.

Aphids

The black margined aphid and yellow pecan aphid are the only major pests in California pecan orchards. Aphids feed on tree compounds that can decrease tree growth. Additionally, aphids secrete honeydew that promotes mold growth. Natural enemies include lady beetles, lacewings, syrphid flies, and spiders. Natural enemies can keep aphid populations low; however, pesticides are still often needed to keep aphid populations below economically damaging levels.

Summary of relevant aspects of pest management for California pecans, including primary pests, natural enemies, and beneficial plants that can attract natural enemies. This information is from the UC IPM Pest Management Guidelines for Agricultural Pests (UC IPM, n.d.), NCAT's Farmscaping to Enhance Biological Control: Pest Management Systems Guide (DuFour, 2000), and the NRCS California eVeg Guide. Asterisks denote California native plants.

INVERTEBRATE PESTS	NATURAL ENEMIES	BENEFICIAL PLANTS
Aphids ▪ Black margined aphid ▪ Yellow pecan aphid	Beetles ▪ Ground beetles ▪ Lady beetles ▪ Leather-winged beetles ▪ Rove beetles ▪ Soldier beetles Bugs ▪ Assassin bugs ▪ Bigeyed bugs ▪ Damsel bugs ▪ Minute pirate bugs Flies ▪ Aphid midge ▪ Syrphid flies Lacewings ▪ Green lacewings ▪ Brown lacewings Praying mantids Predatory thrips Spiders Wasps ▪ Braconid wasps	Buckthorns Amaranth, buckthorn, California lilacs* Buckwheats Common knotweed, California buckwheat*, California lilacs* Carrot family Caraway, Queen Anne's lace, dill, angelica*, fennel, tansy, bishop's weed, coriander, chervil, parsley, anise Cereals & Grasses Corn, rye, blue wildrye*, purple needle grass*, other grains Legumes Berseem clover, subterranean clover, alfalfa, crimson clover, hairy vetch, black locust, hemp sesbania, white clover, cowpea, sweet clover, arroyo lupine*, bull clover*, lacy phacelia*, native lupines* Mint family Spearmint Mustard family Sweet alyssum, mustard, candy tuft, meadowfoam* Sunflower family

	▪ Chalcid wasps	Native goldenrod*, yarrow*, native coreopsis*, cosmos, sunflower*, dandelion, golden marguerite, tidy tips*, daisies, marigold Other Native Wildflowers California poppy*, mountain pride*, ithuriel's spear*, baby-blue-eyes*, native milkweeds*

Summary of pesticides used in California pecan orchards, affected groups, and toxicity to natural enemies. Adapted from the UC IPM Pest Management Guidelines for Agricultural Pests (UC IPM, n.d.): Relative Toxicities of Pesticides Used in Almonds to Natural Enemies and Honey Bees. Toxicities reflect the most conservative (i.e. highest) toxicity level to predatory mites, general predators, and parasites.

PESTICIDE	SELECTIVITY	AFFECTED GROUPS	TOXICITY
Pymetrozine	▪ Narrow	▪ Aphids	▪ Low
Spirotetramat	▪ Narrow	▪ Aphids	▪ Low
Dimethoate	▪ Broad	▪ Insects	▪ High
Potassium salts	▪ Broad	▪ Insects	▪ Unknown
Azadirachtin	▪ Broad	▪ Insects and mites	▪ Medium
Flonicamid	▪ Narrow	▪ Sucking insects	▪ Low
Flupyradifurone	▪ Narrow	▪ Sucking insects	▪ Unknown
Imidacloprid	▪ Narrow	▪ Sucking insects	▪ High

Opportunities for Expansion

With Orchards Alive, EDF is demonstrating that integrating cover can be successful in California pecan orchards. With relatively low pest pressure, there is strong potential for pecan orchards to be managed with native hedgerows and cover crops to support native pollinators and regional biodiversity. As a native riparian species, pecans could theoretically help to reforest land near rivers and creeks while still providing a cash crop for landowners.

Cover crops are relatively common in pecan orchards in eastern regions for the benefits to soil nitrogen content, soil health, weed management, pest control and biodiversity (Dutcher et al., 2010). Effectiveness of cover crops in eastern pecan orchards has been well demonstrated in research studies (Bugg & Waddington, 1994; Smith et al., 1996). However, pest pressures and orchard management differs in the central and eastern US compared to California. For example, pecan orchards only face pest pressures from aphids in California, but in eastern regions major pests include the pecan weevil, hickory shuckworm, pecan nut casebearer, and stink and plant bugs (Mosz, 2002c). Native stands, which are common in the central U.S. (Texas, Oklahoma and Kansas) have particularly different orchard management systems.

APPENDIX B. ANNOTATED BIBLIOGRAPHY

Almond

Beneficial insects move from flowering plants to nearby crops (Long et al., 1998)

Location: Merced County

Merced county almond orchard where a grower planted a mix of winter sectary annuals in 1 of every 10 tree rows. Showed that lacewings, syrphid flies, and parasitic wasps moved up to 100 feet away from the insectary plantings.

Almond orchards with living ground cover host more wild insect pollinators (Saunders et al., 2013)

Location: Australia

Investigated the richness and abundance of potential wild pollinators in commercial temperate almond orchards in Australia and compared them to potential pollinator communities in proximate native vegetation. Assessed the value of ground cover on the richness and abundance of bees, wasps and flies. More insects were caught in orchards with living ground cover than in native vegetation or orchards without ground cover, although overall species richness was highest in native vegetation. Percent ground cover was positively associated with wasp richness and abundance, and native bee richness, but flies showed no association with ground cover. The strongest positive relationship was between native bee abundance and the richness of ground cover plants. Results suggest that maintaining living ground cover within commercial almond orchards could provide habitat and resources for potential wild pollinators, particularly native bees.

Synergistic effects of non-*Apis* bees and honey bees for pollination services (Brittain et al., 2013)

Location: Yolo, Colusa, and Stanislaus Counties

Examines foraging behavior and pollination effectiveness of honey bees in CA almond orchards with simple (honey bee only) and diverse (non-*Apis* bees present) bee communities. Orchards with non-*Apis* bees had higher pollination effectiveness than those without, which translated to greater fruit set. Increased pollinator diversity can synergistically increase pollination service through species interactions that alter the behavior and resulting functional quality of a honey bees. Honey bees increased their proportion of movement between tree rows when non-*Apis* bees were present, thereby improving pollination effectiveness. A potential mechanism for the increased interrow movement is linked to resource depletion; some non-*Apis* bees can fly at lower temperatures and therefore earlier in the day, so they can access the flowers before *Apis* bees. Alternatively, it could be related to scent marks left by non-*Apis* bees — honey bees have been shown to avoid visiting flowers that have been marked by bumblebees.

Almond growers reduce pesticide use in Merced County field trials (Hendricks, 1995)

Location: Merced County

This article reports the results of a 6-year study of three almond orchards in Merced County to identify grower practices that allow reduced pesticide use. The steps to reducing pesticide inputs that were found include: 1) Elimination of in-season insecticide sprays by practicing good winter sanitation and mummy destruction, 2) establishment of a good cover crop and mowing middles alternately, 3) monitoring pests, especially scale, very carefully and not using disruptive insecticide sprays, 4) using two *Bt* applications at bloom rather than an organophosphate plus oil dormant spray, 5) using oil dormant spray if needed for scale and mite egg control, 6) introducing the navel orangeworm parasite, *Goniozus legneri*, if needed, when concerting to lower input, and 7) harvesting promptly.

Landscape context and management effects on an important insect pest and its natural enemies in almond (Eilers & Klein, 2009)

Location: Yolo County

Examines infestation rates and abundance of pests and their natural enemies in organic and conventional almond orchards in California, differing in landscape context, understory plant cover, and plant species richness. Found that pest control promoted by near natural habitats can lower pest pressure from navel orangeworm in almonds.

Wild pollination services to California almond rely on semi-natural habitat (Klein et al., 2012)

Location: Colusa and Yolo Counties

Investigates how the quantity of surrounding natural habitat, organic management, and strips of semi-natural vegetation affect flower visitation frequency of wild and manages pollinators and fruit set in organic and conventional almond orchards. Wild bee species only visited almond flowers in orchards with adjacent semi-natural habitat or vegetation strips. Wild bee species richness and flower visitation frequency, but not honeybee frequency, were related to fruit set. Fruit set increased with increasing percentage of natural habitat surrounding the orchards. The key takeaway is that natural habitat, organic farming, and habitat strips increase wild pollination services in California almond orchards.

Walnut

Beneficial insects move from flowering plants to nearby crops (Long et al., 1998)

Location: Yolo, Fresno, and Merced Counties

Lindell Farms, a Fresno Country farm with several crops including walnuts. They added a 20x660 foot hedgerow of perennials and annual toothpick weed. The results of this study demonstrate that beneficial insects feed on nectar or pollen provided by insectary plants, and that they move into associated crops.

Does use of pesticides known to harm natural enemies of spider mites result in increased number of miticide applications? An examination of California walnut orchards (Steinmann et al., 2011)

Location: California

A secondary pest outbreak can refer to a phenomenon where a species of minor importance attains pest status after an application of a pesticide targeting a different, primary pest species. Although secondary spider mite outbreaks can be caused by several nonmutually exclusive mechanisms, much of the scientific literature assumes that disruption of biological control is the most important influence (also has a bunch of references for this). The goal of this study was to determine whether growers who avoid these harmful pesticides have less need to treat for spider mites. Examined whether California walnut growers, following IPM guidelines to avoid pesticides harmful to the natural enemies of spider mites, achieved lower miticide use. Results showed that fields with harmful applications were 40% more likely to have a miticide application than fields without: only 36% of year-fields without harmful applications needed a miticide, compared with 44% of year-field with harmful pesticides (harmful pesticides are defined as those harmful to the natural enemies of spider mites).

Multiscale habitat mediates pest reduction by birds in an intensive agricultural region (Heath & Long, 2019)

Location: Yolo and Solano Counties

Researchers from UC Davis and UC Cooperative Extension (UCCE) demonstrated that a benefit of increasing natural vegetation is an increase bird presence increases pest control benefits in Sacramento Valley walnut orchards. Bird predation on insects significantly reduces pest pressures from codling moth larvae.

They compared predation of codling moths from birds in orchards with and without woody habitat in margins. Woody margins in the study area were planted and retained primarily to attract beneficial insects, for use as windbreaks, and for erosion control. They also have the benefit of attracting birds which can predate on codling moth.

They found that avian predation of codling moth larvae in cocoons can significantly reduce populations in walnut orchards. Birds as providers of pest control benefits are often overlooked, even though these results suggest that walnut growers receive economic benefits from avian insectivores in orchards. The most simplified agricultural landscapes can likely benefit the most from increasing pest control benefits from birds.

Woodpeckers are particularly beneficial, and they are most attracted to larger, deeply furrowed trees in orchards. Thus, increasing pest control services from birds is possible by maintaining natural or semi-natural vegetation cover, such as with woody margins, and by retaining large, furrowed trees.

Impact of field border plantings on rodents and food safety concerns (Sellers et al., 2016)

Location: Yolo County

Study that focused on the impact of hedgerows of native California plants on rodents and food safety in adjacent crops in the Sacramento Valley. Focused on four walnut orchards in Yolo County. Unique rodent capture showed two peaks in activity: 1) in the middle of the orchard regardless of field border type, and 2) in the hedgerow across all seasons with winter being the most active overall. Fecal analysis demonstrated low prevalence of *E. coli* and *Salmonella*. *Giardia* and *Crytosporidium* were more prevalent, but the distribution was not affected by field-edge habitat. The number of rodent captures was greater in the hedgerows compared with the control field edges. However, there were no differences in trap catches in the interior of the crop indicating that rodents are present in crops regardless of field edge habitat. The low prevalence of food-borne pathogens in the rodents also indicates a low risk of hedgerows to food safety in crop production.

APPENDIX C. KEY RESOURCES

Funding & Incentives

PROGRAM	DESCRIPTION
Environmental Quality Incentives Program (USDA NRCS)	A USDA NRCS voluntary conservation program that provides financial and technical assistance to implement conservation practices. Relevant applicable practices include alley cropping, conservation cover, hedgerow planting, wildlife habitat planting, windbreak establishment, and intensive orchard floor cover cropping to increase soil health. See the NRCS California payment schedules for specific funding available.
Conservation Stewardship Program (USDA NRCS)	A USDA NRCS *performance-based* program that helps growers maintain and improve their existing conservation systems and adopt additional activities. Relevant applicable practices include alley cropping, conservation cover, hedgerow planting, windbreak establishment, and intensive orchard floor cover cropping to increase soil health. See the NRCS California payment schedules for specific funding available.
Healthy Soils Program (CDFA)	A CDFA incentives program that provides financial incentives to California growers to implement conservation practices that sequester carbon, reduce greenhouse gases, and improve soil health. Relevant practices include conservation cover, cover crops, hedgerow planting, and windbreak establishment. Over $22,000,000 was awarded to 316 projects in 2020. See the 2020 list of selected projects.
Seeds for Bees (Project *Apis m.*)	A Project *Apis m.* program that provides free or subsidized seed mixes and detailed technical information to growers. Options for seed mixes include a mustard mix, clover mix, soil builder mix, vetch-grain mix, and wildflower mix.

General Resources

- Cover Crop Seed and Native Seed Vendors for California
- Habitat Planning for Beneficial Insects: Guidelines for Conservation Biological Control – Xerces Society
- Planting a Cover Crop – UC ANR
- Cover Cropping for Pollinators and Beneficial Insects – Sustainable Agriculture Research and Education (SARE)
- Farmscaping: Making Use of Nature's Pest Management Services – eOrganic
- Establishing Hedgerows on Farms in California – UC ANR
- NRCS eVegGuide
- Cover Crop (340) in Organic Systems: Western States Implementation Guide – NCAT

Almonds

- UC IPM Pest Management Guidelines: Almond
  - Relative Toxicities of Insecticides Used in Almonds to Natural Enemies and Honey Bees
- Pest Management: California Almond Sustainability Program

- Seasonal Guide to Environmentally Responsible Pest Management Practices in Almonds

Pistachio

- UC IPM Pest Management Guidelines: Pistachio
  - Relative Toxicities of Insecticides and Miticides Used in Pistachios to Natural Enemies and Honey Bees

Walnut

- UC IPM Pest Management Guidelines: Walnut
  - Relative Toxicities of Pesticides Used in Walnuts to Natural Enemies and Honey Bees
- UC Davis Fruit & Nut Research & Information: Walnuts in California
- UC ANR's Cover Crops for Walnut Orchards

Pecan

- UC IPM Pest Management Guidelines: Pecan
  - Relative Toxicities of Insecticides and Miticides Used in Pecans to Natural Enemies and Honey Bees
- UC Davis Fruit & Nut Research & Information: Pecan in California