Evaluating Cover Crop Benefits to Pollinators and Pollination in Almond Orchards - Assessing Bloom Time, Bee Use, and Orchard Pollination

Project No.: **17-POLL13-Williams**

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Problem and its Significance w/Objectives:

Our project examined the ability of cover crop plantings in almond orchards to provide forage honey bees (*Apis mellifera*) and wild bees. The project was carried out as part of a new collaborative effort to document the multifunctional benefits of alternative flower-rich plantings between orchard rows almond orchards in North Central and Southern growing regions of almond production in California.

Almond production may be limited by insufficient pollination as well as poor soil and nutrient quality. The medium to long-term sustainability of production will thus require careful attention to the management of multiple aspects of the orchard system that can otherwise be degraded by production. These include soil quality/ compaction, which impacts nutrient dynamics and water infiltration, pest management, and robust bee population. Beekeepers and researchers identify the lack of diverse nutrient sources as a primary threat to bees. Flowering cover crops in orchard understories have been identified as a potential strategy to support bees especially immediately preceding and following orchard bloom (DeGrandi-Hoffman et al. 2016, PAm 2018). Cover crops also offer potential benefits to soil health of the orchards (Ramos et al. 2010). Informed choice of plant species might promote dual goals of supporting bees and soil health, but no previous studies have been made to document or understand the potential dual benefits. In the case of pollination, no previous data exist on the impacts of cover crop mixes on pollinators although some beekeepers believe they exist. We partnered with a research and extension team exploring soil health to examine the ability of cover crop mixes targeting soil health versus supporting pollinators to benefit bees and bolster almond yield.

In 2018 we completed four primary research objectives:

(1) We assessed the performance of two cover crop seed mixes, quantifying the flowering density provided by the planted species and timing of flowering. These measures were contrasted with data from orchard rows within the same orchard block and in nearby orchard blocks that were treated with the standard practice of weed management for the farm.

(2) We quantified the use of cover crop flowers by honeybees in our planted, once again contrasting these with unplanted rows.

(3) We measured the potential competition for pollinator visits between our cover crop flowers and the surrounding almond trees, comparing the rate of honeybee visitation to trees in rows planted with cover crop to the rate of visitation to trees in unplanted rows.

(4) We assessed the impact of cover crop plantings on the nut yield of the almond trees above the cover planting compared to controls without it.

Interpretive Summary

- Cover crop plantings focused on soil health and pollinators established in all three regions and provided resources to bees during and after almond bloom; however, in all regions flowering peaked after almond bloom.
- The pattern of orchard responses to forage plantings was consistent across the three regions studied
- Forage plantings between orchard rows did not decrease visitation to orchards when compared to neighboring unenhanced rows, nor when compared to nearby unenhanced orchards illustrating they did not compete with orchards for pollinators.
- Forage plantings did not significantly increase almond nut set.
- Lack of effect may be due to delayed bloom of cover crop plantings. For mixes to benefit bees prior to almond bloom, and to benefit pollination consistent earlier sowing of the cover mix will likely be required. In drier regions and years fall irrigation in will likely be needed.

Materials and Methods

We sampled flowering phenology, bees and pollination at three cover crop plantings and associated orchards designed to examine the ability of cover crops to support multiple ecosystem services, specifically soil health and pollinator benefits for almond production. The three sites, located in Tehama, Merced, and Kern counties, span a gradient of precipitation rates across the California almond-growing region (**Figure 1**). Each site was seeded with two cover crop seed mixes in the fall of 2017. The first mix (hereafter, Soil mix) consisted of plants intended to have beneficial effects on the soil properties of the orchard, the second mix (Hereafter, Pollinator mix) consisted of plant species intended to have the most benefit to honeybee hive health (**Table 1**). The seed mixes were planted in sets of four orchard middles in a stratified random pattern that alternated the soil mix, pollinator mix, and a control that was treated with the growers' typical weed control practice (unplanted) (**Figure 2**). The Southern and Central sites also included an herbicide treated control in their treatment arrangements, though we did not make use of this block for our pollinator sampling. The planting pattern was repeated four times in each orchard, resulting in a total of 48 orchard middles included in our studied treatments. We also included samples in nearby (800-1700m separation) unplanted, control orchard blocks, spreading our sampling throughout the orchard to match the dimensions of the planted orchard blocks. The control blocks in the Central and Southern sites were selected from within the same farm, allowing us to control for differences in management practices, stocking rates, and tree ages between the paired orchard blocks. The Northern site was established in a young orchard, the remainder of which was entirely planted with mustard cover crop, so we selected a control orchard with trees of a comparable age and a similar weed control strategy to that seen in the unplanted middles. However, the honeybee stocking rate and pruning strategy of the orchards differed. The control orchard had slightly larger trees and denser honeybee stocking rates.

Figure 1: Map indicating the location of the three sites studied in the 2018 season

Table 1: Common names and percent by weight of seed species included in the Soil and Pollinator seed mixes. The Soil mix was applied at a rate of 50 lbs/acre at all sites. The Pollinator mix was applied at a rate of 8 lbs/acre at the Northern and Central sites and 10 lbs/acre at the Southern site.

		Common Name	Portion of seed mix (by weight)
	Soil mix	Daikon radish	10 %
		Bracco White mustard	10 %
		Berseem clover	20 %
		Merced rye grain	30 %
		Common vetch	30 %
	Pollinator	Canola	35 %
	mix	Bracco white mustard	15 %
		Common yellow mustard	15 %
		Daikon radish	20 %
		Nemfix yellow mustard	15 %

Flower mix performance
We sampled flowering performance at each of the sites five times in the spring of 2018; once prior to almond orchard bloom, three times during the almond bloom, and once after almond bloom had terminated. On each sample day, we measured flower density in orchard middles from each treatment type (Soil mix, Pollinator mix, and Unplanted) in the planted orchard block as well as in middles from the nearby Control orchard using standardized quadrat sampling to estimate flower density of each treatment. We measured the floral area for each flower species encountered using digital calipers. We combined these floral data to calculate the total floral area observed in each quadrat. Because of the difficulty of distinguishing different varieties of the same mustard species, we counted Bracco white mustard and Common yellow mustard as one group.

Honeybee use of plantings

On the same day we sampled flowering performance of the treatment plots, we observed the rate of pollinator visitation to orchard middles in each of the treatments. We only conducted observations when weather conditions were appropriate for pollinator activity, specifically when the sky was clear or mostly sunny, wind speeds

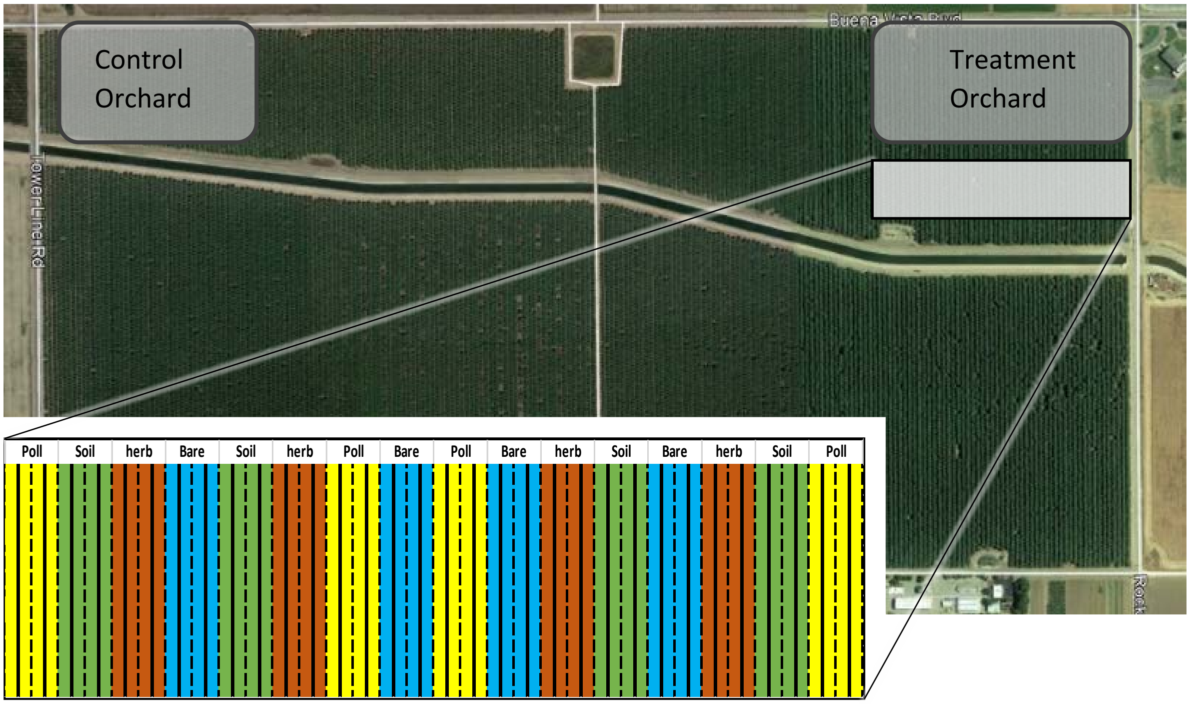

Figure 2. A) Map of the Southern site with the sections sampled for this study marked in gray. The control and treatment blocks are separated by 800m to measure bee activity in independent sections of the orchard. The northern and central sites were established using the same protocol. **B)** A diagram of the pattern in which we applied different treatments to orchard middles. The dotted lines represent donor tree variety rows and the solid lines represent Nonpareil rows. We sample flowering and pollinator data within the Pollinator, Soil, and Unplanted (Bare) treatment rows of the treatment orchard. The blue circles indicate the arrangement of sampled trees throughout the orchard.

were below 3.5 m/s and temperatures above 16ºC, or when wind speeds were below 2.5 m/s and temperatures above 12ºC. At the beginning of a sample day we established 20m belt transects in ten positions in the soil, pollinator, and unplanted treatments and fifteen positions in the control orchard. These transects were spaced evenly throughout the replicates of each treatment (**Figure 2**) to control for the influence of placement within the orchard on bee activity. We observed pollinator visitation to each transect for 2 minutes in the morning and 2 minutes in the afternoon, tallying honeybee visitation to each plant species separately and net collecting any wild pollinators seen visiting flowers within the transect during the sample period. We used this data to estimate "bees observed per minute" in each 20 meter transect. We also used this data and the information on flowering performance of each plant species to assess pollinator preference for the different plant species.

Potential competition for pollinators.
We observed pollinator visitation to almond trees in conjunction with our observations of pollinator activity in orchard middles during the almond bloom period. Immediately after completing each habitat observation transect we selected a nonpareil tree adjacent to the transect in which to observe pollinator activity. We circled this tree for 1 minute, keeping a count of each honeybee seen interacting with flowers in the tree and identifying other pollinators seen to the lowest level possible. Repeating this process after each habitat observation in the morning and afternoon we observed ten trees in

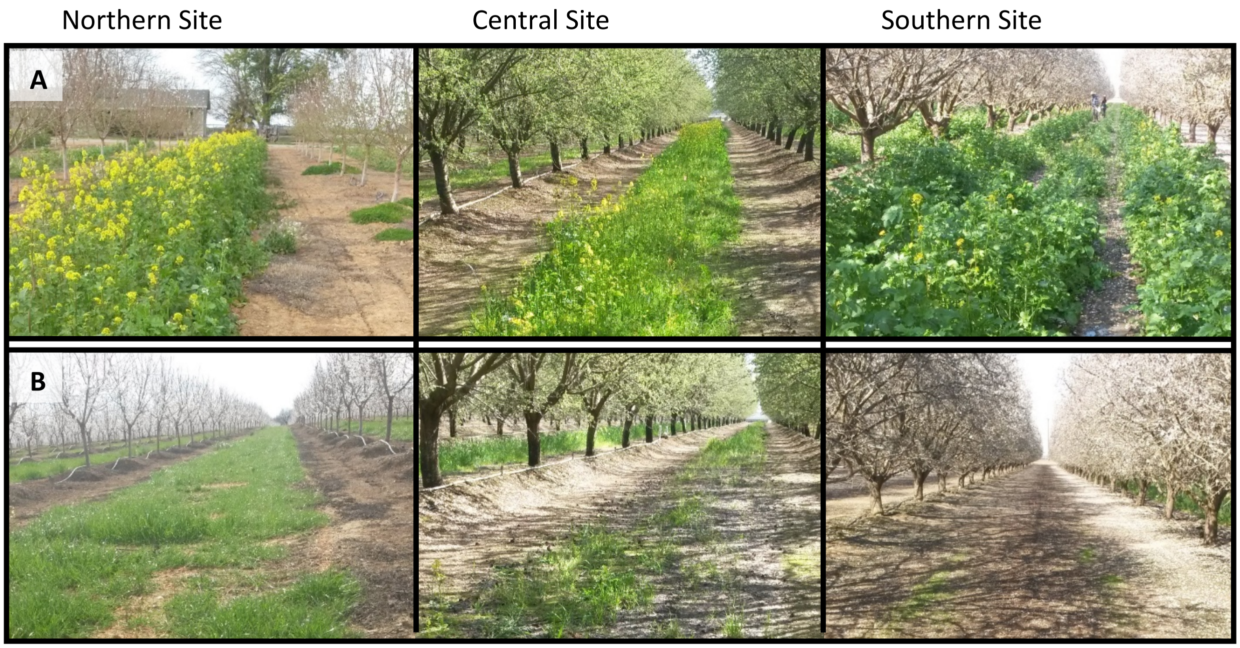

Figure 3. A) Orchard middles planted with pollinator seed mix from the Northern, Central and Southern sites at peak bloom. B) Orchard middles managed with the standard weed management of the same site.

the soil, pollinator, and unplanted treatments and fifteen trees in the control orchard twice each day. Paired with the pollinator observation data, we used PVC cubes inserted into the tree canopy to estimate flower density in each sampled tree, allowing us to control for the attractant effect of more densely flowering trees.

Effect of cover crop on Nut yield

To quantify the impact that cover crop plantings had on overall nut yield we measured the proportion of flowers produced by the tree that developed into mature nuts. At the end of petal fall we located the ten trees of each treatment in the planted orchard and fifteen trees in the control orchard that we had sampled for pollinator activity. We flagged a 1-meter section of a single branch on the west facing side of each tree and recorded the total number of blossoms produced within the section. We returned in April to the marked branches and recorded the number of blossoms that had developed inflated fruit after post-anthesis abortion of the flower. We returned again to the branches in late July and recorded the number of nuts that the sections produced.

Results and Discussion

Both seed mix types established at all of the sites, though with variable success. The planted rows in the northern site established and bloomed at a much higher density than those of the central and southern sites (**Figures 3 & 4**). This difference in establishment success may reflect a difference in the timing of rainfall, with consistent rainfall beginning much earlier at the northern site (January precipitation measurements at nearest weather stations to the northern, central, and southern sites, respectively, 3.43", 2.12" and 1.03" NOAA 2018). The consequences of this lower rainfall were visible in the southern site (**Figure 3c**) where supplemental irrigation was applied to the tree berms in late January. The penetration of the added water at the edges of the orchard middles resulted in denser vegetation growth along the edges of the plantings in the early part of the season. In addition, the smaller tree size at the northern site allowed greater light to the planted seedlings, likely increasing the growth rate of the cover crop.

Neither the soil nor the pollinator mix bloom substantially on the pre-bloom, early bloom, mid-bloom sample dates. Both plantings-initiated bloom by the final sample during almond bloom at all sites, although bloom density was negligible at the central and southern sites for this sample period (**Figure 4**). By the post-almond bloom sample, both the pollinator and soil habitat treatments had significantly higher flower densities than the unplanted and control middles of the same site. Based on these results, it would appear that both the soil and pollinator seed mixes are capable of producing dense floral displays when planted within orchard middles. However, if the objective is to produce floral displays to be available to hives prior to the beginning of almond bloom, then supplemental irrigation may be necessary in dry water years to promote early germination of cover crop seedlings.

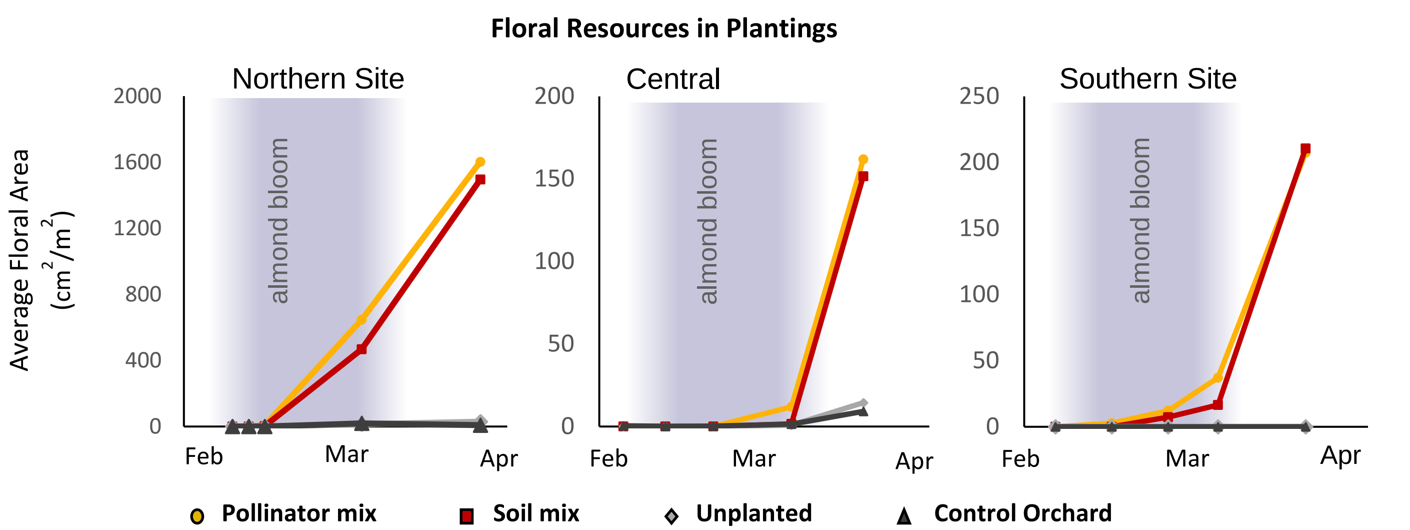

Figure 4. Density of floral resources found through the season at each site. The unplanted orchard middles and control block were kept close to bare of weeds. Flower density in the soil and pollinator mix plantings increased sharply near the end of almond bloom. The stronger establishment success of the plantings in the Northern site is evident in the earlier initiation of bloom and the floral density of the plantings reaching a level nearly an order of magnitude higher than that of the central or southern sites.

Pollinator use of cover crop habitat

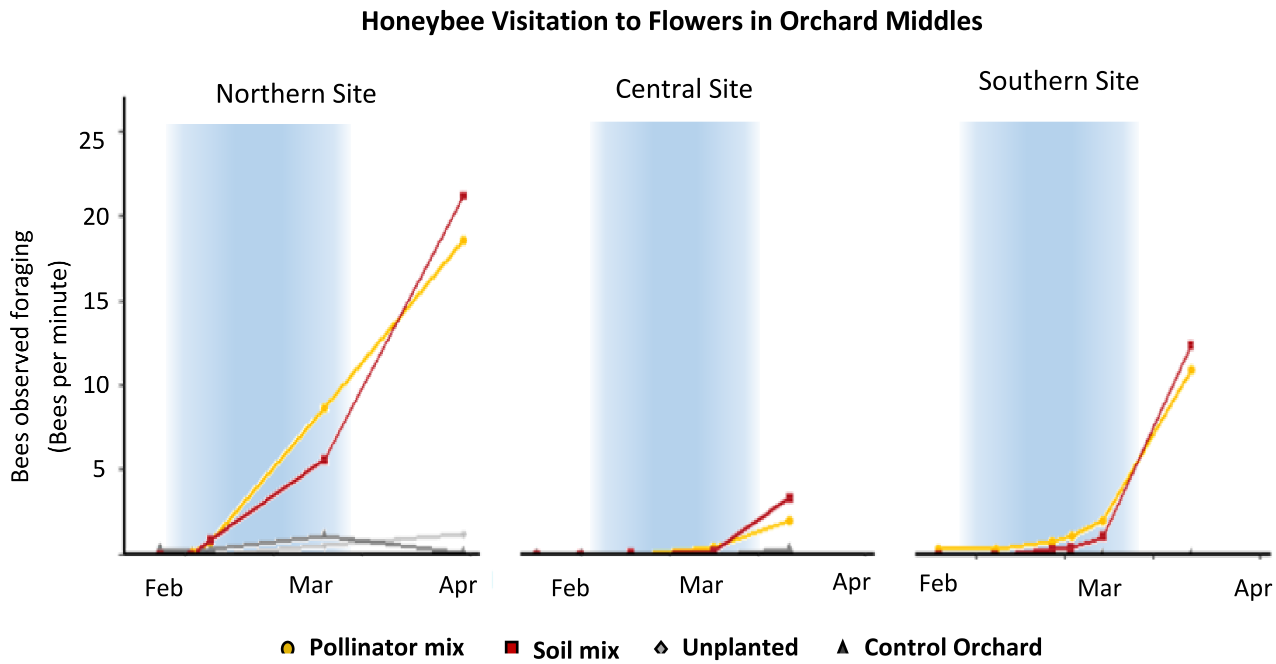

Figure 5: Honeybee activity observed in each treatment across the sample season. Measure of bee activity is reported as average bees per minute observed in transects from each transect type on sample days. Honeybee activity within the planted orchard middles increased sharply at the end of almond bloom in association with a co-occurring increase in planted flower density.

We observed pollinator activity within the planted and control orchards for a total of 2700 minutes across the season. In this time, we observed 3773 honeybee visits and 14 wild bees to flowers within orchard middles **(Figure 5)**. The low number of wild bee visits limits the possibility of interpreting any patterns in habitat preference. Honeybees foraged within the soil and pollinator mixes at similar rates throughout the season. The rate of honeybee foraging within the plantings increased steeply after almond bloom terminated. We lack the ability to use this information to assess competition for pollinators because of the low density of cover crop flowers during bloom. Of note is the fact that visitation rate to the planted orchard middles was

We found evidence that honeybees prefer certain species of plants in the seed mixes. Honeybees visited Bracco white/common yellow mustard and Radish flowers at a much higher rate in proportion to the flowering density of the species than they visited either Canola, Nemfix mustard, or common vetch (**Figure 6**). This result indicates that certain species within the seed mixes are more efficient at meeting the objective of providing foraging habitat to bees.

Potential for competition between cover crop and almond trees

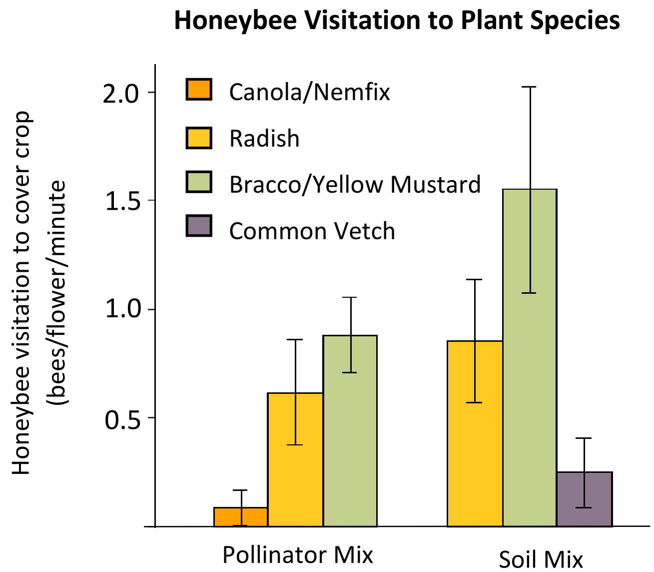

Figure 6: Rates of honeybee visitation to the different plant groups in the soil and pollinator mixes when controlled for the flowering density of each plant group. Radish and

Across the three regions, we observed a total of 5045 honeybee visits and 2 wild bee visits to almond trees across a total of 810 minutes of observation. The low rate of native bee activity during almond bloom precluded any inference about the effect of cover crop on wild bee activity to orchards. Almond trees at the northern, central, and southern sites received pollinator visits at an average rate of 0.41, 1.49, and 1.01 bees per flower per minute, respectively. The difference in rate of honeybee visitation within each site, especially pronounced for the northern site, was likely a result of a difference in stocking rates at each site. We found no evidence of competition for pollination service between almond trees and the cover crop plants. Trees sampled within planted rows and unplanted rows from the same orchard block had similar rates of pollinator visitation per flower (**Figure 7**) indicating that bee movement within an orchard block was not influenced by the presence of cover crop flowers. A comparison of the visitation rates observed in the planted orchards to that of the control orchards showed no reduction of bee activity in response to cover crop plantings. Limiting our ability to extrapolate this response, is the fact that the central and southern sites both experienced limited cover crop flower density until the very end of almond bloom. Whether the data continues to indicate minimal competition in seasons when the cover crop performs as intended (e.g. with plants providing alternate forage for honeybees before, during and after almond bloom) remains to be seen.

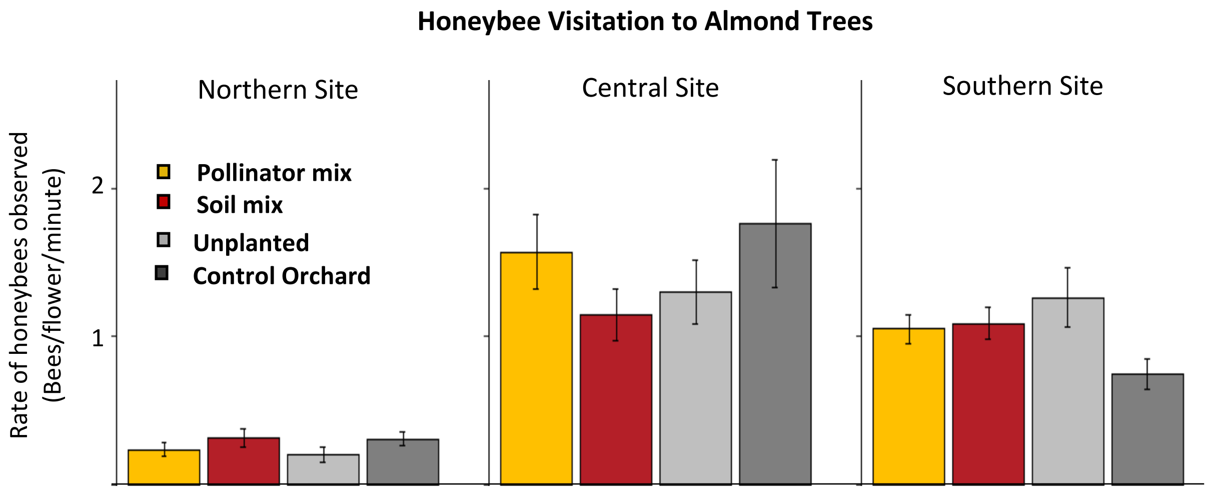

Figure 7: The rate of honeybee interactions with flowers observed on trees within in each treatment type. The rate of honeybee visitation was significantly lower in the northern site, likely due to the lower density of hives in the area compared to the other sites. Within sites there is no apparent effect of cover crop planting on honeybee visitation either at the local nor the landscape scale.

Response of crop yield to cover crop plantings

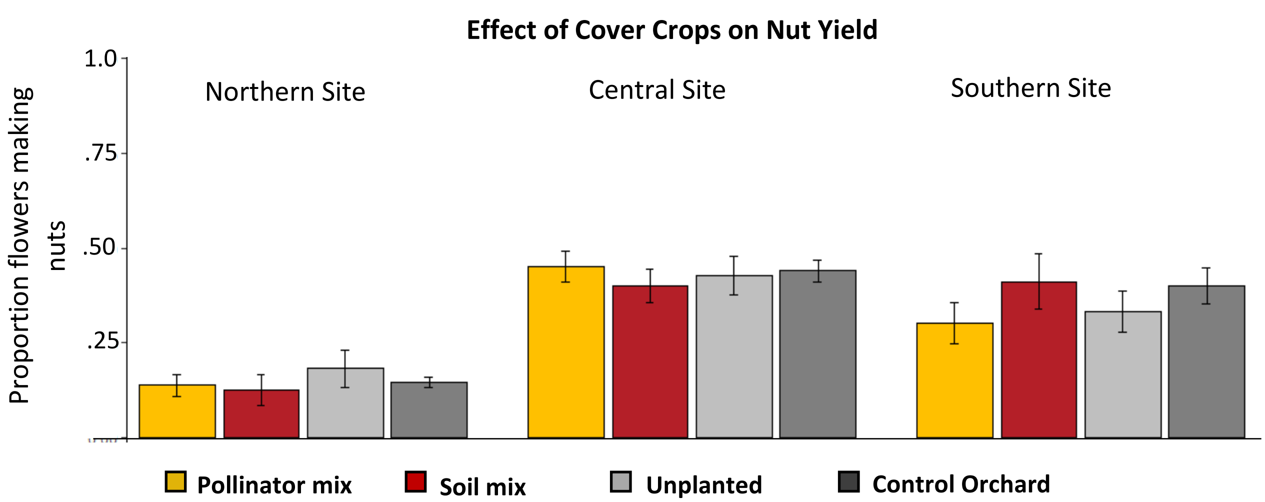

Figure 8: Nut yield effects of cover crop plantings assessed as proportion of flowers that fully developed to nuts. Yield was not affected by the planting type within each orchard, though differences between the sites are evident as a result of tree age and differences in management.

We flagged 1 meter branch sections on 10 trees in the soil, pollinator, and unplanted treatment rows and 15 trees in the control orchard at each of the three sites in order to track the development of flowers to harvest. We successfully tracked 134 branches through to harvest, losing one branch section from the soil treatment at the northern site due to high winds. As with the pollinator activity in trees, we found a strong distinction between the proportion of flowers that developed into nuts at the northern site and the same metric at the central and southern sites (**Figure 8**). However, within each region we found no indication of a change in nut-set in response to cover crop plantings. This result supports the conclusion that there was no response of effective pollination service to cover crop plantings, as both the unplanted and planted orchards appear to have been limited in nut-set by factors other than pollinator visitation rate. It also fails to support the expectation that the cover crop plantings would benefit overall yield through influencing pollination service.

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