Cover Crop Systems for Almond Orchards: Exploring Benefits and Tradeoffs to Inform Management

Project No.: **17-STEWCROP7-Gaudin**

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Objectives:

Planted or natural vegetation cover crop during the fall/winter impact various aspects of tree health and soil quality regulating N, water and C dynamics, which may be of benefit to the sustainability and resilience of the California almond industry. Previous projects and farmers' experience show that this practice is compatible with large scale almond production and growers recognize the theoretical benefits that might come from implementing cover cropping. However, we lack concrete information to optimize cover crop systems for different ecoregions and production objectives and to develop management practices, which help address operational concerns. Over the course of this project, now in its second year, we have aimed to comprehensively determine ecosystem services and production trade-offs associated with different winter cover crop mixes by assessing their impact on water use, pest pressure, and bee, soil and tree health.

The specific objectives of this project are as follows:

- [OBJ 1] Survey almond growers to compile knowledge on the use, management and barriers for adoption of cover crops in irrigated almond orchards.
- [OBJ 2] Quantify the benefits and tradeoffs of (T1, T2) two winter cover crops and (T3) resident vegetation compared to (T4) bare soils in three different geographical regions differing in average annual rainfall. In particular, we are aiming to answer the following questions (**Figure 1**):
    - *Soil health:* What levels of C and N capture and increase in soil health may be provided by common cover crop mixtures or natural vegetation during the winter? How do soil food webs respond to cover cropping and what are the advantages?
    - *Water use:* How do cover crops affect winter soil water storage patterns, water budgets and tree water status in the spring compared to fallowed soils?
    - *Frost damage:* What are the impacts of winter cover crops on soil and air temperatures in frost-prone regions?
    - *Pest suppression:* Can cover crops be used to deter soil born pests such as nematodes and decrease weed pressure?
    - *Cover crop management:* How do benefits and tradeoffs vary between the most popular mixes and when is the best termination date to maximize these benefits?

<u>Note:</u> *Two other teams lead by Neal Williams and Houston Wilson are engaged in this project and have actively worked at our trials this last year to determine the impacts of various cover crops on 1) bee visitation and potential competition with trees for pollination and 2) NOW pressure and natural enemies. Separate reports are being submitted.*

- [OBJ 3] Determine the host status of various cover crops species to key plant-parasitic nematodes.
- [OBJ 4] Provide a cost-benefit analysis for almond production systems to inform farmers of the potential trade-offs associated with this practice.
- [OBJ 5] Extend information and communicate results to growers, consumers and regulators throughout the region.

Interpretive Summary:

In 2017-2018, we first designed and distributed an almond growers' survey (online and paper-formats), which allowed us to gain insight on the specific interests and priorities of CA almond growers with regards to cover cropping. We also established three replicated experiments in grower orchards at Corning (Tehama County), Merced (Merced County) and Arvin (Kern County) where we compared a customized "soil mix" and a "pollinator mix" (the most popular mix in CA almond) to resident vegetation and bare soil. As shown in **Figure 1**, our project's orchard monitoring encompassed a wide series of measurements to provide a full system assessment: (1) soil health shifts (near tree row and in alleyways) and beneficial nematode community shifts, (2) water dynamics (measured through irrigation measurements, neutron probe readings and tree pressure bombing), (3) weed pressure, (4) pollinator visitation at tree bloom, and (5) navel orangeworm (NOW) activity. This work was complemented by greenhouse studies and monitoring of a nematode infested orchard established at Kearney last year to evaluate parasitic nematode suppression ability of each cover crop species and mixes. To address more specific orchard issues, we expanded the scope of our project to include three sub-studies: (1) effect of termination timing on cover crop benefits and tradeoffs, (2) effect of cover cropping on frost damage in trees, and (3) effect of cover crop mixes to remediate for soil compaction and poor water infiltration. We are preparing to harvest our sites and will be recording yields by treatment as well as almond quality. All of our growers have agreed to continue with a second year of this experiment. We are currently compiling and analyzing our first season's datasets as well as preparing for outreach activities to communicate our results in this upcoming year.

Materials and Methods:

Growers' survey:

Our survey was designed in 2017 following the Tailored Design Method (Dillman *et al*., 2009) and using Qualtrics©, a cloud-based survey software. The target group of respondents were individuals involved in the decision-making process of almond farms: owners, managers and/or operators. Respondents of the survey were asked to identify themselves as either users or non-users of cover crops, each of which then followed different questionnaires. Questions addressed to both users and non-users identified perceived benefits and concerns associated with cover cropping. The questionnaire addressed specifically to users included questions relating to their experience with cover crops (types of crops grown, proportion of the land with CC, annual or perennial, winter or spring, single or multi-species mix) and to their management practices (seeding date and date of termination). The target group of respondents did not include external farm advisors nor extension specialists. An IRB human subject's approval has been obtained for this study for the graduate student and PI. The paper-version of the survey was distributed for the first time at the 2017 Almond Board of California Annual Conference in December. An online version was also made available at that time. The survey was communicated at UCCE workshops and continues to be distributed.

Growers Survey URL: https://ucdavis.co1.qualtrics.com/jfe/form/SV_3UepPhXFE82QvS5

Replicated trials:

We established three randomized complete block design (RCBD) trials with four replications (3 tree rows x 4 treatments x 4 blocks). A total of three sites have been chosen in three ecoregions of California: Glenn county in the Sacramento Valley, Merced county in the North San Joaquin Valley, and Kern county, in the South San Joaquin Valley. All orchard sites were clay loam to sandy clay loam with 50% Nonpareil on Nemaguard rootstocks with microsprinkler irrigation. Each orchard was a minimum of 4 acres (final range of 8-40 acres) including floor management treatments: winter planted cover crops – a pollinator mix and a soil building mix, winter resident vegetation and chemically-controlled bare soil. The Arvin/Kern County site also included a ripping treatment (depth of 18 inches/gap of 10 feet/width of 3.5 inches) to compare this practice's capacity to remediate soil compaction as compared to cover cropping. Cover crop mixes were drill-seeded following almond harvest in October to November 2017. Two termination methods of the cover crop were compared: an "early termination" in late-February to mid-March and a "late termination" in early-April. This schedule will be replicated for 3 years. Resident vegetation plots were mowed and maintained to provide a continuous ground cover. Bare soil plots were chemically controlled according to conventional practices.

Measurements:

Soil health: Soil samples were collected pre-planting of the cover crop. In each plot, samples were taken from the center of the middles and at a one-meter distance from the Nonpareil trees at 0-20 cm. Samples were analyzed for chemical properties (pH, soluble salts, OM%, Total C, Sum of Cations (CEC), K, Ca, Mg, Na, S, Olsen P, nitrate and ammonium content and total N) and physical properties (texture, bulk density). Samples were also used to assess soil food webs and the beneficial nematodes present. Additional analyses will be performed next year post-treatment. This will include microbial biomass carbon (MBC), microbial biomass nitrogen (MBN) and labile C using the PoxC method. We will also determine soil water holding capacity and aggregate size distribution and stability. Soil water retention curves will be obtained using the HYPROP system. Penetrometer readings will be taken at each site to determine changes in soil compaction associated to each treatment. In-situ measurements of water infiltration will be taken using a Decagon Dual-Heal infiltrometer.

Cover crop biomass and nutrients: Total cover crop biomass as well as species composition and relative abundance and separate C:N ratio for each species was collected from a 0.25 m^2 area within each plot before each mowing event and each termination. Dry biomass was determined after drying at 60°C to a constant weight. The dry samples were ground to the consistency of a fine powder and analyzed for total N and C.

Weed pressure: To test the effect of cover crops on weeds, we surveyed plant ground cover using a point-intercept transect method. Surveys were performed twice during the winter and early spring after cover crops were planted and again after cover crop termination. We intend to survey plants again after almond harvest before repeating this survey schedule next year.

Frost incidence: The set of a total of 64 sensors and dataloggers were set at our northern-most site in Corning, Tehama county, where frost risks were projected to be the greatest. Sensors were mounted on twelve stations. Two stations were set per treatment in two blocks out of four, so as to obtain sufficient measurement replication within the orchard. Treatments in the orchard were: (1) pollinator cover crop mix (PM), (2) soil cover crop mix (SM), and (3) resident vegetation soil cover (RV). To gain a better understanding of how temperatures fluctuate within orchard microclimates, we monitored top-soil temperatures at a 6 cm depth using ECH_20 5TE sensors (Meter group) connected to EM50 dataloggers. The ECH_20 5TE sensors also provided readings of soil volumetric water content (%) and EC throughout the winter. Bare soil surface and cover crop canopy surface temperatures were measured using infrared radiometers (Apogée Instruments). Diurnal orchard temperatures and relative humidity (%) were recorded using HOBO Pro-v2 loggers (Onset corp.) set at 5 cm above the soil surface, 90 cm (3 feet) and 150 cm (5 feet), which corresponded to the mid-tree canopy height. Finally, to monitor cover crop canopy development and growth rates throughout the winter, we used NDVI/PRI spectral reflectance sensors (Decagon corp.). From December to the end of January, all twelve stations were set within the tree rows, so as to obtain tree row temperature measurements. From February to April, stations were moved to the center of the cover crop middles, using a mobile station system, allowing the grower to remove the stations during orchard operations. The second dataset provided data on the effect of soil cover on above-ground temperatures in the orchard.

Water dynamics and tree water status: In 1989, a short term, non-replicated experiment by Prichard (1989) suggested that orchard cover cropping may result in water losses for orchards of up to 30%. This loss may be minimized through proper cover crop management and particularly, through the right timing of cover crop termination to limit water demand. To provide data on cover crop water use and water budget across CA precipitation gradients, we monitored soil moisture (gravimetric water content at the beginning of the field season in early to mid-November and again at the end of season starting in March to June, with the end date varying between field sites). Each location was sampled to depths 15, 30, 60, 90, 120 cm. We also used calibrated neutron probe readings throughout the winter season to measure weekly volumetric water content, taken from alleyways, at 30 centimeter (cm) increments up to at most 270 cm below the soil surface. Volumetric water content will be estimated from neutron probe count rates based on field specific calibration curves that describe the linear relationship between the relative count rate (count rate divided by a standard count) and volumetric water content. Measurements started in March 2018 and are currently being collected at all three of our sites, on a weekly basis. We have installed water meters on irrigation inlets to monitor water inputs to the orchards. We are also measuring stem water potential in the Nonpareil tree rows using the pressure bombing methodology. Measurements are being collected on a weekly basis to detect potential tree water stress. In our first season, our replicated experimental design did not allow for the use of a Tule station to measure evapotranspiration. For this upcoming year, we are considering the addition of satellite cover crop orchard sites to allow for sufficient surface area to obtain accurate Tule measurements.

Nematode suppression: Greenhouse experiments were conducted to determine host status of the various cover crop species and our mixes. Greenhouse containers were filled with sand-soil mix, planted and plants were inoculated either root lesion nematode or ring nematode soon after emergence. Biomass was measured at harvest after 2 months of incubation and nematodes were extracted from the root zone and counted. The resulting numbers are then compared to the initial numbers inoculated to the plants. If more nematodes are found than were initially inoculated the test plant will be classified as susceptible. If fewer are found it will be classified as resistant or in some cases non-host. Two field experiments established in 2016 at the Kearney Ag Center, one on the rootstock 'Nemaguard' and the second on the rootstock "Lovell' were also used. Both fields had resident plant-parasitic nematodes present and were additionally inoculated. Orchards were planted with individual species as well as experimental mixes of the various cover crop species in a replicated blocked design. Planting of cover crop with supplemental irrigation was done in September. This resulted in copious amounts of biomass requiring one mowing in mid-December, and a second mowing at the beginning of February. Biomass production was recorded, and nematode numbers were monitored in soil samples.

Results and Discussion:

[Objective 1] Survey almond growers to compile knowledge on the use, management and barriers for adoption of cover crops in irrigated almond orchards.

First of all, it is important to note that we are just starting to distribute our survey and that all of our current respondents were located between Yolo to Merced county. We will therefore need to develop our outreach potential to obtain Kern county and Tehama county responses. Our respondents were relatively well-partitioned between different floor management practices (**Figure 2**) with 17% of respondents using bare soil and 83% using a vegetative ground cover during all or part of the year (28% winter cover crop, 14% in-season cover crop, 14% perennial cover crop and 28% resident vegetation). However, considering that there are about 94% of CA almond growers who use bare soil, our data is currently skewed towards cover crop adopters. In fact, amongst our respondents, 85% indicated that they have used cover cropping in the last 5 years (**Figure 3**). All growers reported having soil-related issues in their orchard with poor soil biology and poor water retention being the most important issues (**Figure 4**). All respondents recognize that cover cropping could provide potential benefits and indicated soil health and pollinator habitat as the most important (**Figure 5**). However, although benefits are recognized, our data indicated that some growers discontinued cover cropping because its performance did not match expected returns. Regarding potential tradeoffs of cover cropping, operational difficulties were identified as a greater concern than agronomic and economic challenges related to cover cropping. Of operational concerns, difficult establishment of the stand was the most important operational concern (**Figure 6**). Overall, our survey results (n=26) suggested that a lack of BMPs is currently the most important barrier to cover crop adoption in almond. We are in the process of collecting more data and hope to reach a representative sample of 500 growers over the next year.

[Objective 2] Quantify the benefits and tradeoffs of (T1 & T2) winter cover crops and/or resident vegetation (T3) compared to (T4) bare soils in three different geographical regions differing in average annual rainfall:
<u>Soil health</u>: A key component of our systems-based cover crop assessment is identifying the effects of cover cropping on orchard soil health. So far, we have collected baseline samples and will take another round post treatment in the coming year. Our soil baseline analyses have revealed a heterogeneity in orchard soil properties at all three of our sites with identical trends: (1) higher organic matter content and total carbon content in orchard middles compared to tree rows, possibly due to residue placement, (2) higher total nitrogen in middles and (3) greater sodium contents in tree rows, possibly related to fertilizer applications (**Figure 7**). All of these differences may also be associated to the location of the wetting zone in these micro-sprinkler irrigated systems. As such, our cover crop post-treatment analyses will keep in mind these soil condition differences in the orchard. In term of soil biology, baseline samples showed that the sites with the oldest plantings, Castle Farm in Merced and Wegis & Young in Bakersfield, had the highest levels of ecological structure, with greater numbers of predatory and omnivorous nematodes (**Figure 8**). The Bakersfield site had the greatest number of bacterial feeders and castle farm the highest number of herbivore pests.

<u>Cover crop biomass and performance:</u> Our three field sites in order of decreasing seasonal precipitation were as follows: Corning (Tehama County), Merced (Merced County) and Arvin (Kern County). Biomass production was proportional to precipitation amounts by vegetative cover type and the seeded cover crop produced more biomass than the local resident vegetation at all three sites: 312% more dry matter than resident vegetation in Corning, and 180% more in Merced (**Figure 9**). However, it is important to note that the species composition of the cover crop mixes varied widely amongst regions (**Figure 10, 11**). The soil mix for example was composed of 60% white mustard in Corning whereas it was composed of 59% ryegrass in Merced. This must be considered when selecting cover crop species for a particular purpose in an orchard. Due to differences in species composition, the C:N ratio

of the cover crop also varied amongst sites (**Figure 12**). The soil mix had a lower C:N ratio in Corning and Arvin as compared to the soil mix in Merced. Our results highlight the need to develop region-specific almond cover crop BMPs in California.

Weed pressure: Growers at each location determined weed management practices and used the same management practices across cover crop treatments. We found that weed densities and diversity decreased at higher levels of cover crop establishment (**Figure 13**). Furthermore, we did not observe any indications of cover crop weediness, such as cover crops in the tree strip or ineffective cover crop termination. In the next year, we hope to break out some parts of this project in order to test secondary effects of cover crops on weeds. These projects could include the effects of cover crops on insect predation of weed seeds or the effects of cover crop management intensity on weed suppression.

Frost incidence: The focus of the frost study was to: (1) Determine whether cover cropping increased the risk of almond frost damage, (2) Identify critical frost time points during the winter and (3) Gain a better understanding of orchard heat transfer from the soil to the almond budding zone. Our measurements indicated that the end of February (2/19 to 2/28) was the most critical time point for frost damage this winter in Corning. Temperatures surpassed the threshold level (-2°C on 5 days), irrespective of the vegetative groundcover (cover crop or control). When analyzing top-soil temperatures respective to groundcover treatments during this critical time, we saw a difference between cover cropped and control plots with lower soil temperatures in cover cropped plots on average (**Figure 14**). However, this did not translate into aggravated frost events in the orchard as indicated by diurnal temperature variations at four different levels: (1) topsoil, (2) two inches aboveground, (3) three feet and (4) five feet (**Figure 15**). Our data indicated less temperature fluctuations in (1) and (2), suggesting that cover crops may create a barrier to heat flow. However, at greater heights aboveground (5 feet), temperatures remain relatively identical to the control during the critical time points for frost damage. Furthermore, IR surface temperature measurements indicate that although control plot surface temperatures may be greater than in cover cropped plots during the day, differences during frost nights are less visible (**Figure 16**). As such, our first season's dataset suggests that cover cropping may not increase frost risks in almond orchards.

Water dynamics and tree water status: This effort at our three sites complements work being conducted by a larger team of water and crop scientists in 11 almond orchards across the Valley. Each subset of data will be analyzed individually to reveal the effect of winter cover crops on gravimetric water content, volumetric water content, and evapotranspiration. Data from all 11 sites will be analyzed in a multi-factor model, which will include climate data, biomass production and canopy cover development, to describe the hydrologic implications of winter cover crops for different cover crop types, management systems, and regions of the Central Valley. Seasonal change in the water budget between the experimental and control fields will reveal the impact of winter cover crops on infiltration, soil water holding capacity, and groundwater recharge. Dr Mitchell has also spoken with Dr. Terry Prichard, Emeritus Water Scientist in the Department of Land, Air and Water Resources to exchange ideas and to further refine our approaches about this work and anticipate having a follow-up discussion with this this fall.

We anticipate having and being able to report results by this time next year.

[Objective 3] Determine the host status of various cover crops species to key plant-parasitic nematodes.
A combination of greenhouse and field experiments were conducted to determine how cover crops might shift nematode pest pressure and the host status of our species. Focus of the greenhouse work at the Kearney Ag center has been on determining the host status of leguminous cover crops including different clovers (Berseem, Crimson, Persian, subterranean), medic and lupine. We found significant differences among the different legumes, noteworthy was the performance of 'Hykon rose' clover. It allowed for only little reproduction of two different populations of root-knot nematodes, root lesion nematodes, and ring nematodes (**Figure 17, 18**). At the experimental orchard, a first nut harvest is expected for 2018. No major shifts of nematode population densities were recorded at this time. The three on-farm experimental field sites were also sampled for nematodes. All three sites were low for ring nematode but had some root lesion nematode infestations (Butte: 15.8, Kern: 3.5, and Merced 6.1 vermiform nematodes per 250 ml of soil). Pin nematode was found at the Kern and Merced county sites (34.9 and 145.4 respectively). Monitoring will be conducted again at the end of our experiment.

[Objective 4] Provide a cost-benefit analysis for almond production systems to inform farmers of the potential trade-offs associated with this practice.
This objective will be fulfilled in year 4 of the project

[Objective 5] Extend information and communicate results to growers, consumers and regulators throughout the region.
We are still in the process of collecting data and did not start to share our preliminary baseline data from this first year with growers at outreach events. A website, currently under construction, was created to communicate the survey as well as report on almond cover crop research activities and upcoming results. Mitchell and the team are also putting together a video to show our research in action and our study's potential impacts to a broader audience. PI and team members have been disseminating knowledge and raising awareness of the project with multiple stakeholders, from CalCAN (project to be featured in the Governor's report) to CDFA and Xerces Society. Our team also was also awarded additional funding to support this project:

- HSP demonstration project, CDFA
- Western SARE graduate student award to Cynthia Creze (Gaudin lab)
- Annie's Sustainable Agriculture Scholarship to Cynthia Creze (Gaudin lab)

We held a fruitful team workshop in Merced on May 31st, 2018 to go over our collective work and plan our summer measurements and next year's work.

Research Effort Recent Publications:

N/A

References Cited:

Dillman, D.A., Smyth, J.D., & Christian, L.M. (2009) Internet, mail, and mixed-mode surveys: The tailored design method, Third ed. Hoboken, NJ: John Wiley & Sons, Inc.

Figures:

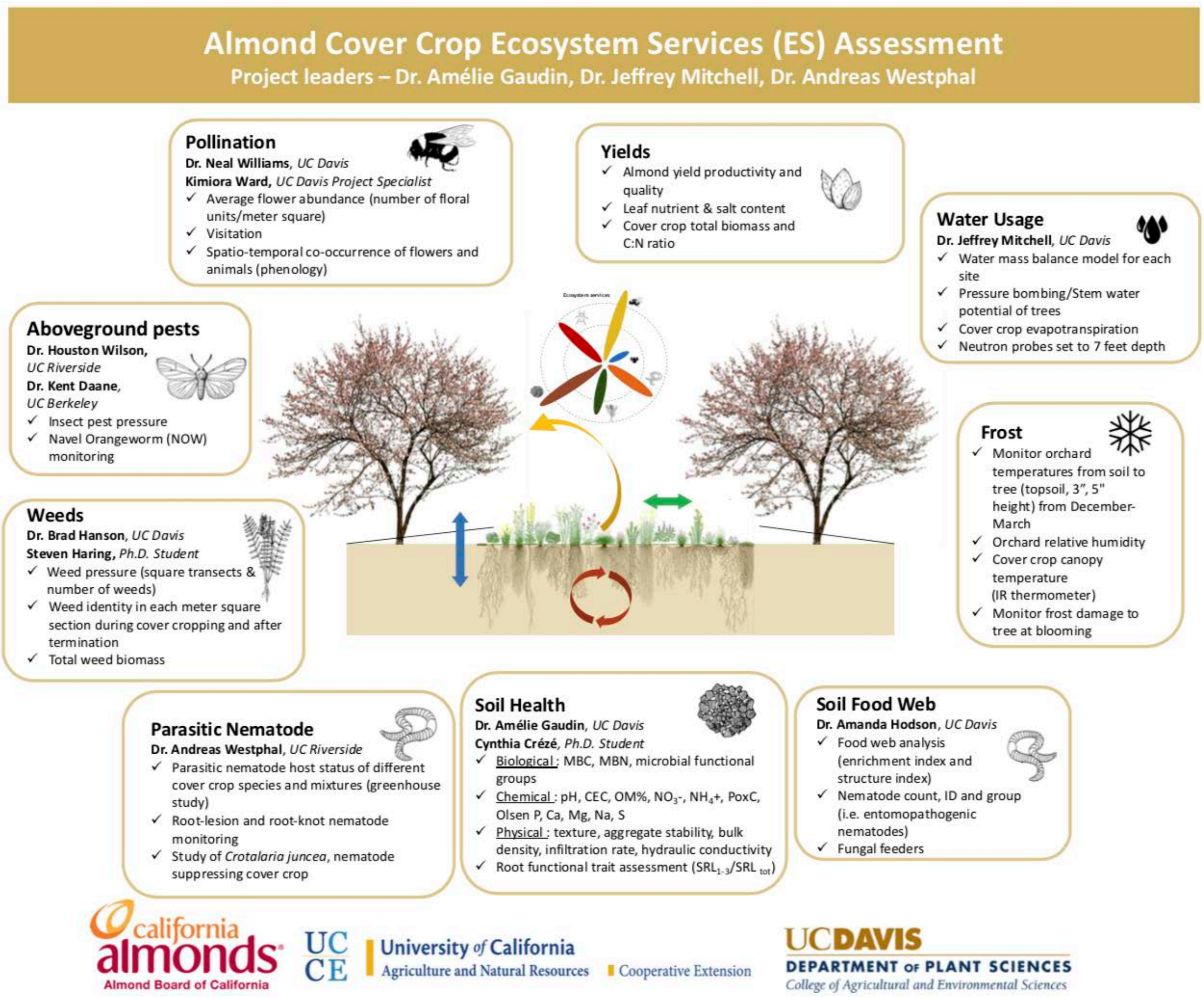


Figure 1: Orchard system-based measurement framework

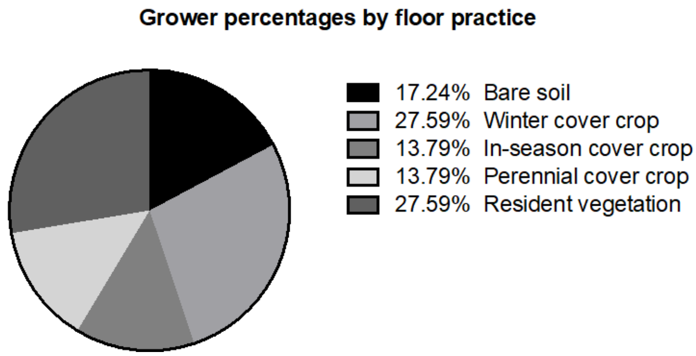


Figure 2. Percentage of respondents by floor management practice. The survey question was: "How do you manage the middles of your orchard?"

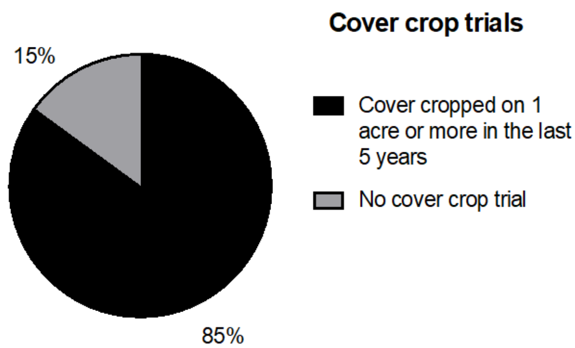


Figure 3. Percentage of respondents who experimented with cover cropping. The survey question was: "Have you used cover cropping on 1 acre or more in the last 5 years?"

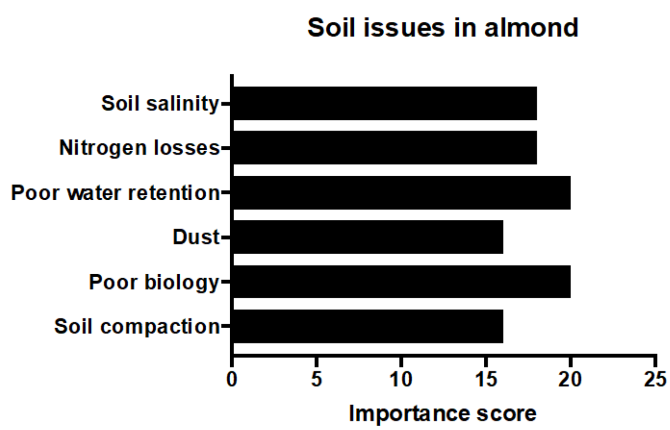


Figure 4. Importance of soil issues in almond orchards. The survey question was "How important are these soil issues in your orchard?" *The importance score was calculated as a sum of points (Not important = 0 points; Somewhat important = 1 point; Most important = 2 points).*

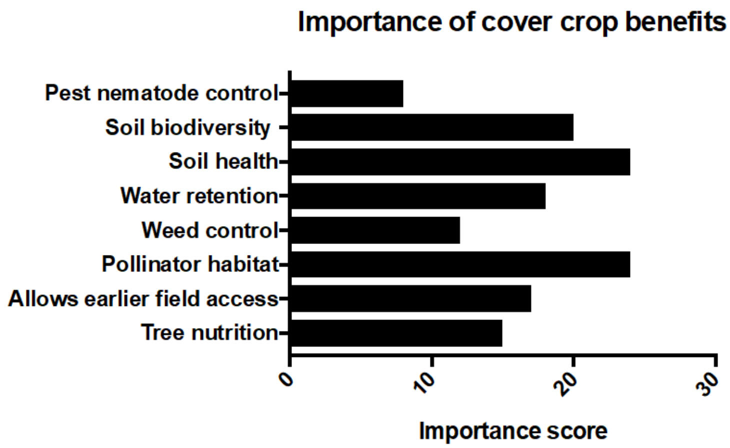


Figure 5. Importance score for potential cover crop benefits. The survey question was: "In your opinion, which of the following are most improved by cover cropping?" *The importance score was calculated as a sum of points (Not improved = 0 points; Somewhat improved = 1 point; Most improved = 2 points).*

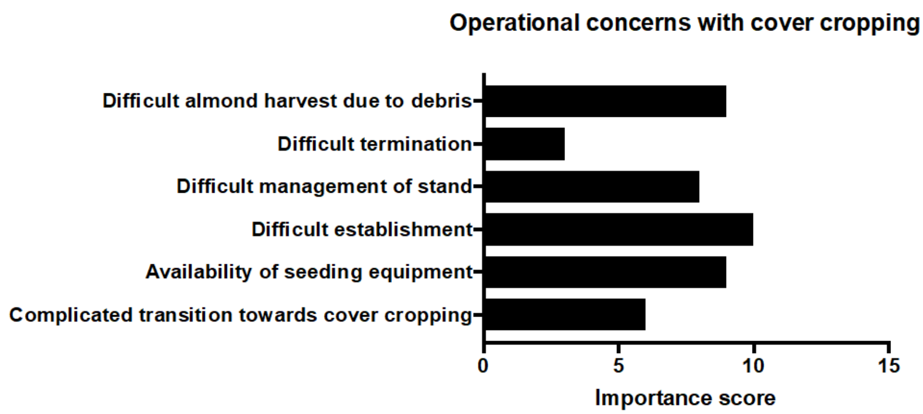


Figure 6. Importance of operational concerns with cover cropping. The survey question was: "If your concerns are mostly operational, how would you rank the following issues?" *The importance score was calculated as a sum of points (Not important = 0 points; Somewhat important = 1 point; Most important = 2 points).*

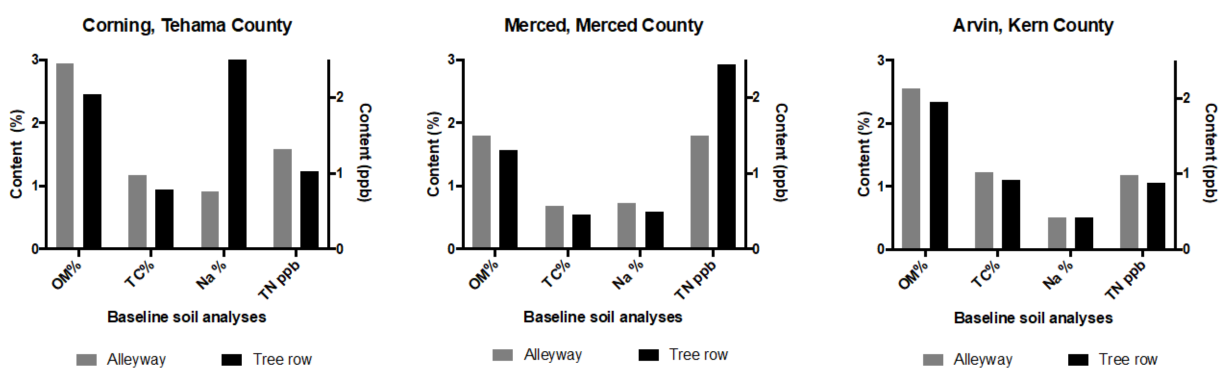


Figure 7. Baseline soil analysis (organic matter (%), total carbon (%), sodium (%) and total nitrogen (ppb)) from a total of 112 baseline soil samples. Other soil properties not presented in this figure included CEC, NO_3^-, NH_4^+, Olsen P, pH, soluble salts, potassium, sulfate, calcium, magnesium, texture, hydraulic conductivity, bulk density, and penetrometer readings.

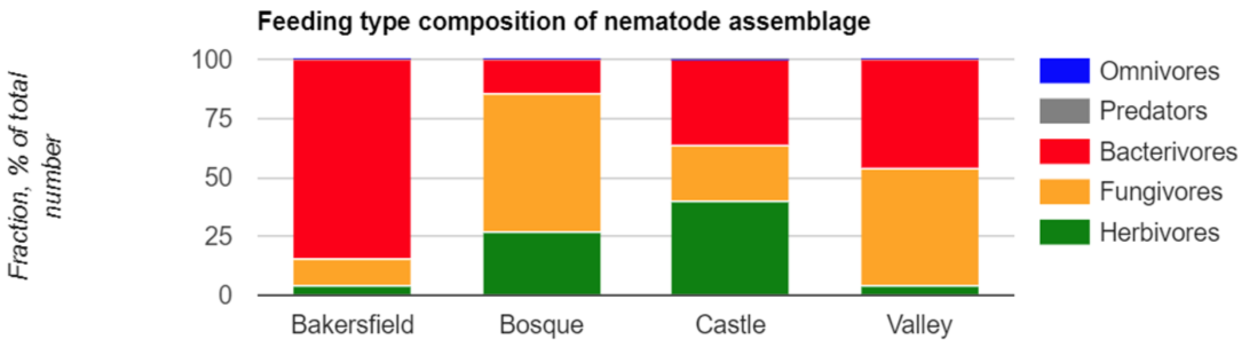


Figure 8. Free living nematode fractions at all sites.

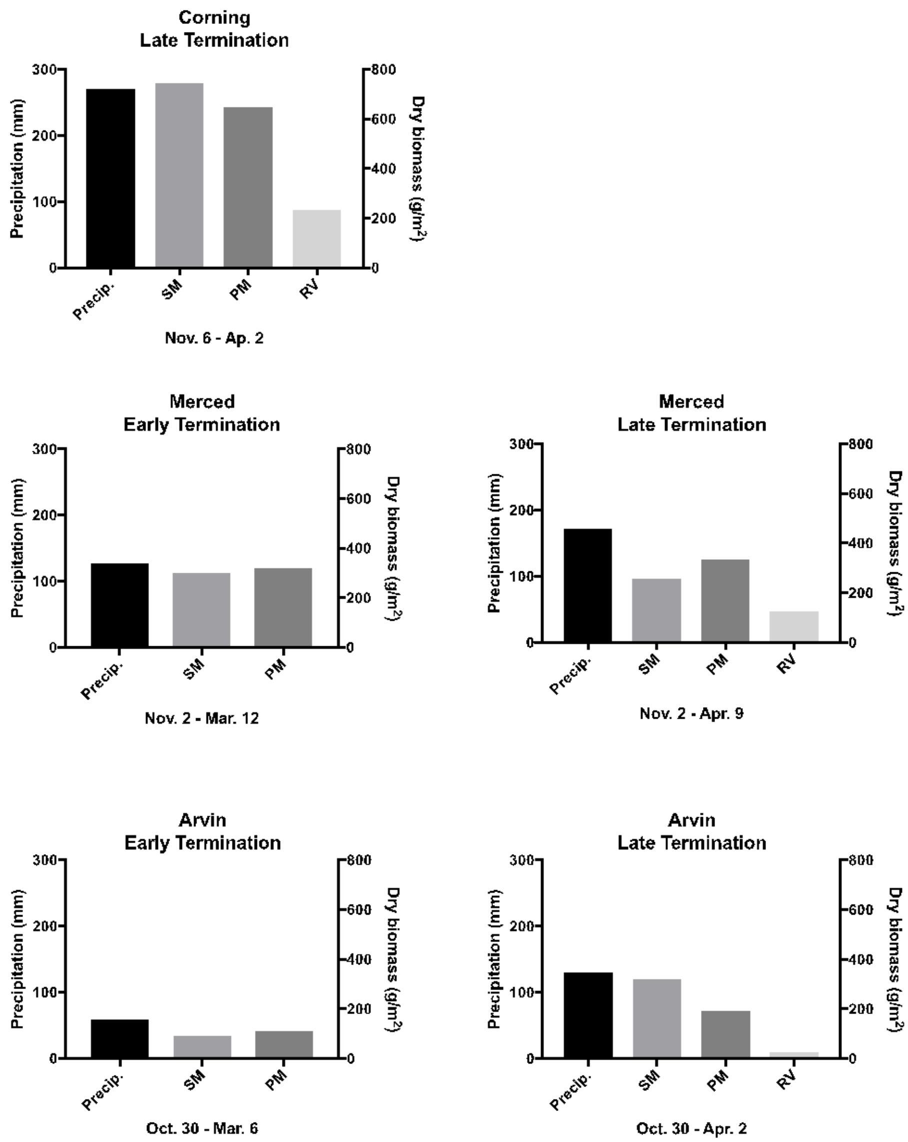


Figure 9. Cumulative precipitation and biomass production by vegetative cover type (soil mix (SM), pollinator mix (PM) and resident vegetation (RV)), by site and by termination date

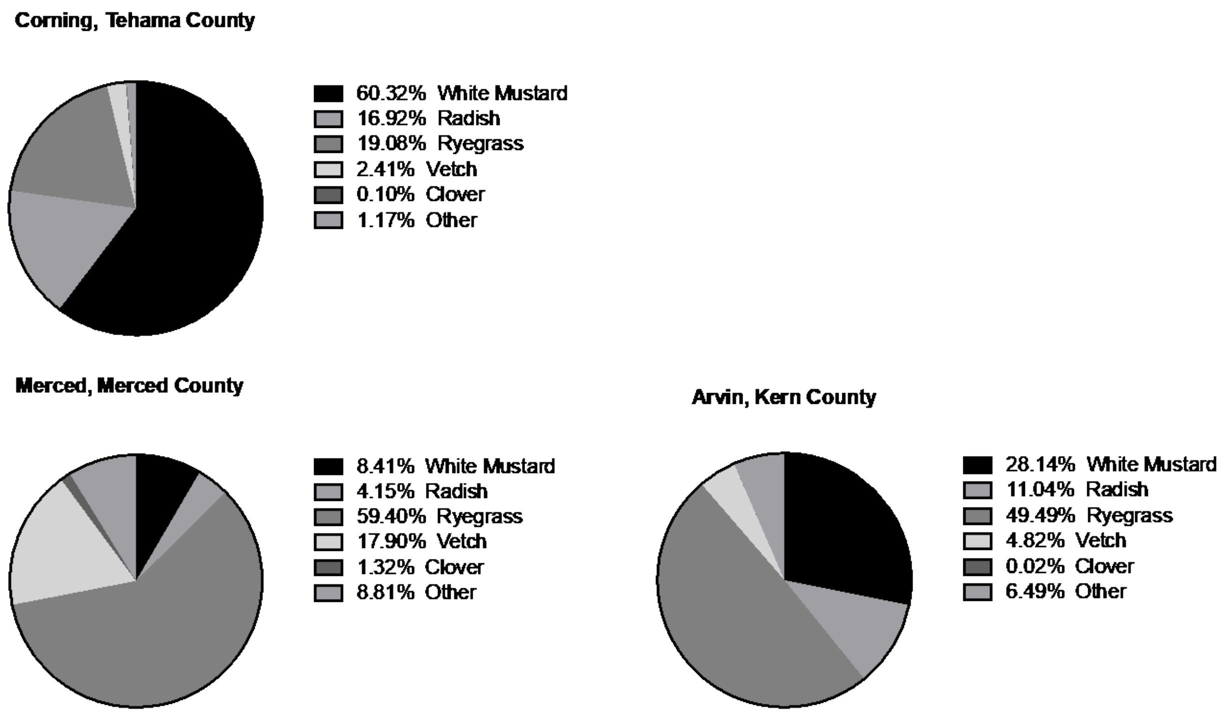


Figure 10. Soil mix species composition by dry-matter weight proportion by site

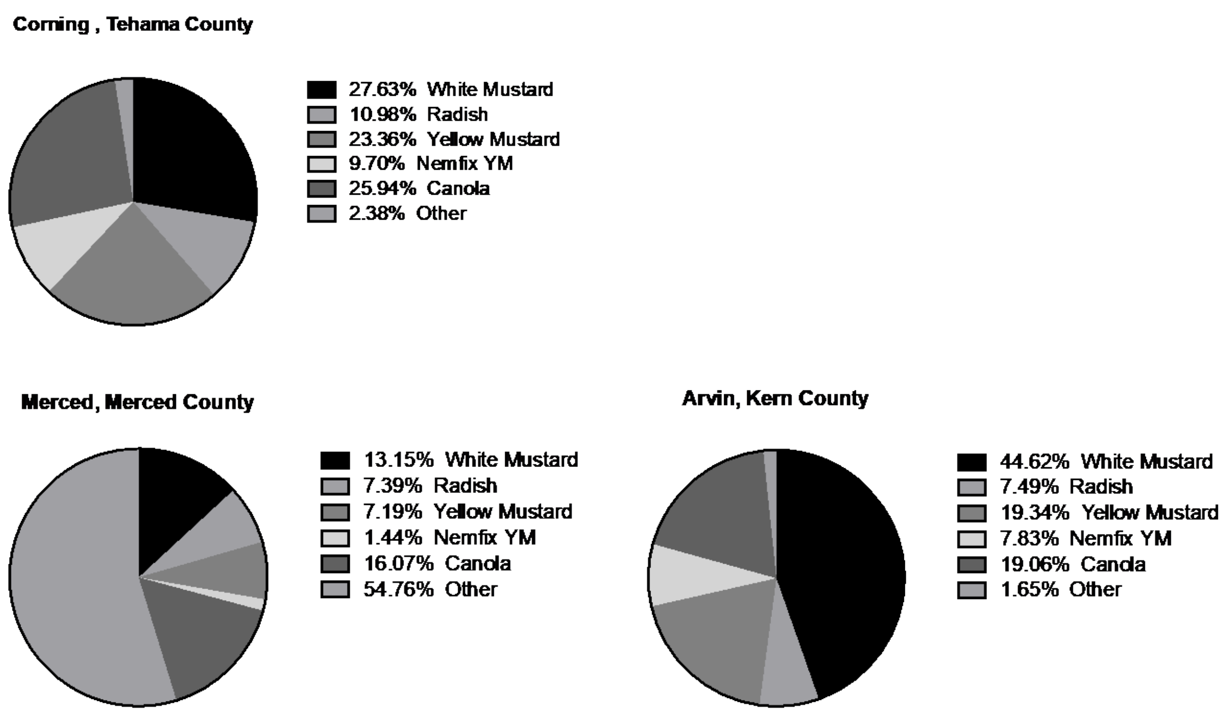


Figure 11. Pollinator mix species composition by dry-matter weight proportion by site

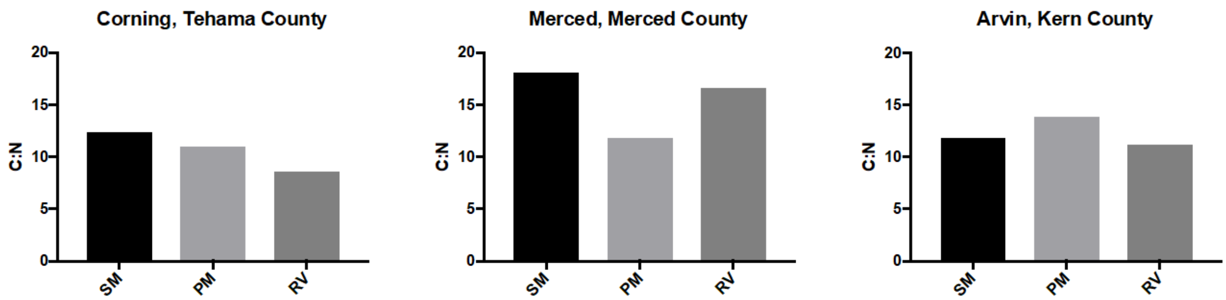


Figure 12. C:N ratio by vegetative cover type (soil mix (SM), pollinator mix (PM) and resident vegetation (RV)) and by site

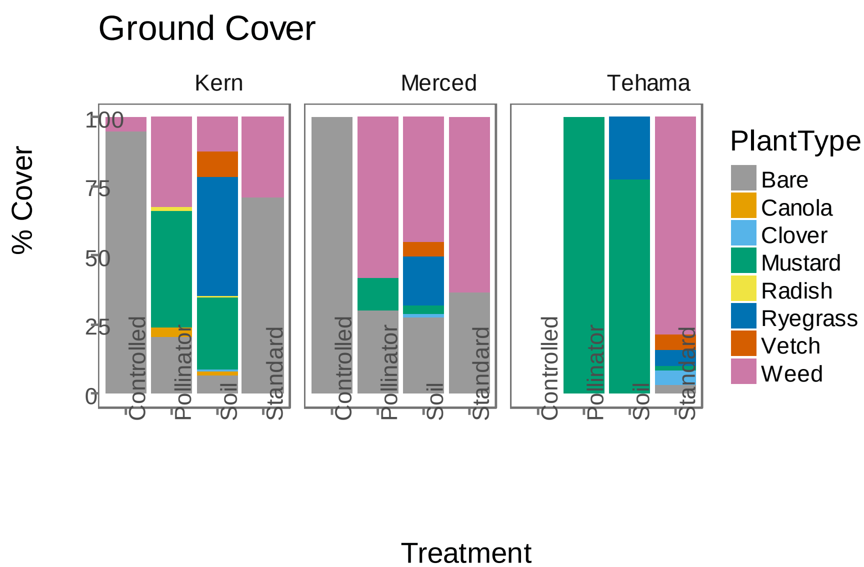


Figure 13. Relative orchard floor cover at each of three experimental sites, as observed in the spring following cover crop establishment. Bare ground is shown in gray, weeds in pink, and each cover crop group is in a separate color. Cover crop establishment varies inversely with weed cover.

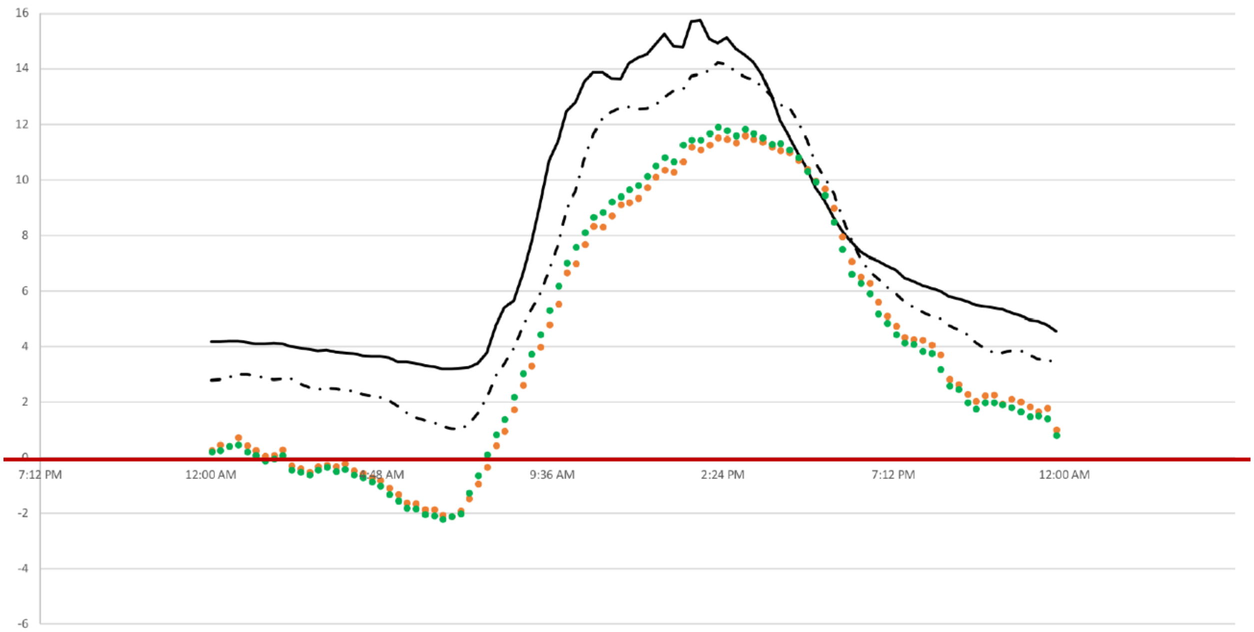


Figure 14. Temperatures of top soil (in black) and at 5 feet aboveground (green and orange) averaged from five frost days. The solid black and orange plots are the control. The dotted black plot and green plots are the cover crop treatment.

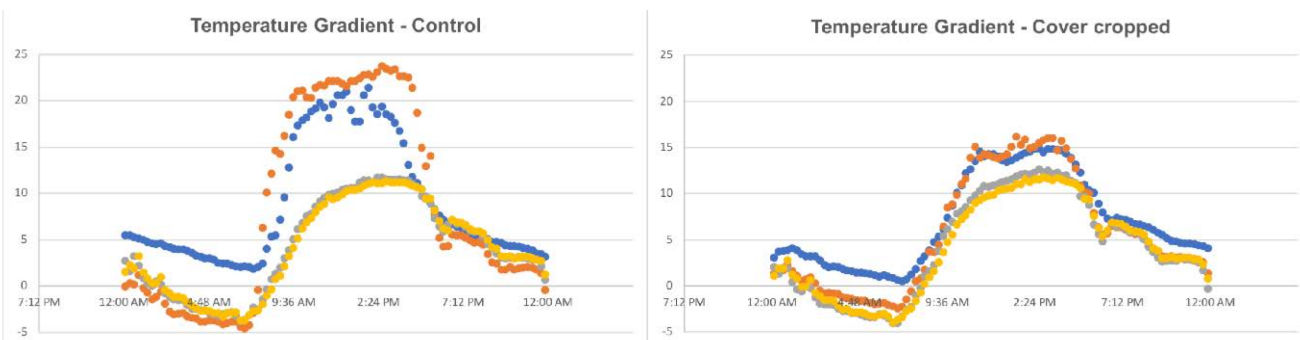


Figure 15. Average diurnal temperatures (°C) from a frost day (blue = topsoil, orange = 2 inches aboveground, grey = 3 feet and yellow = 5 feet).

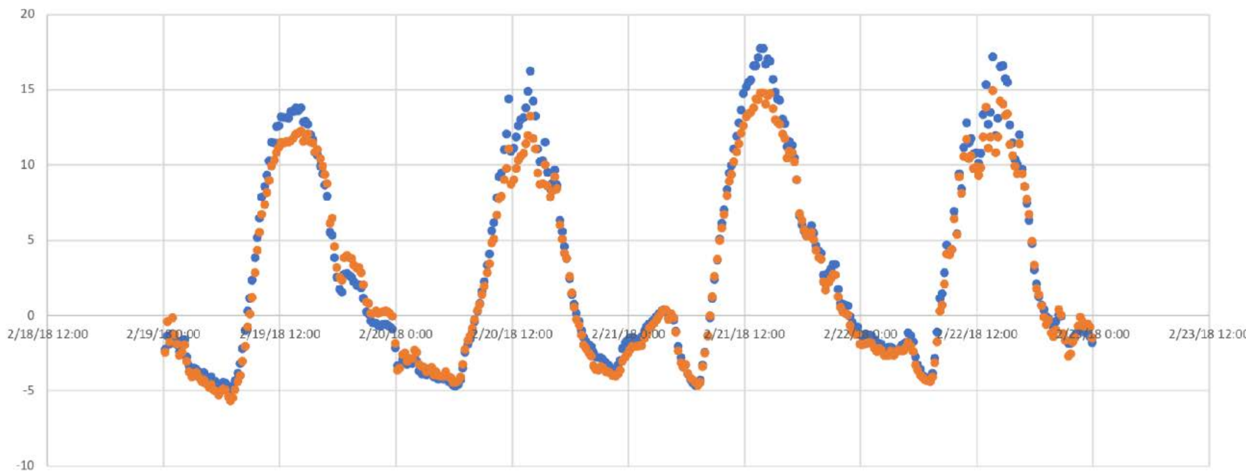
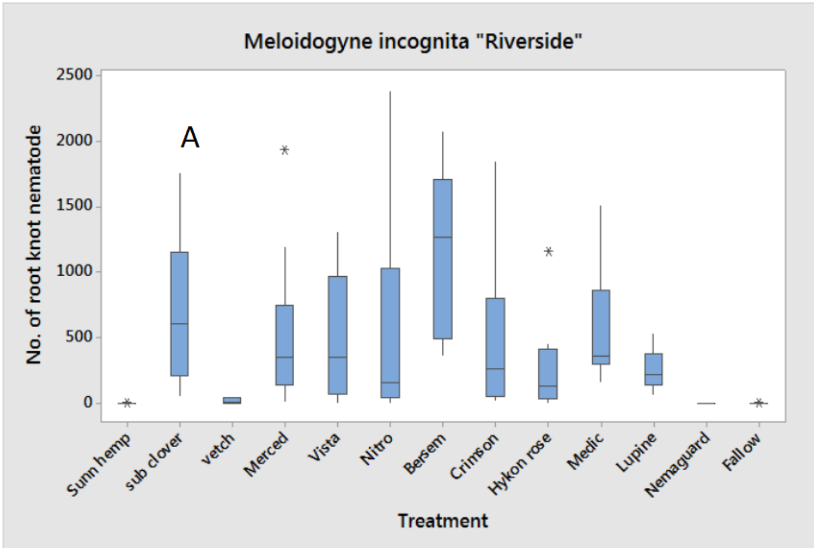


Figure 16. Infrared radiometer readings during four consecutive frost nights. The control is the blue plot.



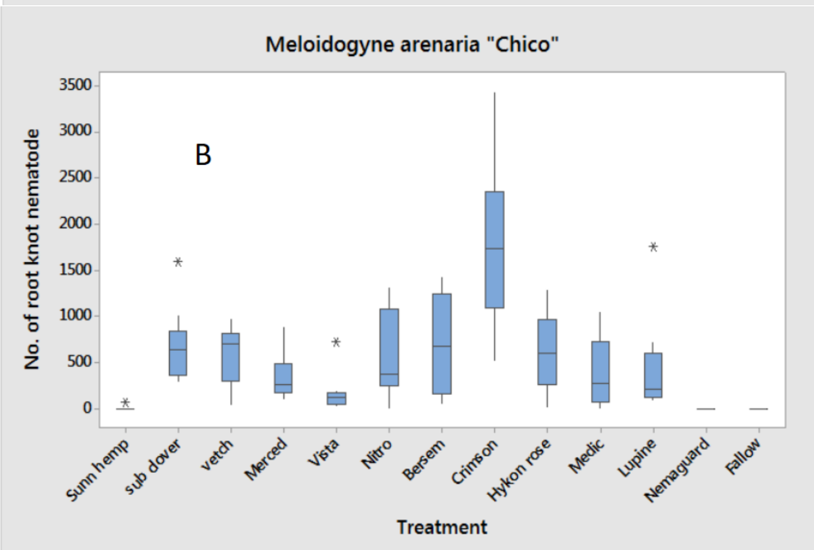


Figure 17. Final population densities of two root-knot nematode species on different potential cover crops (A) *M. incognita* and (B) *M. arenaria*

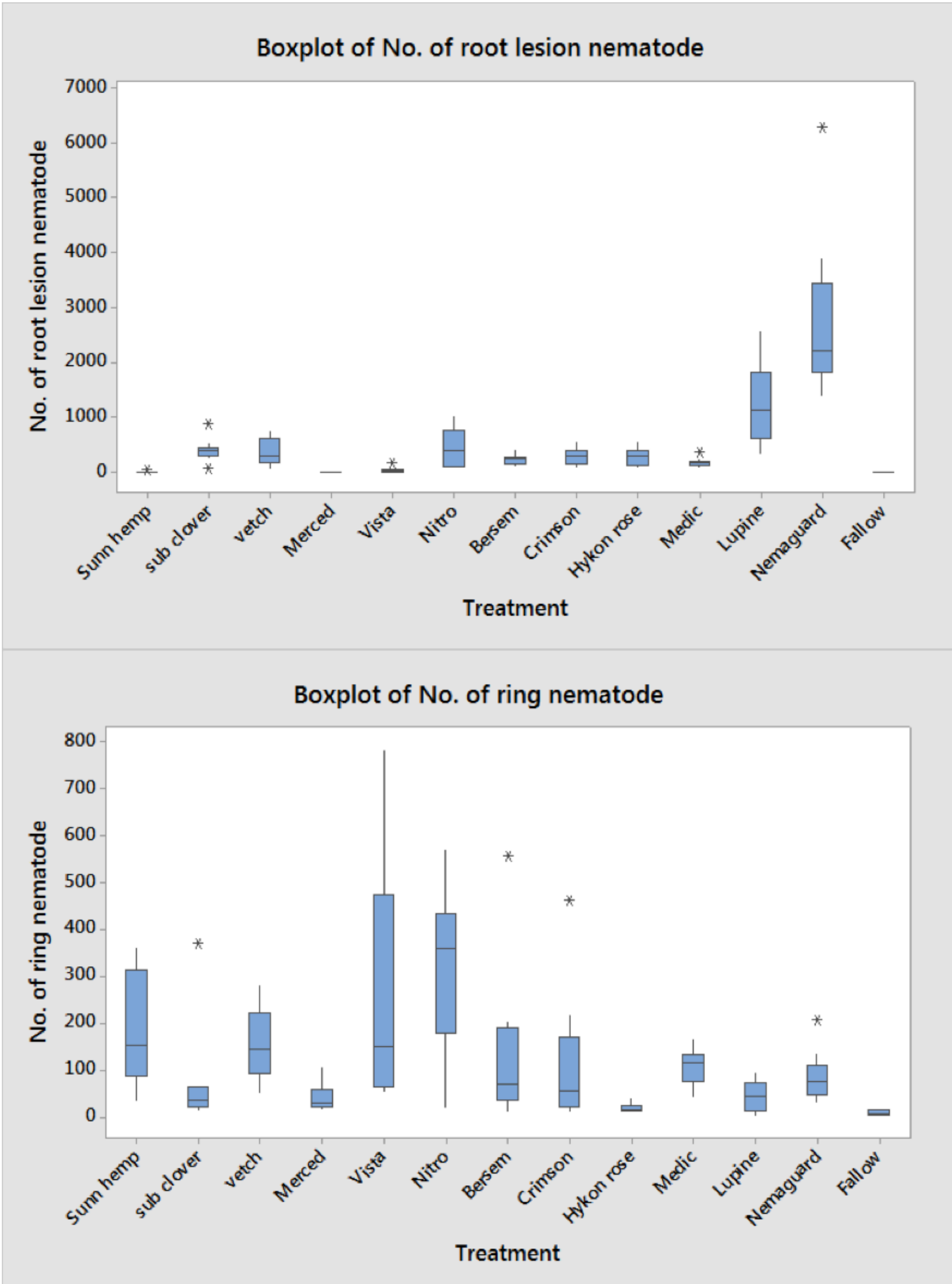


Figure 18. Final population densities of (A) root lesion nematode and (B) ring nematode species on different potential cover crops