Final Report for the Organic Farming Research Foundation

Title: Integrated soil-borne disease and weed management for organic strawberries using anaerobic soil disinfestation, broccoli residue incorporation, and mustard cake application

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Executive Summary

A lack of effective soil-borne disease management practices besides crop rotation and the high cost of weed management are two great challenges in organic strawberry production in coastal California.

Verticillium wilt, caused by ***Verticillium dahliae,*** is a lethal soil-borne disease for strawberries and poses a great threat for organic strawberry production in the state. To avoid this disease, organic strawberry growers have to implement a long-term crop rotation with non-host crops of ***V. dahliae***. Even with a longer crop rotation, however, the disease may not be able to be avoided. This has been the case for the organic farm of the Center for Agroecology and Sustainable Food Systems (CASFS) at UC Santa Cruz. This organic farm has been facing multiple outbreaks of Verticillium wilt on strawberries in spite of its 7-year crop rotation system. As a small-scale, diversified organic farm, it is difficult to rotate only with non-Verticillium hosts, and when host crops are planted this can result in increased populations of ***V. dahliae*** in the soil. Weed management costs in organic strawberries can be very expensive; it is not unusual to cost as much as $2,000/acre or more.

To combat these challenges, we examined the effects of anaerobic soil disinfestation (ASD), a biological alternative to methyl bromide fumigation developed in The Netherlands and in Japan, mustard cake (MC), a byproduct of biodiesel production, and broccoli residue incorporation, alone and in combination, on ***V. dahliae*** and weed suppression in organic strawberry production.

Objectives of the projects are to:

1. Determine an appropriate application rate for locally pressed mustard cake in terms of its effectiveness at weed suppression, ***V. dahliae*** suppression, nitrogen (N) provision, and fruit yield. The results will be used to determine the optimal mustard cake application rate in the broccoli-strawberry rotation experiment for Objective 2.

2. Demonstrate effects of anaerobic soil disinfestation (ASD), broccoli residue incorporation, mustard cake (MC) application, and a combination of all three on ***V. dahliae*** suppression, weed suppression, and strawberry fruit yield in a working organic farm with high Verticillium wilt pressure on the central coast of California.

3. Disseminate results to organic strawberry growers in the coast of California through a combination of workshops, field trips and written materials.

Tasks accomplished:

Objective 1. A split-split plot randomized block design field experiment with in-season N application rates (2 levels - none and grower's standard) as main plots, compost application (2 levels - 0 and 5 t/A) as split plots, and mustard cake application rates (3 levels - 0, 1.5 and 3 t/A (***Sinapis alba*** L. cv. Ida Gold)) as split-split plots was established with 4 replications. Strawberry (cv. Albion) was grown from Nov. 2010 to Sep. 2011 during which monthly soil inorganic N monitoring, weed biomass sampling, viable ***V. dahliae*** counts in topsoil, and weekly fruit yield monitoring were conducted.

Strawberry plants in all plots grew without any problem until April, 2011. Then some plants showed leaf edge discoloration. The number of plants with the symptom was highest in

MC 3 t/A plots and lowest in MC 0 t/A plots. Soil analysis confirmed that the symptom was attributed to the high salinity caused by excess accumulation of nitrates especially with MC at 3 t/A plots. Significant effects of MC (***P***=0.03*) and MC x compost interaction (***P***=0.02*) were observed on cumulative marketable fruit yield; for the interaction, compost 0 t/A + MC 3 ton/A plots and compost 0 t/A + MC 1.5 t/A plots had significantly greater yield than compost 0 t/A + MC 0 t/A plots.[1] Fertigation (***P***=0.45) and compost (***P***=0.48) had no effects on fruit yield. This indicates that use of MC at a rate of 1.5 t/A without fertigation or compost was the most efficient in producing high fruit yield. Very few weeds emerged from planting holes in the black plastic mulch since the grower minimized the size of planting holes to reduce weed biomass; this prohibited the evaluation of weed suppression. There was no effect of any treatment on the viable ***V. dahliae*** microsclerotia numbers in topsoil.

Objective 2. A split-plot experiment (4 replicates) with 3-year crop rotations: 1) broccoli-strawberry-lettuce, 2) cauliflower-strawberry-lettuce, and 3) fallow-strawberry-lettuce as main plots; and ASD with rice bran 9 tons/A, MC (1.5 tons/A), ASD plus MC (7.5 t/A of rice bran and 1.5 t/A of MC), and untreated control (UTC) as split plots was established at the UCSC organic farm. In summer 2011, broccoli and cauliflower were grown at assigned plots. After harvesting these crops, each main plot was divided into 4 sub plots and sub treatments were applied. Strawberry (cv. Albion) was grown from Nov. 2011 to Sep. 2012. Marketable fruit yield, degree of plant wilt level, ***V. dahliae*** infection on strawberry plants, soil inorganic N, viable ***V. dahliae*** numbers, weed density under clear plastic mulch, and weeding time for bed area were monitored during the strawberry growth period. After strawberry, a legume-cereal winter cover crop mix (winter 2012-spring 2013) and romaine lettuce (cv. Salvius, summer 2013) were grown at all plots and biomass and yield were measured.

Head yield of broccoli and cauliflower averaged 6.4 t/A and 4.2 t/A, respectively. No significant differences were found between plots assigned to different sub-treatments for either crop (***P***>0.80) showing good uniformity of production across the field. Strawberry plants experienced some salt burn damage in early season. Some plants started to wilt in May 2012 and the wilting progressed as plants became senescent. At the end of the season, UTC had the highest wilt score and ASD the lowest (***P***=0.043*). This coincided with the plants from UTC having higher ***V. dahliae*** infestation rates than ASD and ASD+MC (***P***=0.006**). No differences in biomass, wilt scores and ***V. dahliae*** infestation rate were found between main plots. Cumulative marketable fruit yield was greatest in ASD+MC, followed by ASD, MC, and lowest for UTC (***P***=0.0001***). There was no difference in cumulative marketable fruit yield between main plots (***P***=0.58). No significant differences were found between any treatments on total dry aboveground cover crop biomass. Romaine lettuce marketable yield showed no significant difference either in main (***P***=0.43) or split (***P***=0.18) plots. Viable ***V. dahliae*** microsclerotia numbers in the topsoil were rather low throughout the trial; the average ranged from 0.5 to 1.5 per gram soil. At lettuce harvest, it increased to 2.8 at UTC but it remained significantly lower

[1] A significant MC x compost interaction means MC has significant effect on fruit yield either when compost was applied or not (or, the effect of compost is significant only at certain MC application rate(s), not at all application rates). Although MC main effect has a significant effect, when an interaction exists at similar or greater probability, which is true for this case, the interaction overrides the main effect. In this case, therefore, MC's significant effect on yield is observed only when compost was not applied.

than UTC at ASD (0.3) and ASD+MC (0.7) indicating the disease suppressiveness of the ASD treatment. Cauliflower plots had lower weed density than broccoli and fallow plots (***P***=0.046), but no difference was found between subplots (***P***=0.17). Although weeding time showed a similar trend as the weed density, there was no difference between the main plots, and UTC (average 34 hrs/acre) had longer weeding time than ASD (average 20 hrs/acre).

The present study showed that ASD can increase marketable fruit yield of strawberry by reducing ***V. dahliae*** infection of strawberry plants and providing nutrients. Further, ASD kept ***V. dahliae*** microsclerotia inoculum very low in the soil for two years even when lettuce, a host of the pathogen, was planted during the period. This has a significant implication for organic strawberry growers in the region by giving them more flexibility in crop rotation. MC and broccoli alone did not show significant effects in ***V. dahliae*** reduction and weed suppression. Also additive or synergistic effects of combining ASD with MC or broccoli rotation in disease/weed suppression and yield increase in strawberry and lettuce were not observed in this trial. A partial reason may be unexpectedly low ***V. dahliae*** microsclerotia numbers in the soil. For MC, the rate we used might have been too low for weed suppression. Given the results of Objective 1, it may be difficult to realize weed suppression by MC in current strawberry systems in the central coast of California.

Economic analysis for the entire rotation period at each treatment was conducted. The revenue, costs of production and net returns per acre are calculated for each treatment at the UCSC trial. A hypothetical 25-acre farm is simulated for each treatment, resulting in twelve simulations. It showed the net return above land costs increased ~30% by ASD and ASD+MC over UTC and MC, suggesting the economic benefits of ASD not only in strawberries but also in the overall crop rotation compared in the trial.

Objective 3. Co-funded by the USDA-Western SARE Program, a non-replicated demonstration trial (0.1 acre) with the same design as the Santa Cruz trial in Objective 2 was established at ALBA, Salinas in 2012. Strawberry plants started to show wilt symptom caused by ***V. dahliae*** in April 2013, and by May significant plant mortality occurred. For main plots, mortality was highest in the broccoli plots, followed by the fallow plots, and the lowest in the cauliflower plots. For sub plots, UTC and MC plots had higher mortality compared to ASD and ASD+MC plots. Cumulative fruit yield reflected the mortality of the plants; for main plots, the cauliflower plots had the highest yield, followed by the fallow plots, and the lowest in the broccoli plots. For sub plots, the order was ASD > ASD+MC > MC > UTC. There was a strong negative correlation between mortality and cumulative fruit yield (***P***=0.0001***). Unexpectedly, broccoli plots resulted in higher mortality than the cauliflower and fallow plots. A multi-cut broccoli variety De Cicco was used in this broccoli treatment suggesting that the effect of broccoli residue incorporation on ***V. dahliae*** suppression may be variety dependent.

Using this demonstration trial, a field day/workshop on soil-borne disease management in organic strawberry production was conducted at ALBA on 7/9/13. The workshop mainly targeted Latino growers. We had 14 participants and simultaneous Spanish translation was provided. According to the post-workshop survey, the event was well received by most participants.

A part of the data from this project was presented at multiple outreach meetings. Data from the project were presented at the Second International Organic Fruit Research Symposium, held at Leavenworth, Washington, June 18-21, 2012. A paper based on this project was presented at the Eighth International Symposium on Chemical and Non-Chemical Soil and Substrate Disinfestation (SD 2014) in Torino, Italy, in July 2014 (in press in Acta Horticulturae).

Project Justification and Background

The issues we are addressing in this project are related to organic strawberry production in coastal California and are twofold; first, a lack of effective soil-borne disease management practices besides crop rotation, and second, high cost of weed management.

The former issue is critical for organic strawberry growers in California for multiple reasons. First, Verticillium wilt, caused by ***Verticillium dahliae,*** is a lethal soil-borne disease for strawberry and poses a great threat for organic strawberry production in the state. The disease is difficult to control due to its wide range of host crops including major crops in California such as lettuce, cauliflower, tomato, potato, eggplant, pepper, spinach, artichoke, cherry, apple, cotton, and strawberry (Bhat and Subbarao, 1999). ***V. dahliae*** also forms overwintering structures (microsclerotia) that can survive more than 5 years even without host crops. Further, current strawberry cultivars are highly sensitive to Verticillium wilt (Koike, personal communication); even 1 microsclerotium per gram of soil can cause significant rates of disease in strawberry. To avoid this disease, organic strawberry growers have to implement a long-term (5 or more years) crop rotation with non-host crops of ***V. dahliae*** (Muramoto et al., 2014). Even with a longer crop rotation, however, the disease may still occur. This has been the case for the organic farm of the Center for Agroecology and Sustainable Food Systems (CASFS) at UC Santa Cruz. This internationally recognized 25-acre organic farm established in 1972 has been facing multiple outbreaks of Verticillium wilt on strawberry (particularly in 2001 and 2009) regardless of its 7-year crop rotation system. As a small-scale, diversified organic farm, it is difficult to rotate only with non-Verticillium hosts, and when host crops are planted this can result in increased populations of ***V. dahliae*** in the soil as found at CASFS where in one field the ***V. dahliae*** population reached as high as 30 microsclerotia/gram soil.

Our research team of Carol Shennan, then director of CASFS, Joji Muramoto, then CASFS researcher, Steve Koike, UC Cooperative Extension plant pathology advisor, and Jim Leap, then farm manager at CASFS, has been working together on this issue ever since the first major outbreak of Verticillium wilt in 2001. We started to try a newly developed biological soil disinfestation method, anaerobic soil disinfestation (ASD). The soil disinfestation methods using anaerobic decomposition of organic matter were developed in The Netherlands (Blok et al., 2000; Goud et al., 2004) and Japan (Shinmura, 2000; Momma et al. 2013) as an ecological alternative to methyl bromide fumigation. ASD integrates principles behind solarization and flooding to control nematodes and pathogens in situations where neither method is effective or feasible by itself. ASD works by creating anaerobic soil conditions by incorporating readily available carbon-sources into topsoil that is irrigated to saturation (not flooded) and subsequently covered with a plastic tarp. The tarp is then left in place to enable anaerobic decomposers to respire using the added carbon and produce anaerobic by-products that are toxic to pathogens, but that are degraded rapidly once the tarp is removed or holes are made through the tarp for planting. In Japan, hundreds of farmers use ASD to control soilborne pathogens (including ***V. dahliae***) and nematodes in strawberry and vegetables.

Broccoli residue incorporation has been demonstrated to be effective in suppressing Verticillium wilt on strawberry (Subbarao et al., 2007; Muramoto et al., 2014) and cauliflower

(Subbarao et al., 1994) in California. Many organic strawberry growers in central coastal California have been implementing a broccoli-strawberry rotation.

The second issue we address in the proposal is the high cost of weed management in organic strawberry. Weed management is one of the greatest challenges in organic production (Sooby et al., 2007). Although opaque plastic mulch application, a common practice in organic strawberry production in California, suppresses weed pressure to some degree, manual weeding can cost as much as $2,000/acre annually (Bolda et al., 2006).

Mustard cake amendments (MC) were shown to have the capacity to suppress weeds and to create disease suppressive soils. Although such materials were commonly viewed as effecting disease control through “biofumigation” (release of toxic products during residue decomposition), specific elements of the soil biological community have also been shown to contribute to disease or weed control (Cohen et al., 2005; Mazzola et al., 2007; Hoagland et al., 2008). It is likely that the modes of action may vary from pathogen to pathogen (Mazzola et al., 2007) and that the source of the product can also modulate disease control efficacy (Mazzola and Brown, 2010).

We are not aware of any report that compared effects of ASD, broccoli residue incorporation, mustard cake, and a combination of all three on Verticillium wilt suppression, weed suppression, and strawberry yield in organic production.

Currently the lack of an effective method to suppress Verticillium wilt in organic strawberry is not only a major hindrance to new organic strawberry production but also a serious challenge in sustaining organic production in coastal California. Weed management is another challenge in organic strawberry production. Thus, developing and disseminating feasible soil-borne disease and weed management practices such as these is likely to benefit all organic strawberry production in coastal California.

Objectives and Measurable Outcomes

Objectives of the projects are to:

1. Determine an appropriate application rate for locally pressed mustard cake in terms of its effectiveness at weed suppression, soil-borne disease suppression, and nitrogen (N) provision, and overall economic feasibility. The results will be used to determine the optimal mustard cake application rate in the broccoli-strawberry rotation experiment.

Measurable outcomes for this objective are:

1) Marketable fruit yield increase by different treatments over untreated control,
2) Differences among treatments in N mineralization patterns, crop N acquisition and apparent N loss during the rainy winter season,
3) Difference in weeding time and weed biomass between treatments,
4) Difference in pathogen (***V. dahliae***) suppression between treatments, and
5) Based on 1) through 4), an optimum application rate of mustard cake to organic strawberry.

2. Demonstrate effects of anaerobic soil disinfestation (ASD), broccoli residue incorporation, mustard cake (MC) application, and a combination of all three on ***V. dahliae*** suppression, weed suppression, and strawberry fruit yield in a working organic farm with high Verticillium wilt pressure on the central coast of California.

Measurable outcomes for this objective are:

1) Marketable fruit yield increase by treatments over untreated control,
2) Reduction of ***V. dahliae*** in soil and wilt symptom on plants by treatments over untreated control,
3) Difference in weed density and weeding time between treatments, and
4) Estimated net income increase by each treatment over untreated control using fruit yield data, weeding time, input costs, and operational costs.

3. Disseminate results to organic strawberry growers in the coast of California through a combination of workshops, field trips and written materials.

Measurable outcomes for this objective are:

1) Number of attendees at each workshop and field trip, and
2) Number of organic strawberry growers who showed interest in adopting proposed management practices.

Summary of Task Completion

Objective 1.

1-1. Major activities

A field trial was established in the Redman site (Conejo clay loam soil. CCOF certified), Watsonville, CA. Steve Pedersen at the High Ground Organics is our collaborative grower for this trial. A split-split plot randomized block design experiment with in-season N application rates (2 levels - none and grower's standard ("AgroThrive LF" 2.5-2.5-1.5. Density: 9.6 lbs/gallon. 5 to 15 gallons per application every other week from Feb. to Sep. totaling 75 gallons/A)) as main plots, compost application (2 levels - 0 and 5 t/A (Herbert farm, Hollister, CA)) as split plots, and mustard cake application rates (3 levels - 0, 1.5 and 3 t/A (***Sinapis alba*** L. cv. Ida Gold. from Farm Fuel Inc. Freedom, CA)) as split-split plots was established on 11/4/10. C/N content of mustard cake and compost used and total C and N applied through mustard cake and compost are shown in Table 1 and 2, respectively. Each plot has 4 replications, making a total of 48 plots. Each plot size is 20 ft long x 5.3 ft width (one bed) with 2 rows of strawberry plants per bed. Strawberry (cv. Albion) was transplanted to all plots on 11/30/10 about four weeks after the cake applications to avoid phytotoxicity by mustard cake. During the growth period, we continued monthly soil inorganic N monitoring (0-6 and 6-12 inch depths), weed biomass sampling, and weekly fruit yield monitoring at 20 marked plants at each plot (April – Sep.) (Fig.1). N loss during the winter rainy season (Nov. 2010-Apr. 2011) was estimated from changes in soil inorganic N content and plant biomass N. Viable ***V. dahliae*** propagules in topsoil were counted using the modified Anderson sampler method with NP-10 semi selective medium.

Figure 1. On-farm trial at the Redman site, Watsonville, CA

Table 1. C/N content of mustard cake and compost used in the experiment.

Amendment	C % oven dry	N % oven dry	C/N
Mustard cake	50.6 (0.11)*	6.30 (0.14)	8.0 (0.19)
Compost	9.28 (0.13)	0.98 (0.02)	9.5 (0.06)

Amendment	C % fresh	N % fresh	Fresh moisture %
Mustard cake	45.3 (0.15)	5.63 (0.12)	10.6 (0.14)
Compost	6.72 (0.15)	0.71 (0.01)	27.6 (2.2)

*( ): standard deviation. n=4.

Table 2. Total C and N applied through mustard cake and compost at each treatment.

Compost rate	Mustard rate	Total C applied (lbs/ac)	Total N applied (lbs/ac)
0 t/ac	0 t/ac	0	0
0 t/ac	1.5 t/ac	1358	169
0 t/ac	3.0 t/ac	2715	338
5.0 t/ac	0 t/ac	672	71
5.0 t/ac	1.5 t/ac	2030	240
5.0 t/ac	3.0 t/ac	3387	409

1-2. Strawberry plant growth

Strawberry plants in all plots grew without any problem until April, 2011. Plant biomass sampled on 2/22/11 was highest at MC 3 t/A, followed by 1.5 t/A, and 0 t/A (***P***=0.05). In April, however, some plants showed leaf edge discoloration (Fig. 2). The number of plants with the symptom was highest in MC 3 t/A plots and lowest in MC 0 t/A plots (***P***=0.0003***). Soil analysis confirmed that the symptom was attributed to the high salinity caused by excess accumulation of nitrates especially with MC at 3 t/A plots. Fruit harvest began on April 26. In July, the two-spotted spider mite population increased, which reduced plant vigor in all plots. In August, powdery mildew further damaged all plants and resulted in dramatic reduction of late season fruit yield.

Figure 2. Leaf edge discoloration of strawberries caused by high salinity.

1-3. Marketable fruit yield

Since all plants were greatly affected by mites and powdery mildew from August onwards, here we discuss treatment effects on cumulative fruit yield through July. Significant effects of MC (***P***=0.03*) and MC x Compost interaction (***P***=0.02*) were observed on cumulative marketable fruit yield (Fig. 3); for the interaction, Compost 0 t/A + MC 3 ton/A plots and Compost 0 t/A + MC 1.5 t/A plots had significantly greater yield than Compost 0 t/A + MC 0 t/A plots. Fertigation (***P***=0.45) and Compost (***P***=0.48) had no effects on fruit yield. This indicates that use of MC at a rate of 1.5 t/A without fertigation or compost was the most efficient in producing high fruit yield. Salt damage at MC 3 t/A plots may have limited the fruit yield of these plots. Use of compost and fertigation may have contributed to high salinity in this trial and reduced any growth benefit from the added fertility.

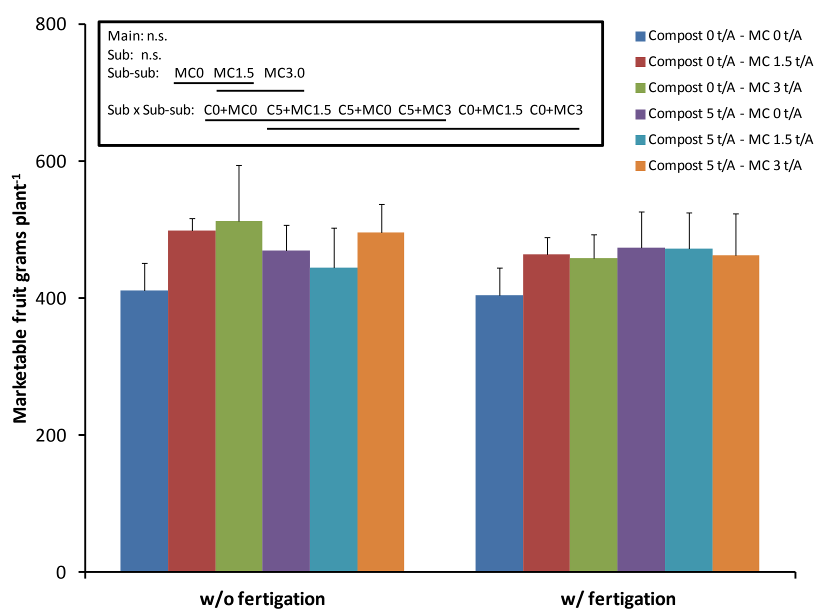

Figure 3. Cumulative marketable fruit yield at the Redman trial. Harvest period: 4/26/11 – 7/28/11. No significant difference was found between any treatments on the same line with Tukey's HSD test (***P***=0.05).

1-4. Soil inorganic N dynamics

Throughout the entire growth season, the MC application rate appeared to be the main driver of the soil inorganic N dynamics at both depths (***P***<0.0001 by May 2011 and ***P***<0.10 between June and Aug. 2011). Nitrate-N in the topsoil of all plots was 30 to 50 mg/kg for the first two months (until Jan. 2011). In Feb., topsoil nitrate-N increased dramatically according to MC application rate and peaked in March at 50, 110, and 190 mg/kg for MC 0, 1.5 t/A and 3 t/A respectively. A total of 7 inches of rain in March flooded the field and nitrate-N in topsoil decreased. Topsoil nitrate-N remained in a range of 20 to 50 mg/kg for the rest of the growth period. Little effect of fertigation or compost on soil nitrate-N was observed. Soil ammonium-N was generally low (< 5 mg/kg) at both depths except for Dec. in the MC 3 t/A plot when it reached 17 mg/kg.

1-5. Soil salinity and plant damage

Many studies show that soil nitrate concentrations correlate well with the soil salinity measured as electrical conductivity (EC) in upland fields (Soil Quality Institute, 1998). Further, strawberry is known to be sensitive to salinity. Leaf edge discoloration is a typical symptom of salinity damage of strawberry. Indeed soil $EC_{1:1}$ (electrical conductivity measured with soil:water =1:1 volume ratio) was measured in April and found to be positively correlated with the level of leaf discoloration of strawberry plants (measured as percent of damaged plants) (R^2 = 0.219, ***P***=0.0008***). Soil $EC_{1:1}$ and soil nitrate in April showed a strong positive correlation ($EC_{1:1} = 0.281 \times NO_3\text{-}N^{0.2748}$, R^2=0.7779, ***P***<0.00001***). Based on this correlation,

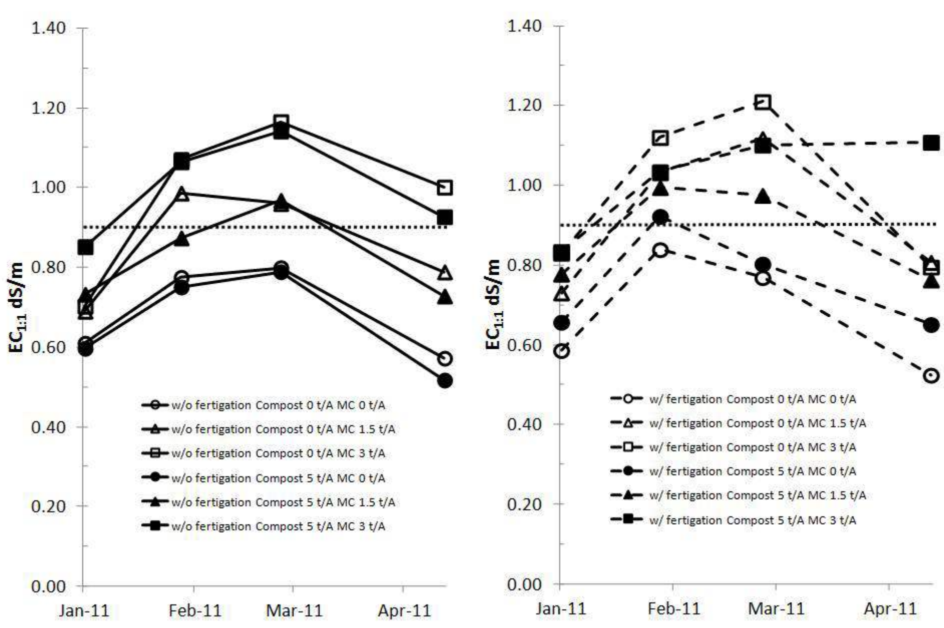

Figure 4. Changes in $EC_{1:1}$ of topsoils at without fertigation main plots (left) and with fertigation main plots (right) in the Redman trial from Jan. to Apr. 2011. $EC_{1:1}$ values in Jan., Feb., and Mar. 11 were estimated based on the correlation between NO_3-N and $EC_{1:1}$ of Apr. samples. See text for more information.

changes in topsoil $EC_{1:1}$ through Jan. and Apr. were estimated and contrasted with the threshold above which yield reduction occurs for salt sensitive crops including strawberries: 0.90 decisiemen per meter (dS/m) (Soil Quality Institute, 1998). All MC 3 t/A plots had topsoil $EC_{1:1}$ above the threshold from Feb. to Mar. (1.0 to 1.2 dS/m) and 75% of these were still above the threshold in Apr. (Fig. 4). In contrast, for MC 1.5 t/A plots, 75% of the plots had over the threshold $EC_{1:1}$ in Feb., 100% in Mar., and none in Apr., and for MC 0 t/A levels were generally below the threshold throughout.

1-6. N mineralization from MC

Initial analysis of changes in soil inorganic N in MC plots versus non-MC plots suggest that little mineralization (14%) of N from the MC occurred in the period from incorporation (11/4/10) through early Jan., whereas the bulk (an additional 65%) mineralized between early Jan. and early Feb. However, some inorganic N may have been lost due to rainfall between Nov. and Feb. leading us to underestimate mineralization during that period. Mustard cake has a high N content (6.3%) and a low C/N ratio (8.0) so it is not surprising that at least 80% had mineralized within 3 months. Soil temperatures at the closest CIMIS station (Watsonville West 2) during this period (Nov. 2010 to Mar. 2011) ranged from 50 to 65° F.

1-7. Estimated N loss during the winter rainy season

The amount of N loss during the winter rainy season was estimated from the changes in soil inorganic N content from 0-12 inch depth (strawberry's main root zone) and plant N uptake. Here we used changes between 3/7/11 and 4/22/11 since soil inorganic N content was highest on 3/7/11 and decreased afterwards due most likely to 7 inches of rain in the month that flooded the field. The loss was estimated only for plots without fertigation and does not account for any N mineralized from MC and soil organic matter during this period, and therefore represents a conservative estimate. This loss is a sum of leaching, surface run off, denitrification, and immobilization by soil microbes. Table 3 shows that significant amounts of N were lost during the intense rain events in March with more than 130 lbs-N/A/ft soil lost in all treatments that received either compost or MC. The combination of compost+MC led to the highest losses, up to 250lbs-N/A/ft soil.

Table 3. Estimated N Loss During the Winter Rainy Season (lbs-N/A/0-12 inch depth soil).

Compost	Mustard Cake	Soil inorganic N lbs-N/A/ft			Plant biomass N lbs-N/A			N-Loss
		3/7/11	4/22/11	ΔSoil	3/7/11	4/20/11	ΔPlant	ΔSoil-ΔPlant
Compost 0 t/A	MC 0 t/A	130	61.4	68.7	5.92	15.5	9.55	59
Compost 0 t/A	MC 1.5 t/A	284	154	130	7.83	21.5	13.6	117
Compost 0 t/A	MC 3 t/A	425	238	187	8.14	19.1	10.9	176
Compost 5 t/A	MC 0 t/A	220	44.9	175	6.30	14.8	8.48	167
Compost 5 t/A	MC 1.5 t/A	319	105	214	7.10	19.3	12.2	201

Compost 5 t/A	MC 3 t/A	495	239	256	7.08	14.1	7.02	249

Without fertigation plots only.

1-8. Weed suppression by MC

Weed biomass in the planting holes and weeding time per each plot were measured on 4/5/11 and 5/3/11; however, very few weeds emerged from planting holes in the black plastic mulch since the grower minimized the size of planting holes to reduce weed biomass. Apparently the strategy worked very well. No treatment effects were observed, and in future studies a better test of weed suppression would be to use a window of clear plastic mulch in each plot to monitor weed growth.

1-9. ***Verticillium dahliae*** suppression by MC

There was no effect of any treatment on the viable ***V. dahliae*** microsclerotia numbers in topsoil (0-6 inch depth). The baseline ***V. dahliae*** population on 11/3/10 was 2 to 11 microsclerotia/gram soil; 4 weeks after MC incorporation, the population level range was similar (0.5 to 9 microsclerotia/gram soil) and remained unchanged by 4/22/11 (0.5 to 7.5 microsclerotia/gram soil.

1-10. Overall evaluation of MC

If growers are to use MC in strawberry production, a rate of 1.5 t/A of MC appears to be more appropriate than 3 t/A since similar yields were achieved with lower salinity damage to plants and lower N loss. However, we still observed >100 lbs-N/A of N loss during the winter at 1.5 t/A plots and it would be worth testing lower rates (e.g. 1 ton/A) in future studies. Here we deliberately incorporated MC in the top 3 inches to suppress weeds, but the small planting holes used and limited weed growth made it impossible to evaluate suppression. MC was not effective in suppressing ***V. dahliae*** population in topsoil (0-6 inch depth), possibly due to the shallow depth of incorporation. In other experiments, including the trial below, we are testing the effectiveness of MC application on ***V. dahliae*** when incorporated evenly in the top 6 inches of soil. Mineralization of organic N in MC in soil was slow for the first two month (14% mineralized) but it increased rapidly in the third month (an additional 65% mineralized). We did not observe any effect of fertigation or compost on fruit yield when 1.5 t/A of MC was applied. Thus, with 1.5 t/A of MC, pre-plant compost may be eliminated if N provision is the main goal of the application. Fertigation may also be reduced or eliminated; however, plant damage caused by mites and powdery mildew late in the season meant we could not determine whether fertigation would have improved late season production.

Objective 2.

2-1. Major activities

A field trial was established at the UCSC organic farm (Elkhorn sandy loam. CCOF certified) and baseline soil samples were taken on 6/15/2011. Based on a preliminary ***V. dahliae*** soil test, the site with the highest baseline ***V. dahliae*** population was selected (5 microsclerotia/gram soil). Thanks to additional funds from the Western-SARE program, the trial design was expanded as follows: a split-plot experiment (4 replicates) with 3-year crop rotations: 1) broccoli-strawberry-lettuce, 2) cauliflower-strawberry-lettuce, and 3) fallow-strawberry-lettuce as main plots; and ASD, MC (***Brasicca juncea*** : ***Sinapis alba,***1:1 by weight), ASD plus MC, and untreated control (UTC) as split plots. In the main treatments broccoli serves as a "suppressive crop" (Subbarao et al, 2007), whereas cauliflower is neutral in terms of ***V. dahliae*** since it only hosts a strain that does not attack strawberry or lettuce (Bhat and Subbarao, 1999; cauliflower was not included in the original OFRF proposal). The W-SARE grant also allowed us to establish another trial with a similar design including fumigation control in a conventional site in Salinas (not reported here).

Broccoli (cv. Gypsy) and cauliflower (cv. Snow Crown) were transplanted in designated plots on 6/16/2011. Fallow plots were kept bare and cultivated periodically to suppress weeds. Broccoli and cauliflower were harvested at maturity from 8/15/11 till 8/31/11 (6 times) and aboveground biomass was sampled on 8/15/11 and 8/31/11 (Fig. 5 top). The broccoli and cauliflower residues were flail mowed on 8/31/11, soil samples for ***V. dahliae*** assays (0-6 inch depth) and inorganic N tests (0-6 and 6-12 inch depths) were taken on 9/1/11, and residues incorporated into the soil on 9/2/11.

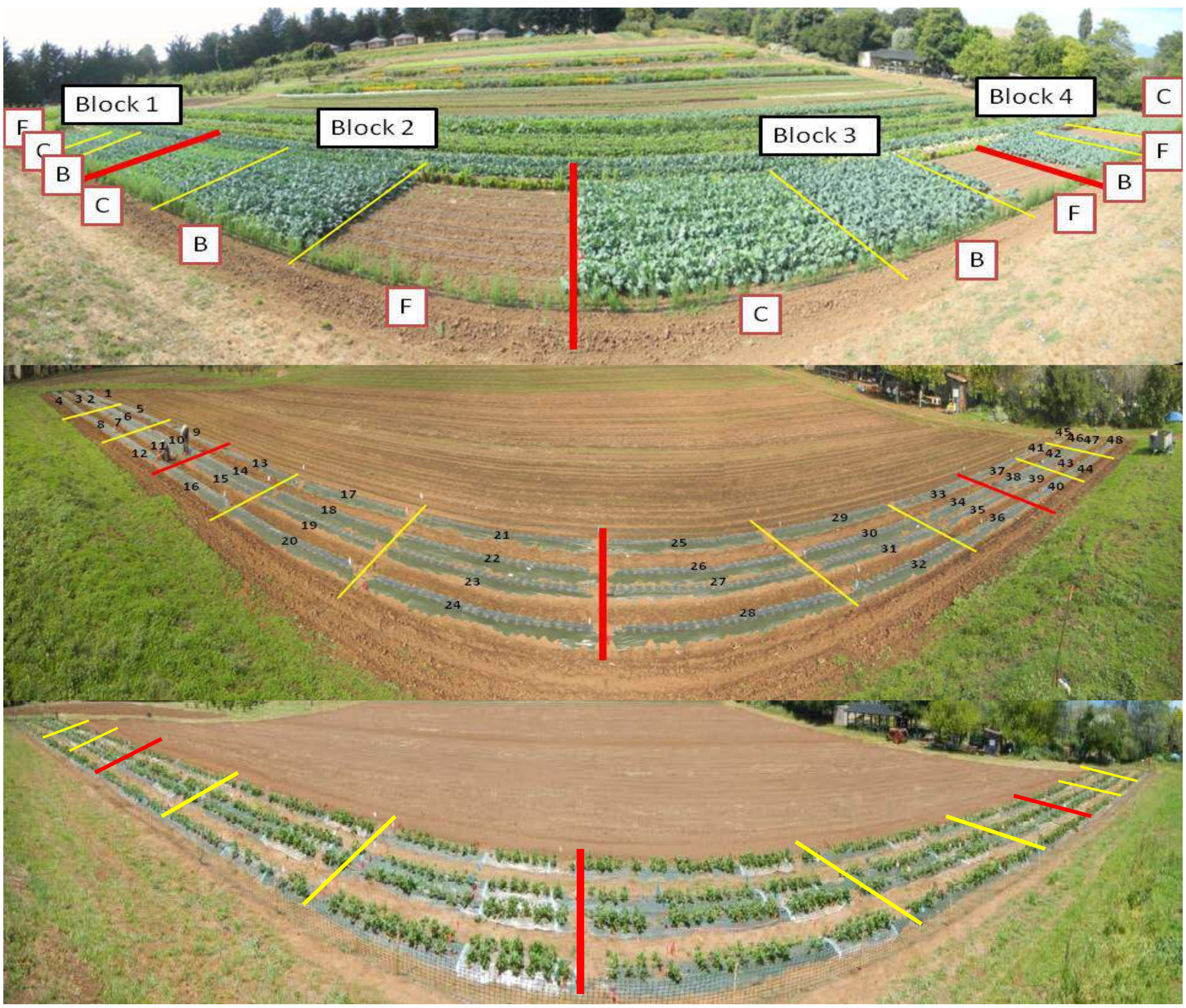

Figure 5. Integrated trial at UCSC organic farm. Top: main plot; broccoli (B), cauliflower (C), and fallow (F) (photo taken on 8/12/11). Middle: strawberry (11/16/11). Sub plot was assigned to each plot (indicated by #). Bottom: strawberry (5/04/12). Clear plastic area in each plot is a weed observation window in which weed densities were counted.

On 9/20/11, strawberry beds were listed and soil samples (post-broccoli incorporation/ pre-ASD treatment) were taken. Split plot treatments were established on 9/21/11 as follows: for the ASD treatment, 9 t/A of rice bran was applied to the bed surface and rototilled to a 6-inch depth. For the mustard treatment, MC was applied at 1.5 t/A based on the Redman trial's data, and incorporated to a 6-inch depth of the bed, then covered with plastic mulch. For the ASD+MC treatment, 7.5 t/A of rice bran and 1.5 t/A of MC (total 9 t/A) were applied and incorporated in the same manner. Drip tapes were laid and plastic mulch applied on the same day. Drip irrigations to ASD and ASD+MC plots were applied on 9/26, 9/27, and 10/10 (total of 4.3 inches) to maintain soil water above field capacity. Moderate anaerobic conditions were developed at the 6-inch depth of ASD and ASD+MC plots (8,700 – 73,000 cumulative Eh mV hrs below 200 mV)[2]. Soil temperature averaged 23°C (min: 14°C, max: 36°C) at the 6-inch depth of ASD and ASD+MC plots. Post-ASD/MC treatment soil samples were taken on 10/31/11. Strawberry (cv. Albion) was transplanted into all plots on 11/16/11 (Fig. 5 middle).

Strawberry fruits from a harvest station with 20 marked plants at each plot were harvested and weighed for marketable and unmarketable fruits twice per week from 4/9 to 9/27/12 (Figure 6). Strawberry biomass samples were taken on 1/10, 2/24, 4/20, and 9/28/12. Degree of plant wilt level was visually evaluated for plants in the harvest station on 5/29, 7/16, and 9/6/12 using the following severity scale: 1 = healthy plant, 2 = moderately stunted, 3 = moderately stunted and slight outer rosette of dead leaves, 4 = moderately stunted and moderate outer rosette of dead leaves, 5 = significantly stunted and slight outer rosette of dead leaves, 6 = significantly stunted and moderate outer rosette of dead leaves, 7 = significantly stunted and significant rosette of dead leaves, and 8 = dead plant. Four plants were taken on 9/27/12 and tested for ***V. dahliae***. Soil samples for inorganic N monitoring (0-6 and 6-12 inch depths) were taken on 12/2/11, 1/17/12, 2/22/12, 4/13/12, 6/20/12, 8/7/12 and 10/4/12. Topsoil samples taken on 10/4/12 were tested for viable ***V. dahliae*** propagules as well. A clear plastic window (3.3' x 1.65') for weed density measurement was created in each plot on 12/12/11 and the weed sampling was done on 1/30, 2/24, 4/5, 5/17, and 8/2 in 2012 (Fig. 5 bottom). In addition, weeding time for bed area was measured for each plot on 1/30, 4/5, 5/17 and 8/2/12.

[2] Soil Eh, a measure of redox potential, generally ranges between -1,000 mV to +1,000 mV. Above 200 to 300mV indicates aerobic condition, -50 to 300mV moderately reducing condition, and below -50 mV strongly anaerobic condition. To express the intensity of anaerobic conditions during the 3-week ASD treatment period, we introduced the concept of cumulative Eh mV below 200 mV (Cum Eh). This value is calculated using hourly average Eh values measured by an automated data logger attached with oxidation-reduction potential sensors. First, only hourly Eh averages below 200 mV are selected from the 3-week period. Then, the difference between 200 mV and the hourly average is expressed as an absolute value (e.g. if the hourly average is 180mV, the absolute difference between 200 mV is 20 mV). The sum of the absolute values during the 3-week period is Cum Eh (mV).

Figure 6. The Santa Cruz trial at UCSC organic farm (4/27/2012).

After the end of the strawberry season, in fall 2012, plants were mowed and the field was disked and springtooth cultivated. Soil pH was measured at the end of strawberry season (9/28/12) and 4 t/ac of dolomite was applied to all plots to correct acidity based on the pH buffer curve developed using the plot soil. A legume/cereal cover crop mix (45% bell beans, 45% vetch, 10% rye cv. AGS104) was direct seeded at 300 lbs/acre for all plots on 11/6/12 and grown over the winter. On 3/18/13, aboveground cover crop biomass was sampled in a 0.25 m^2 quadrat in each plot. Fresh biomass for each type of cover crop was recorded and a subsample taken for moisture and nutrient analysis. Between 3/20 and 3/27/13, the cover crop was mowed and incorporated by a spader. Soil samples for inorganic N monitoring for top- (0-6 inches) and sub- (6-12 inches) soils were taken on 12/13/12, 1/17/13 and 3/11/13.

At the end of July 2013, the field was springtooth cultivated and 36-inch wide beds were listed. On 7/30/13, romaine lettuce transplants (cv. Salvius) were planted in a single row per bed with 12-inch spacing for all plots. Lettuce was harvested on 9/10/15 in block 3-4 and on 9/13/13 in block 1-2. Marketable head yield and total biomass of lettuce was recorded. Two plants per plot were subsampled for moisture and nutrient analysis. Top- (0-6 inches) and sub- (6-12 inches) soils for inorganic N monitoring and chemical analysis were taken before (7/29/13) and after (9/10/13; 9/13/13) lettuce growth.

Economic analysis for the entire rotation period at each treatment was conducted. The revenue, costs of production and net returns per acre are calculated for each treatment at the UCSC trial. A hypothetical 25-acre farm is simulated for each treatment, resulting in twelve simulations (Table 5). The revenue is based on the yields for each treatment. The cost of each farming operation is calculated based on the equipment, materials, and hours of labor used in the trial for each treatment. The net returns are calculated as the total revenue minus costs. The cost of land rental or ownership is not included. Therefore, the net returns should be interpreted as a return to management, land, and risk. All values are on a per acre basis.

2-2. Broccoli and cauliflower yield and biomass

Head yield of broccoli and cauliflower averaged 6.4 t/A and 4.2 t/A, respectively. Residue biomass (dry weight) of broccoli was 3.5 t/A, and of cauliflower was 4.0 t/A. For head yield and residue biomass, no significant differences were found between plots assigned to different sub-treatments for either crop (***P***>0.80) showing good uniformity of production across the field.

2-3. Strawberry growth and fruit yield

From Dec. 2011 to Jan. 2012, salt burn damage on strawberry leaves was observed in all plots but was slightly higher in MC (data not shown). In Feb., plant biomass was highest at ASD and lowest at MC (***P***=0.007**). In April, ASD, ASD+MC and MC had greater biomass than UTC (***P***=0.0007***). Some plants started to show wilt symptoms in May and the symptom progressed as plants senesced. At the end of the season, UTC had the highest wilt score and ASD the lowest (***P***=0.043*). This coincided with the plants from UTC having higher ***V. dahliae*** infection rates than ASD and ASD+MC (***P***=0.006**. Fig.7). No differences in biomass, wilt scores and ***V. dahliae*** infection rate were found between main plots (broccoli, cauliflower or fallow in preceding year). Throughout the harvest season, fruit yield was higher in ASD+MC and ASD treatments than UTC and MC (Fig. 8a). Cumulative marketable fruit yield was greatest in ASD+MC (averaged 862 g/plant), followed by ASD (781 g/plant), MC (646 g/plant), and lowest for UTC (618 g/plant) (***P***=0.0001***, Fig. 8b). There was no difference in cumulative marketable fruit yield between main plots (***P***=0.58).

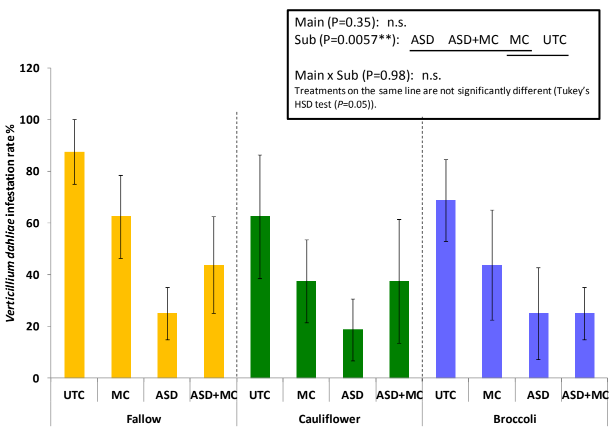

Figure 7. *Verticillium dahliae* infection rate of strawberry plants sampled on 9/27/12 in main plot (fallow, cauliflower, broccoli) and split plots (UTC: untreated check; MC: mustard cake; ASD: anaerobic soil disinfestation). Each bar indicates mean ± SEM (n=4). Infestation rate (%) = # of infested plants/4 plants tested x 100.

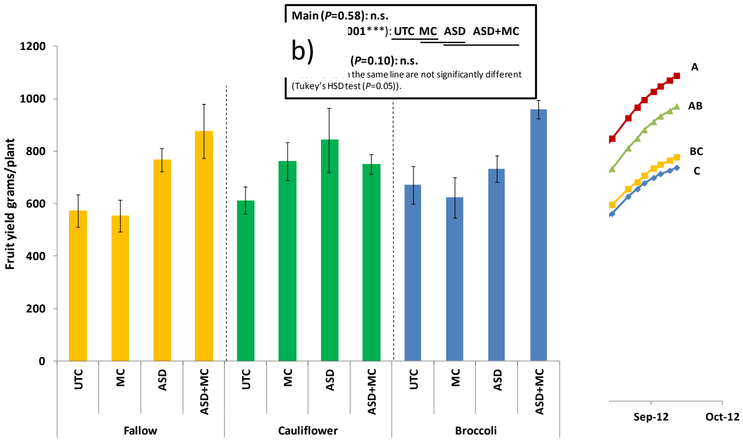

Figure 8. Marketable fruit yield at the Santa Cruz site. a) Cumulative marketable fruit yield in subplots. Treatments with the same letter are not significantly different (Tukey's HSD test (***P***=0.05)). b) Total marketable fruit yield. Each bar indicates mean ± SEM (n=4).

2-4. Cover crop biomass

Cover crops grew uniformly across treatments. No significant differences were found between any treatments on total dry aboveground cover crop biomass (Fig. 9). Similarly, uniformity across treatments was observed in each cover crop species biomass (data not shown). No difference was found among main treatments and the only significant difference among split treatments was between ASD and UTC; ASD plots had a higher bell bean biomass compared to UTC (***P***=0.008**).

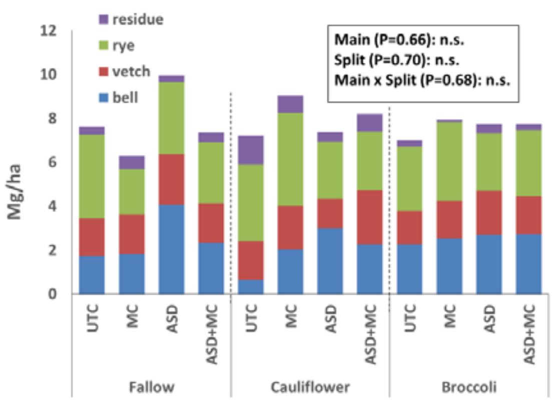

Figure 9. Total dry aboveground cover crop biomass.

2-5. Romaine lettuce yield

Romaine marketable yield showed no significant difference either in main (***P***=0.43) or split plots (***P***=0.18) (Fig. 10). No difference occurred in total yield (heads and residue) where values in main and split plots averaged around 1 ton/acre (data not shown).

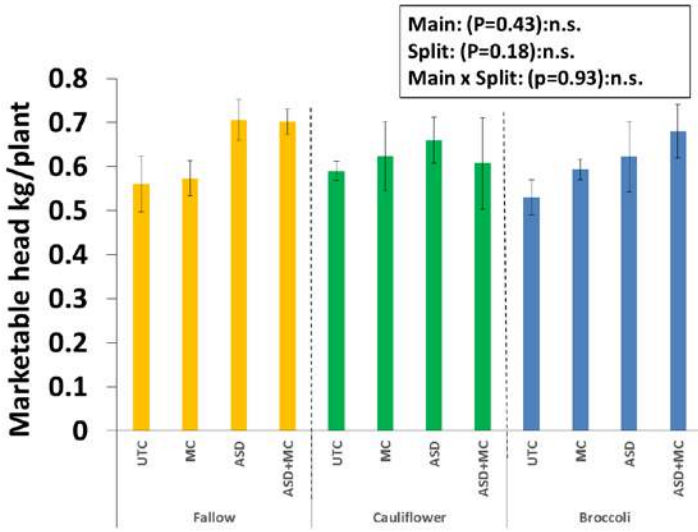

Figure 10. Marketable head weight of romaine lettuce (kg/plant). Each bars indicates mean ± SEM (n=4).

2-6. Viable microsclerotia population of ***V. dahliae*** in soil

Baseline viable ***V. dahliae*** microsclerotia numbers in topsoil were rather low and averaged 0.5 per gram soil. At pre-ASD/MC application, they increased slightly to an average of 1.5 per gram soil.

Table 4. *Verticillium dahliae* microsclerotia numbers in the topsoil of the Santa Cruz site.

Treatment	Sampling Date					
	Baseline 6/15/2011	Post-Broccoli/Cauliflower 9/1/2011	Pre-ASD/MC 9/20/2011	Post-ASD/MC 10/31/2011	Post-Strawberries 9/28/2012	Post-Lettuce 9/10/2013
Main plot						
Fallow	0.6	0.0	1.5	0.5	0.0	1.3
Cauliflower	0.4	0.4	2.1	0.0	0.0	0.9
Broccoli	0.5	0.3	1.0	0.1	0.0	1.8
ANOVA (***P***)	***0.81***	***0.24***	***0.51***	***0.35***	**-**	***0.37***
Subplot						
UTC	1.2	0.7	1.5	0.5	0.0	2.8 a
MC	0.0	0.2	1.7	0.3	0.0	1.3 ab
ASD	0.5	0.0	1.3	0.0	0.0	0.3 b
ASD+MC	0.3	0.0	1.7	0.0	0.0	0.7 b
ANOVA (***P***)	***0.06***	***0.08***	***0.99***	***0.15***	**-**	***0.019****

Statistical analysis was performed for log-transformed data. Numbers in the table show the back-transformed populations of viable ***V. dahliae*** microsclerotia/gram soil. Averages with the same letter do not have significant difference at the ***P***=0.05 by Tukey-HSD test.

At post-ASD/MC application, ***V. dahliae*** was not detected at all in ASD and ASD+MC plots, whereas it was 0.3 to 0.5 for MC and UTC (***P***=0.15). At the end of the strawberry season,

V. dahliae was below the detection limit at all plots. However, at lettuce harvest, it increased to 2.8 at UTC and remained significantly lower than UTC at ASD (0.3) and ASD+MC (0.7) (Table 4).

2-7. Weed density and weeding time

Weed density was measured in the observation window created in the strawberry beds from Jan. to Aug. 2012. Cauliflower plots had a lower weed density than broccoli and fallow

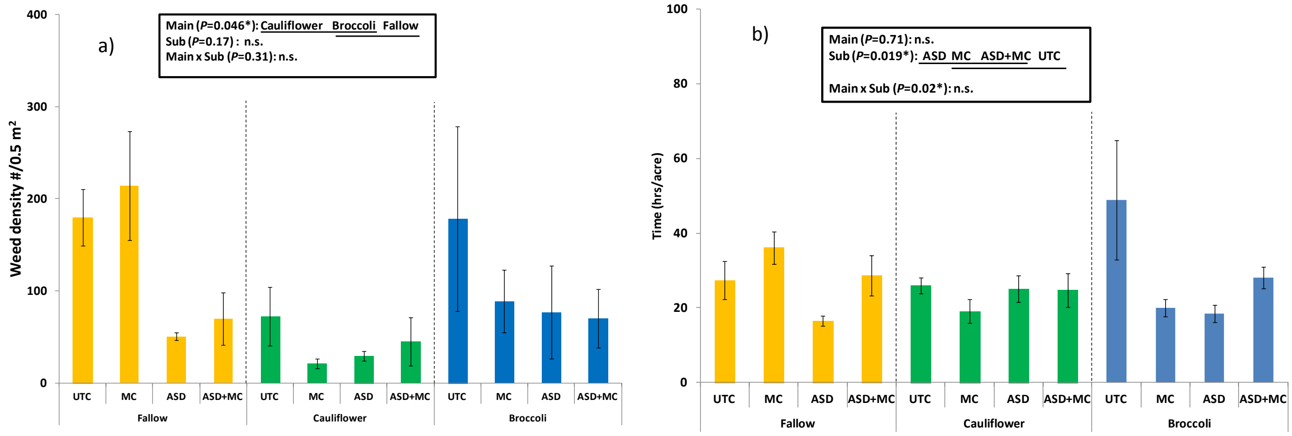

Figure 11. a: Weed density (# of weeds/0.5 m^2) and b: weeding time (hrs/acre) for the period Jan. to Aug. 2012. For both measurements, statistical analysis was performed for log-transformed data. Bar shows mean ± SEM (n=4) of the original data.

plots (***P***=0.046), but no difference was found between subplots (***P***=0.17. Fig. 11a). Although weeding time showed a similar trend with the weed density, there was no difference between the main plots and UTC (average 34 hrs/acre) had longer weeding time than ASD (average 20 hrs/acre) (Fig. 11b).

2-8. Economic analysis

Table 5. Type of Crop Rotations

Nov. 2010	June 2011 Sept. 2011	Sept 2011	Nov. 2011 Oct. 2012	Nov. 2012	July 2013 Sept. 2013
Cover crop	Broccoli	ASD	Strawberries	Cover crop	Lettuce
Cover crop	Broccoli	MC	Strawberries	Cover crop	Lettuce
Cover crop	Broccoli	ASD+MC	Strawberries	Cover crop	Lettuce
Cover crop	Broccoli	UTC	Strawberries	Cover crop	Lettuce
Cover crop	Cauliflower	ASD	Strawberries	Cover crop	Lettuce
Cover crop	Cauliflower	MC	Strawberries	Cover crop	Lettuce
Cover crop	Cauliflower	ASD+MC	Strawberries	Cover crop	Lettuce
Cover crop	Cauliflower	UTC	Strawberries	Cover crop	Lettuce
Cover crop	Fallow	ASD	Strawberries	Cover crop	Lettuce

Cover crop	Fallow	MC	Strawberries	Cover crop	Lettuce
Cover crop	Fallow	ASD+MC	Strawberries	Cover crop	Lettuce
Cover crop	Fallow	UTC	Strawberries	Cover crop	Lettuce

Costs of production. An equipment complement for the farm is developed to accommodate the practices used for each treatment assuming that the grower owned all equipment and there was a mix of new and used equipment resulting in a value of 60 percent of new costs. Equipment prices are those obtained from local suppliers. The hourly costs of operating equipment are based on agricultural engineering equations to calculate the fuel and repair costs for each piece of equipment. The number of hours for equipment use are also based on agricultural engineering equations for a 25-acre farm and not based on the hours of operation for the field trial. Field trial hours of use are always higher than actual use due to the configuration of the plots and the small size of the plots.

The material costs (water, seed, mustard cake, rice bran, fertilizer, drip tape, and gopher traps) are the actual costs realized by the research project. The cost of non-machine labor is assumed to be $10 an hour and tractor labor was $10.88. The cost of spreading rice bran and mustard cake is $10 a ton. The cost of the pre-strawberry soil treatments includes the materials, spreading, and incorporation. The costs are shown in table 6. The cost of ASD is the lowest cost due to the high cost of the mustard seed cake compared to rice bran. Of course, the cost of ASD with mustard seed cake shows the highest cost.

The labor costs for equipment operators is based on the hours of tractor use resulting from the simulation multiplied by a factor of 1.1 to account for setup time and time moving equipment to and from the field. The non-machine labor hours for irrigation, setting out drip tape, transplanting, hand hoeing, and harvesting are based on the hours recorded on the field trial. It is assumed that there would be no economies of scale for these hand labor operations.

Table 6. Costs of Pre-Strawberry Soil Treatments

	ASD	MC	ASD+MC
Spread material	$90	$15	$105
Incorporate material	27	27	27
Rice bran (9 tons)	2,262	…	2,262
Mustard seed cake (1.5 tons)	…	2,501	2,501
Total	2,379	2,543	4,895

The cover crop costs are $331 per acre with the majority of costs, $275 per acre, going to cover crop seed, a legume cereal mix planted at a rate of 275 pounds per acre. The additional costs are for equipment and labor for planting, mowing and spading the cover crop before each of the vegetable crops.

Harvest represents the highest cost operation for each of the crops and is hand harvested in all cases. In the trial, for each crop, all treatments were harvested at once and no records were kept to separate the hours of labor by treatment. In other words, the total hours per crop are known. The harvest costs are based on the actual hours of labor per crop in the trial and adjusted for the proportion of total yields in each treatment for each crop.

Revenue and net revenue. The revenue for each treatment is the sum of the revenue for each crop in that treatment (table 5). The revenue is the yield per acre multiplied by the price per unit of production. For each vegetable crop the yield is equal to the field trial result for each crop and soil treatment. The strawberry yields are for each of the 12 treatments and are the total yields from 50 individual harvests. The prices of organic strawberry for the actual dates of each harvest were obtained from the Agricultural Marketing Service (AMS), Fruit and Vegetable Market News, for the Salinas-Watsonville shipping point http://marketnews.usda.gov/portal/fv. The yield for each date is multiplied by the average price for the same date to get the daily revenue. The sum of the revenue for each harvest is the total revenue. The broccoli and cauliflower from the trial were used in CSA boxes and therefore no direct sales occurred. No prices for organic broccoli or cauliflower were available from AMS for any shipping point or dates and so the conventional price on the harvest date with a Salinas-Watsonville shipping point is used with the assumption of a 50 percent premium for organic over conventional prices. For lettuce, all product was sold. The average price from these sales is used (Table 7).

The net revenue is the difference between the total revenue and the costs. The cost of land is not included as a multitude of ownership and lease arrangements exist. Therefore, the net return is above land and management costs.

Economic Performance. The gross revenue for each crop in each treatment and the total gross revenue for each treatment are shown in Table 8. The corresponding costs are in Table 9 and the resulting net revenue above land costs are in Table 10. Clearly, strawberry is the economic driver in the rotation with the highest gross and net revenues of all of the crops in the rotation with between 75 and 86 percent of total revenue. The costs for strawberry are also the highest of all crops primarily due to the cost of transplants and harvest. The net revenue for strawberry is roughly 90 percent of the total net revenue. Therefore, the crops and treatments before strawberry should be viewed in terms of their contribution to increased strawberry yield as well as their individual contribution to farm income. Looking at net returns, there is no clear pattern as to whether or not strawberry did better following broccoli, cauliflower, or fallow. The highest net returns from strawberry were $29,328 per acre from the broccoli under ASD+MC followed by fallow under ASD+MC at $25,683 and cauliflower under ASD at $24,637 per acre. When taking the cost of soil treatment into account and subtracting that cost from the net returns to strawberry, the top three stay unchanged but the order changes with broccoli ASD+MC at $24,433 ($29,328 - $4,895), cauliflower ASD at $22,258 ($25,683 -$2,379) and fallow ASD+MC at $20,788 ($25,683 - $4,895).

It should be noted that all three of the highest treatments used ASD and the first and third highest used ASD plus MC. However, the difference in net revenue from strawberry is decreased by $2,528 (the additional cost of MC) between broccoli ASD+MC and cauliflower ASD when the higher cost of ASD+MC is taken into consideration. Similarly, the difference between cauliflower ASD and fallow ASD+MC increases by $2,528 when the cost of soil treatment is taken into account.

The revenue from the broccoli crop is greater than the cauliflower crop due to poor yields in cauliflower. Costs of production are identical except for harvest costs. The soil treatment should not have had an impact on broccoli or cauliflower yields because they took place after those crops were harvested. However, both vegetable crops yielded highest on the untreated control plots. Cauliflower contributed little to total net returns while broccoli contributed between $2,075 (ASD) and $3,397 (untreated control).

Net returns from lettuce are highest following fallow for the ASD plots, following broccoli for the ASD+MC plots and following cauliflower for the ASD plots. In the absence of ASD, cauliflower appears to improve the performance of lettuce over broccoli and fallow. The highest net returns for lettuce was for the fallow ASD ($3,993), followed by fallow ASD+MC ($3,950), and broccoli under ASD+MC ($3,725). The use of ASD has a greater impact on lettuce performance than the preceding vegetable crop. Lettuce performed better with a combination of mustard cake and a preceding vegetable crop than fallow with MC and better following cauliflower for the untreated control than following broccoli or fallow.

The results of these crop impacts are that the highest net returns of all treatments is broccoli ASD+MC ($30,319) due to the optimum performance of strawberry and lettuce and the additional contribution of strawberry even with the highest treatment costs. The second highest net revenue is from cauliflower ASD ($25,762) due to the excellent performance of strawberry in this treatment. The third highest is fallow with ASD+MC ($24,407).

Overall, the net returns for treatments by crop are highest for those including broccoli plots (the average of ASD, MC, ASD+MC, and untreated control, $23,324) followed by those including cauliflower plots ($21,157) and fallow plots ($18,787). The broccoli plots have the highest average due primarily to the contribution of broccoli to the net revenue while cauliflower plots outperform the fallow plots primarily due to their impact on strawberry and lettuce yields in the absence of ASD (Tables 10 and 11).

Turning to the soil treatments, ASD and MC alone perform best with cauliflower and ASD+MC and the untreated control perform best with broccoli. For the broccoli treatments, ASD+MC performed the best, for cauliflower it was ASD, and for fallow it was also ASD+MC. None of the crop treatments performed as well without ASD. The highest average net returns (broccoli, cauliflower, and fallow) are from ASD+MC ($24,566) followed by ASD ($23,931). The untreated control ($18,448) actually outperformed the mustard cake treatment ($17,412) due to the high cost of the mustard cake treatment ($2,543) even though mustard cake improved lettuce and strawberry yields (Tables 10 and 11).

Table 7. Prices for Broccoli, Cauliflower, Lettuce, and Strawberry

	$/Unit	Unit
Broccoli	$13.00	23-pound box
Cauliflower	$13.00	23-pound box
Lettuce	$49.51	Hundredweight
Strawberry	$14.93	Carton

Table 8. Total Revenue ($ per acre)

	Cover crop	Broccoli	Cauliflower	Treatment	Strawberry	Lettuce	Total
Broccoli - ASD	0	6,783	0	0	58,303	9,851	74,937
Cauliflower - ASD	0	0	4,409	0	67,137	10,450	81,996
Fallow - ASD	0	0	0	0	61,320	11,185	72,505
Broccoli - MC	0	7,348	0	0	49,183	9,401	65,932
Cauliflower -MC	0	0	4,635	0	60,062	9,870	74,567

Fallow - MC	0	0	0	0	43,415	9,076	52,491
Broccoli - ASD+MC	0	7,348	0	0	76,588	10,777	94,713
Cauliflower - ASD+MC	0	0	4,748	0	59,342	9,621	73,711
Fallow - ASD+MC	0	0	0	0	69,566	11,120	80,686
Broccoli - UTC	0	7,687	0	0	52,942	8,396	69,025
Cauliflower - UTC	0	0	5,200	0	47,921	9,345	62,466
Fallow - UTC	0	0	0	0	44,299	8,880	53,179

Table 9. Production and Harvest Costs ($ per acre)

	Cover crop	Broccoli	Cauliflower	Treatment	Strawberry	Lettuce	Total
Broccoli - ASD	331	4,707	0	2,379	37,977	6,737	52,131
Cauliflower - ASD	331	0	4,083	2,379	42,500	6,941	56,234
Fallow - ASD	331	0	0	2,379	39,376	7,192	49,278
Broccoli - MC	331	4,856	0	2,543	33,508	6,583	47,821
Cauliflower -MC	331	0	4,142	2,543	39,168	6,743	52,927
Fallow - MC	331	0	0	2,543	30,660	6,472	40,006
Broccoli - ASD+MC	331	4,856	0	4,895	47,260	7,053	64,394
Cauliflower - ASD+MC	331	0	4,172	4,895	38,684	6,658	54,740
Fallow - ASD+MC	331	0	0	4,895	43,883	7,170	56,279
Broccoli - UTC	331	4,945	0	0	35,448	6,240	46,309
Cauliflower - UTC	331	0	4,290	0	33,028	6,564	44,213
Fallow - UTC	331	0	0	0	31,414	6,405	38,150

Table 10. Net Returns Above Land Costs ($ per acre)

	Cover crop	Broccoli	Cauliflower	Treatment	Strawberry	Lettuce	Total
Broccoli - ASD	-331	2,075	0	-2,379	20,326	3,114	22,806
Cauliflower - ASD	-331	0	326	-2,379	24,637	3,509	25,762
Fallow - ASD	-331	0	0	-2,379	21,944	3,993	23,227
Broccoli - MC	-331	2,492	0	-2,543	15,675	2,818	18,111
Cauliflower -MC	-331	0	492	-2,543	20,894	3,127	21,640
Fallow - MC	-331	0	0	-2,543	12,755	2,604	12,486
Broccoli - ASD+MC	-331	2,492	0	-4,895	29,328	3,725	30,319
Cauliflower - ASD+MC	-331	0	576	-4,895	20,658	2,963	18,971
Fallow - ASD+MC	-331	0	0	-4,895	25,683	3,950	24,407
Broccoli - UTC	-331	2,742	0	0	17,494	2,156	22,716
Cauliflower - UTC	-331	0	910	0	14,893	2,781	18,253
Fallow - UTC	-331	0	0	0	12,885	2,475	15,029

Table 11. Summary of Revenue, Costs, and Net Returns

	Revenue	Costs	Net Returns
ASD	76,479	52,548	23,931
MC	64,330	46,918	17,412
ASD+MC	83,037	58,471	24,566
UTC	61,556	43,109	18,448
Broccoli	76,152	52,828	23,324
Cauliflower	73,185	52,028	21,157
Fallow	64,715	45,928	18,787

2-9. Overall evaluation of ASD, mustard cake and broccoli rotation in ***V. dahliae*** and weed suppression in organic strawberry

The present study showed that ASD can increase marketable fruit yield of strawberry (Fig. 8) by reducing ***V. dahliae*** infection of strawberry plants (Fig. 7) and providing nutrients (especially N) from the rice bran (data not shown). The infection took place regardless of very low, near the detection limit microsclerotia level in the soil (Table 4), showing the high sensitivity of strawberry plants to this disease. Further, ASD kept soil ***V. dahliae*** microsclerotia numbers very low for two years regardless of lettuce, a host of the pathogen, being planted during the period (Table 4). This has a significant implication for organic strawberry growers in the region where they often have no choice but to plant strawberry after lettuce, resulting in outbreaks of Verticillium wilt. ASD may provide more flexibility in crop rotation for organic strawberry growers. The mechanism of this long-term disease suppression needs to be explored. Though it was not perfect (Fig. 11a), ASD was also the only practice that reduced weeding time during the strawberry growth period compared to UTC (Fig. 11b).

MC and broccoli alone did not show significant effect in ***V. dahliae*** reduction (Fig. 7 and table 4) or weed suppression (Fig. 11a and 11b). Also additive or synergistic effects of combining ASD with MC or broccoli rotation in disease/weed suppression and yield increase in strawberry and lettuce were not observed in this trial. A partial reason may be unexpectedly low ***V. dahliae*** microsclerotia numbers in the soil. For MC, the rate we used (1.5 tons/A) might have been too low for weed suppression. At an apple orchard, MC reduced weeds at a rate of 3 tons/A (Hoagland et al, 2008), the rate that caused a salt damage on strawberry plants in our rate trial (Fig. 2 and 4). Therefore, it may be difficult to realize weed suppression by MC in current strawberry systems in the central coast of California. As seen in the rate trial (see section 1-8), physical measures such as use of opaque plastic multi with small planting holes may reduce weeding cost to some degree.

Economic analysis also confirmed the similar trend: the net return above land costs increased ~30% by ASD and ASD+MC over UTC and MC suggesting the economic benefits of ASD not only in strawberry but also in overall crop rotation compared in the trial (Table 11). Rice bran-based ASD used in the trial has been implemented in commercial berry production; total ASD-treated acreage in California was 120 acres in the 2012-2013 season, and increased to 430 acres in the 2013-2014 season (Farm Fuel Inc. personal communication).

Efforts to further optimize ASD to California strawberry systems are in progress. To reduce the costs and N input, we are examining different carbon sources such as grape pomace, cover crops, and molasses, alone or in combination. We are also evaluating the environmental impacts of ASD in terms of nitrate leaching and greenhouse gas emission. Effect of ASD for other emerging soilborne pathogens for strawberry such as ***Fusarium oxysporum*** and ***Macrophomina phaseolina*** are ongoing. Research for better understanding the mechanisms of disease suppression by ASD are also in progress.

Objective 3

3-1. Demonstration trial at ALBA

Co-funded by USDA's Western SARE Program, a non-replicated demonstration trial (0.1 acre) with the same design with the Santa Cruz trial in Objective 2 was established at ALBA, Salinas in 2012. Prior to establishing the trial, tomato was planted at the site to increase the ***V. dahliae*** population. Broccoli and cauliflower were grown on 1/3 of the site in the summer 2012 as main plots. After harvest, crop residues from broccoli and cauliflower were mowed and incorporated. Split plots of ASD, MC, ASD+MC, and UTC were created as described previously before transplanting strawberry. Strawberry (cv. Albion) was transplanted to all plots on 11/13/12. A wooden sign in Spanish and English explaining the goals, approaches, and funding sources of the trial was established at the site in Jan. 2013 (Fig. 12). Strawberry fruit yield from each plot was monitored throughout the harvest season in 2013.

Figure 12. A wooden sign in Spanish and English and the demonstration trial at ALBA, Salinas.

Strawberry plants started to show wilt symptoms in April 2013, and by May significant plant mortality occurred. For main plots, mortality was highest in the broccoli plots, followed by the fallow plots, and the lowest in the cauliflower plots (Fig. 13). For subplots, UTC and MC plots had higher mortality compared to ASD and ASD+MC plots. The diseased plants were taken to the UCCE diagnostic lab and ***V. dahliae*** was identified as the sole pathogen present.

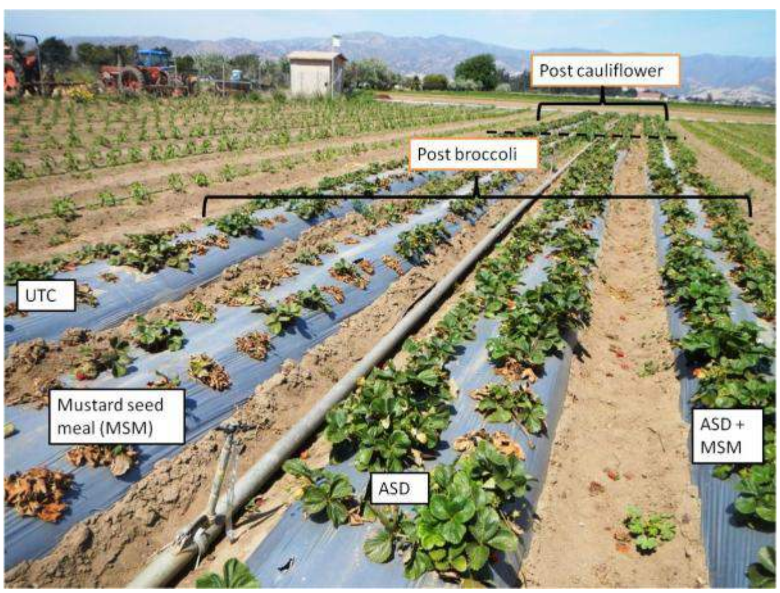

Figure 13. Verticillium wilt of strawberry plants (cv. Albion) at the demonstration trial at ALBA, Salinas. Photo was taken on 5/15/2013.

Cumulative fruit yield reflected the mortality of the plants; for main plots, the cauliflower plots had the highest yield, followed by the fallow plots, and the lowest in the broccoli plots. For subplots, the order was ASD > ASD+MS > MC > UTC (Fig. 14). There was a strong negative correlation between mortality and cumulative fruit yield (Fig. 15. ***P***=0.0001***).

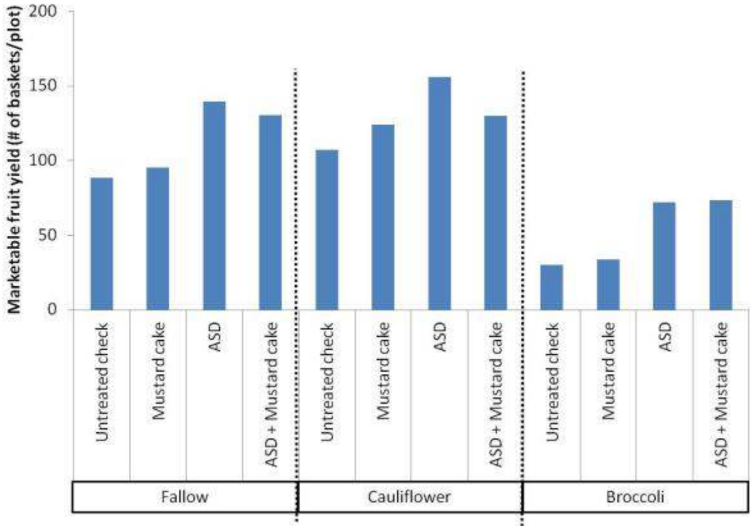

Figure 14. Cumulative marketable fruit yield at the non-replicated demonstration trial at ALBA, Salinas.

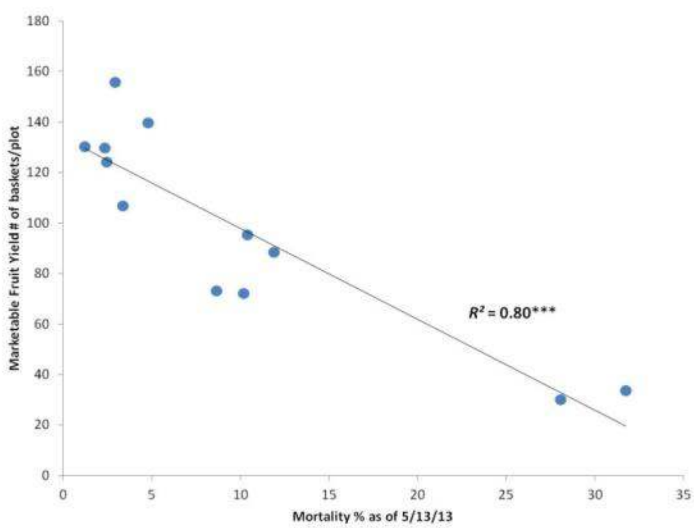

Figure 15. Correlation between mortality of strawberry plants and cumulative marketable yield of strawberry at the demonstration trial at ALBA, Salinas.

Based on earlier studies, the broccoli treatment was included in this rotation trial with the expectation of an additive or synergistic ***V. dahliae*** suppression effect with ASD and/or MC. However, it resulted in a higher mortality than the cauliflower and the fallow plots. A multi-cut broccoli variety De Cicco was used in this broccoli treatment suggesting that the effect of broccoli residue incorporation on ***V. dahliae*** suppression may be variety dependent.

Using this demonstration trial, a field day/workshop on soilborne disease management in organic strawberry production was conducted at ALBA on 7/9/13. The workshop mainly targeted Latino growers. We had 14 participants and simultaneous Spanish translation was provided. According to the post-workshop survey, the event was well received by the most participants (Table 12).

Table 12. A summary of evaluations for the field day/workshop held at ALBA on 7/9/2013. There were 14 signed participants and 10 returned evaluations. Numbers are in percentages.

For Everyone	Yes	No	N/A	No Answer
Improved my awareness of the topics covered	90	0	0	10
Provided new knowledge	90	0	0	10
Provided new skills	90	0	0	10
Modified my opinions and/or attitudes	90	0	0	10

How many people do you estimate you will share some aspect of this project within the next 12 months?

3	4	5	10	100s	As Many As Possible	No Answer
10	20	10	10	10	30	10

For Producers	Yes	No	N/A	No Answer
In the next year I am likely to use some aspect of this project to:				
Adopt one or more of the practices shown	90	0	0	10
Increased the operation's diversifications	70	10	0	20
Reduce my use of purchased off-farm inputs	40	10	30	20
Increase my networking with other producers	60	10	10	20
Incorporate value-added into some aspect of my operation	60	10	10	20

3-2. Other outreach activities accomplished

A part of the data from this project was presented at multiple outreach meetings such as Farming without Fumigants symposium organized by the California Strawberry Commission and UC Cooperative Extension, December 5, 2013, in Watsonville, CA and the Soil Health Symposium organized by California Department of Pesticide Regulation, June 17, 2014.

Data from the project were presented at the Second International Organic Fruit Research Symposium, held at Leavenworth, Washington, June 18-21, 2012. A paper based on this project was presented at the Eighth International Symposium on Chemical and Non Chemical Soil and Substrate Disinfestation (SD 2014) at Torino, Italy in July 2014 (in press in Acta Horticulturae).

Publications

Zavatta, M., Shennan, C., Muramoto, J., Baird, G, Koike, S.T., Bolda, M.P., Klonsky, K. 2014. Integrated Rotation Systems for Soilborne Disease, Weed and Fertility Management in Strawberry/Vegetable Production. In press, Acta Horticulturae (ISHS).

Shennan, C., Muramoto, J., Baird, G., Koike, S.T., Bolda, M.P., and Klonsky, K. 2012. Integrated rotation systems for soil borne disease, weed and fertility management in strawberry/vegetable production. Abstract for poster presentation. The 2nd International Organic Fruit Research Symposium, June 18-21, 2012. Leavenworth, WA.

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