Effect of biosolarization and cover crops on weeds and soil-biome pathogens

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Project Summary

Field experiments were conducted at the Cal Poly Organic Farm in San Luis Obispo, California in order to test the effects of soil solarization and sudangrass residues on weeds, *Verticillium dahliae* populations, plant health, and yields in organic strawberry production. Using a split plot design, sudangrass was grown, mowed and then developed into two treatments: surface mulch or incorporated into the soil. The sudangrass treatments and a control were tested with and without soil solarization (n=4). Maximum soil temperatures in solarized plots were 53°C at a soil depth of 5 cm and 42°C at a soil depth of 15 cm. Solarization significantly reduced weed biomass during the first 3.5 months after tarp removal (p=0.03), reduced *Verticillium dahliae* populations (p=0.01) and disease incidence (p<0.01), and increased yields (p<0.01) over non-solarized plots. Sudangrass treatments did not affect *V. dahliae* populations (p=0.33) or yields (p=0.25). However, mulched plots contained lower weed biomass (p=0.03) and plant mortality (p<0.01) than other sudangrass treatments (p=0.03) Results indicate solarization can be used in central coast organic strawberry production to reduce hand-weeding, disease incidence, and increase yields.

Introduction

Weed and soil-borne pathogens are among the most difficult problems for organic growers. Solarization is one of the tools that growers resort to in areas with hot summer temperatures. Biosolarization, which combines the use of organic soil amendments and soil solarization, has been proven to enhance the results of solarization in numerous field experiments. Multiple studies have shown increased efficacy of solarization by combining solarization with application of organic amendments. Tarping the soil prevents biocidal gases released during decomposition of organic materials from escaping and increases their penetration throughout the soil via heat exposure (Gamliel et al., 2000). These gases result in direct toxicity against soilborne organisms. Incorporating organic amendments into soils increases microbial activity. These microbes can compete with and suppress detrimental soilborne organisms (Simmons et al., 2016). Increased microbial activity during biosolarization can increase soil temperatures from 2 to 5°C during soil solarization (Gamliel and Stapleton, 1993; Simmons et al., 2013). However, this effect is not consistent across all biosolarization treatments (Peachey et al., 2001). Additionally, tarping soil amended with high carbon inputs (i.e., rice bran, molasses) can lead to an increase in accumulation of organic acids released from anaerobic bacteria which are toxic to many soilborne pathogens (Simmons et al., 2016). Lastly, disinfestation resulting from anaerobic conditions and high temperatures from soil solarization still result during biosolarization.

Multiple studies have documented success controlling pathogens at sublethal solarization temperatures when organic amendments were used in combination with solarization (Blok et al., 2000; Núñez-zofío et al., 2011; Tjamos and Fravel, 1995). For example, the biosolarization of cabbage residues on 2 kinds of Phytophthora root rot were shown to reduce the population of both species in soil depths where an adequate soil temperature to kill the pathogen was not achieved (Coelho et al., 2001). Similarly, the solarization of broccoli and other cruciferous residues have controlled *M. incognita* even at temperatures below lethal levels (Stapleton and Duncan, 1998). Biosolarization could potentially expand the use of solarization to temperate regions where normally solarization would not generate lethal temperatures for soilborne pests.

Several studies on biosolarization in Spain have documented the capability of different biosolarization treatments against the strawberry pathogens *M. phaseolina* and *F. oxysporum*. Microreactor experiments showed that incorporating grass residues into soil can reduce soilborne pathogen populations of root knot nematodes, *Sclerotium rolfsii* Sacc. and *Pythium ultimum* Trow. (Stapleton et al., 2010). In field trials, *Sorghum* spp. Moench. such as sorghum, sudangrass, and sudex, a sorghum-sudangrass hybrid, have been shown to reduce populations of root knot nematodes when incorporated into the soil as a green manure (Widmer and Abawi, 2000). Additionally, incorporation of sudangrass residues has shown the ability to reduce populations of *V. dahliae* and reduce Verticillium wilt disease incidence in potatoes improving yields over controls (Davis et al., 2004; MacGuidwin et al., 2012). However, reduction of inoculum density over untreated soil is variable, and did not occur in all experiments although reduction in disease incidence of potatoes was consistent (Davis et al., 2004). Likewise, the biofumigation of sudangrass is not effective against all pathogens and nematodes. Sudangrass has been found to have no effect on reducing populations of *Pratylenchus penetrans* Cobb. and *Phytophthora cinnamomi* Rands. when incorporated as a green manure (MacGuidwin et al., 2012; Pinkerton et al., 2002).

Objectives

1) to determine if soil solarization can reduce weed and pathogen pressures and improve plant health and strawberry yields in San Luis Obispo County,

2) to determine if the effect of sudangrass cover crop residues will increase the effects of soil solarization, and

3) to compare the effects of sudangrass residue mulching vs. incorporation on weed populations, pathogen populations, and strawberry health and yields.

Materials and Methods

4.1. Site Description

This study was conducted at the Cal Poly Organic Farm in San Luis Obispo, California (35°18'16.90" N 120°40'19.83" W). The soil texture of the field is clay loam. Composite soil samples for chemical analysis were taken on 20 May 2019 (Table 5.1).

Cropping history of the fields includes organic strawberry and vegetable production. Immediately before this project the field was cropped with romaine lettuce (*Lactuva sativa* L.). Lettuce residue was mowed and incorporated in late winter. To prepare for planting the cover crop, the field was ripped and disked twice in April 2018. 4.2. Plot design

The field experiment tested two factors: different sudangrass residue treatments and soil solarization. The experimental field was organized according to a split plot design with 4 replications. The main plot was sudangrass treatment and the sub-plot factor was solarization. Thus, each main plot (sudangrass) was divided into one solarized plot and one non solarized plot. Plots were laid out into 4 blocks and randomized within each block. Plots were 1.5 m wide by 6 m long. There was 1.5 m buffer zone in between each plot to allow for equipment operation.

<u>4.3. Cover crop planting</u>

Sudangrass was planted on 11 May 2018. 'Piper' sudangrass was drilled 3 cm deep in 1.5 m x 6 m rows corresponding with cover cropped plots at a density of 45 kg per hectare using a Schmeiser grain drill (Schmeiser vineyard series 2nd generation-series 98, T.J. Schmeiser Co. Inc., Selma, CA, USA). The seed germination rate in a lab setting was 75.2%. The actual field germination rate was 48.2%. Immediately after planting the field was fertilized (14-0-1) using a broadcast spreader (Hard Push Spreader p10-500BH, Brinly-Hardy Company, Jeffersonville, IN, USA) at a rate of 67 kg of nitrogen (N) per hectare. Six weeks after planting 33 kg of N (14-0-1) per hectare were hand broadcast across all plots. The field was irrigated using a fixed solid set sprinkler system for 30 minutes per week. Starting 5 weeks after planting irrigation was increased to 90 minutes per week. Fields were irrigated at a net application rate of 6 mm per hour. Watering was stopped a week before mowing the cover crop.

Before mowing, cover crop biomass and height readings were recorded. Biomass readings were taken using a randomly selected 30 cm section of one row in each cover crop plot. Biomass samples were placed in paper bags then dried in a forced air convection oven at 70°C for 48 hours and then weighed. Additionally, cover crop height was determined by measuring the highest point of the sudangrass at 3 different locations in each plot and averaging across each plot.

Cover crops were chopped and shredded with a tractor drawn flail mower on 17 July 2018. On 19 July residues from cover crops were incorporated into the soil using a tractor drawn disc. On 23 July two 0.75 m by 20 cm inch beds were listed per row. On 25 July two beds originally listed were combined into a single 1 m wide bed that was raised by 25 cm.

In mulched plots, cover crop residue was left on the surface. No beds were created. In solarized, mulched plots solarizing plastic was laid over the mulched stubble. In-non solarized, mulched plots sudangrass regrew. Sudangrass was mowed again on 3 September and 14 October 2018 and did not die in mulched, non-solarized plots till it winter killed in December.

4.4. Solarization

On 26 July 2018, 2.4 mil low-density polyethylene plastic (Agfabric 2.4 mil Plastic Covering, WellCo Industries Inc., Corona, CA, USA) was hand applied onto solarized plots. Creation of the beds left furrows in which the edges of plastic were laid. Then plastic was pulled tight, and edges were covered with soil. After applying plastic, fields were irrigated for 72 hours using one line of drip tape till fields reached field capacity. Tarps were left on for 5 weeks and removed on 31 August 2018. Temperatures were monitored using ibutton dataloggers (Ibutton Thermocron F5, Maxim Integrated, San Jose, CA, USA) and echo dataloggers (ECHO EM50 Datalogger and STE 50 Data Probe, Decagon Instruments, Pullman, WA, USA) at 5 cm and 15 cm depths. Temperatures were only recorded in 3 of the solarized replications. One replication of solarized, mulched treatment was excluded from the study as a result of uneven solarization due to unlevel field preparation.

4.5. Strawberry planting

Before planting, two lines of drip tape were laid in beds. 100 kg per hectare of 8-5-1 fertilizer was applied to all beds and incorporated into the top two inches of the surface. Beds were then covered with 6 mil black polyethylene plastic. On each bed, 1.33 m was left as a weedy check, and strawberries were planted in 16 × 4 ft beds. Fields were pre-irrigated the day before planting. Strawberries crowns, 'Sweet Anne' (Lassen Canyon Nursery, Redding, CA) were planted on beds with 2 rows of plants per bed on 23 and 24 October. Rows were spaced 12 inches apart and plants were spaced 12 inches apart within rows. Strawberries were sprinkler irrigated for the first 4 weeks to get plants established then drip irrigated afterwards. From December through February, plots were side dressed once per month with 12 kg of N/per hectare using 8-5-1 fertilizer. Every two weeks starting in March, fertilizer was applied through the drip at a rate of 8 kg of N per hectare (14-0-1).

4.6. Weed populations

After tarp removal, fields were drip irrigated for 6 hours per week for 6 weeks to stimulate weed germination. Measurements on weed biomass, density and relative species cover were taken on 12 October from 3 randomly selected locations in each bed using a 1 × 1 m quadrat. Relative species cover was estimated based on the percent area each weed species covered. For weed biomass, all aboveground plant material in the quadrat was cut using shears at the base of the plant and placed in paper bags. Paper bags were placed in a drying oven set at 70°C for 72 hours. Weeds were weighed upon removal from oven.

Remaining weed biomass and relative species cover measurements were taken in November and December from weedy checks on the edge of each plot (1.33 m × 1.33m). Weed biomass readings were taken using a 0.33 m × 1 m quadrat and dry weight was measured. The relative species composition of the entire weedy check was recorded. Remaining weed density measurements were recorded in 30 cm × 30 cm areas surrounding 16 randomly chosen strawberries per plot in November and December. Measurements were not taken in January as frosts killed many weeds affecting biomass and relative species cover measurements.

4.7. *Verticillium dahliae* inoculum density

Soil samples were taken using a 2.5 cm soil core from a depth of 0-15 cm in all plots before and after treatments to determine inoculum density of *V. dahliae* Kleb. Three random samples were taken per plot and mixed together to comprise one composite sample. Samples were air dried in open plastic bags at room temperature for 3 weeks.

After air drying, soil samples were ground up with a mortar and pestle for 5 minutes. For each composite sample, five randomly selected 0.1 g subsamples were analyzed, then they were mixed with 900 µL of water and evenly spread onto Sorenson's NP-10 media (Kabir et al., 2007) prepared in petri dishes (*100 mm x 15 mm*). Plates were incubated for 2 weeks at room temperature (21°C) under dark conditions. After incubation, soil was gently rinsed off plates and *V. dahliae* colony forming units were counted under a dissecting microscope.

4.8. Disease incidence in strawberries

Strawberries started to show signs of disease in early March 2019. After first signs of disease all plants were rated weekly on a scale of 0 to 5 (0=no signs of disease, 1=leaf discoloration in <20 percent of leaves, mild stunting, 2=25-50% of leaves discolored or showing signs of disease, moderate stunting. 3=50-75% leaves dead or discolored, severe stunting, 4=75-95% leaves dead or discolored, very severe stunting, almost dead, 5= dead) (Figure 4.1).

Figure 4.1: Examples of strawberries ranked from 0-5 on the disease severity scale. A=0, B=1, C=2, D=3, E=4, F=5.

Individual symptomatic plants were selected for disease assays to determine the causal agent. Plants chosen for pathogen analysis were washed under tap water and cut into roots, crown, and petioles. Plant were then surface sterilized in a 1% bleach solution for 60 seconds. Plant parts were removed from solution, rinsed with sterile water, then placed on sterile paper towels in a laminar flow hood. After drying, roots, crowns and petioles were placed on petri dishes containing potato dextrose agar (Sigma Aldrich, St. Louis, MO, USA) and Sorensen's Np 10 (Kabir et al., 2007). Plates were incubated under illuminated conditions at 25°C. Plates were inspected after 3 to 7 days using a compound microscope. Additionally, plants were tested for *Phytophthora* spp. using Agdia immunostrips (Agdia Inc., Elkhart, IN, USA) following the manufacturer instructions.

4.9. Strawberry health and yields

Canopy volume measurements (width × length × height) were taken every two weeks from 15 March to 30 June 2019 from five randomly selected plants per plot. Yields were taken twice a week from 15 March to 30 June 2019. Rotted and misshapen fruit were picked and discarded as they comprised a small percentage (2-3%) of fruit. Picked fruits were divided into three categories: marketable, vertebrate damage, and small fruit (<10 g). Weight and number of fruits were recorded for each category.

Degrees °brix was measured from marketable fruit during April and May. Early yields in March and late yields in June did not produce enough fruit across all plots to support °Brix data. °Brix measurements were taken weekly and used five randomly chosen fruit from each plot. The middle of each fruit was squeezed until 2-3 drops collected on a refractometer. Two measurements were taken for each fruit and averaged.

4.10. Statistical analysis

Data were analyzed using SAS University Edition 9.4 (SAS Institute, Cary, NC, USA) using a standard split plot analysis. Sudangrass treatments, solarization treatments, block, and interaction between sudangrass and solarization treatments were incorporated into a PROCGLM model. A separate error term (sudangrass treatment*block) was used to analyze sudangrass data. If multiple measurements were taken per plot, measurements were averaged leading to a single value for each plot. A significance level of 0.05 was used for all data. For pairwise comparisons a protected Fisher's LSD was used.

Project Results

5.1 Cover crop growth

Cover crops grew to an average height of 1.52 m and accumulated an average biomass of 9,802 kg per hectare. Sudangrass regrew in mulched, non-solarized plots growing to a height of 1.5 meters before mowing and subsequent application of black plastic on beds. After application of black plastic, sudangrass continued to grow in mulched plots until December when it winter killed. Mulched, non-solarized plots required weeding of sudangrass regrowth to allow for strawberry establishment.

5.2 Soil temperatures

Maximum soil temperatures achieved in solarized plots were 53°C at a soil depth of 5 cm and 43°C at a soil depth of 15 cm (Table 5.2). Average daily maximum temperatures were 2.5°C higher in incorporated and no sudangrass solarized treatments than in solarized, mulched treatments. All solarized treatments resulted in temperatures at least 10°C higher than non-solarized plots. At 5 cm solarized treatments resulted in 135 to 188 cumulative hours above 40°C and 0 to 51 hours above 45°C. At 15 cm, solarized treatments resulted in 0 to 33 cumulative hours above 40°C.

Table 5.2. Average maximum temperatures, maximum temperature achieved (not averaged), and average number of hours where temperature was above 40°C and 45°C at a depth of 5cm. Data recorded in all solarized plots (n=3) and in control plots (n=4).

Treatment	Average max temperature (°C) 5 cm	Average max temperature (°C) 15 cm	Max temperature (°C) 5 cm	Max temperature (°C) 15 cm	Hours >40°C 5 cm	Hours >40°C 15 cm	Hours >45°C 5 cm	Hours >45°C 15 cm
Mulched, solarized	40.9 ± 1.22	34.9 ±1.04	46	39	135	0	0	0
Incorporated, solarized	42.6 ± 1.26	37.3 ± 1.13	53	41.5	189	24	32	0
No sudangrass, solarized	43.2 ± 1.30	37.2 ± 1.16	49	43	188	33	51	0
No sudangrass, non-solarized	30.3 ± 0.92	28.2 ± 0.85	35.5	32	0	0	0	0

5.3 Weed population

Weeds present

Little mallow (*Malva parviflora L.)* and annual sowthistle *(Sonchus oleracea L.)* comprised most of the weed population. Other species present were nettleleaf goosefoot (*Chenopodium murale* L.), common purslane (*Portulaca oleracea* L.) bristly oxtongue (*Picris echioides* L.), sharppoint fluvellin (*Kickxia elatine* L.), curly dock (*Rumex cripus* L.), black nightshade (*Solanum nigrum* L.), and purple crabgrass (*Digitaria sanguinalis* L.).

Weed biomass

Solarized plots had significantly lower weed biomass and weed density than non-solarized plots at 1.5 months and 2.5 months after solarization (Table 5.3). In the December reading (3.5 months after tarp removal) weed biomass was lower in solarized than non-solarized plots, but weed density was similar in those two treatments (Table 5.3). The difference in weed biomass between solarized and non-solarized plots decreased from one reading to the next. Solarized plots reduced weed biomass over non-solarized plots by 95.2% in October, 90.0% in November, and 49.8% in December.

Sudangrass treatments did not have a significant effect on weed populations until December. However, throughout the experiment mulched plots tended to have lower weed biomass than no sudangrass and incorporated plots. In October and November mulched plots reduced weed biomass by 81.2% to 93.2% over incorporated and no sudangrass plots. In December, mulched plots had significantly lower weed biomass than incorporated plots although similar weed biomass levels to no sudangrass plots (Table 5.3). Although not significantly different, mulched plots reduced weed density by 77.4 and 79.5% compared to other sudangrass treatments in December.

A solarization × sudangrass treatment interaction was observed in weed biomass measurements taken in December (Figure 5.1). Sudangrass treatments reacted differently depending on whether or not they were solarized. In non-solarized plots, mulched plots had significantly lower weed biomass than no sudangrass plots (p=0.045) and incorporated plots (p=0.0008). Incorporated, non-solarized plots had the highest levels of weed biomass recorded out of all non-solarized plots. In solarized plots, incorporated and no sudangrass plots tended to have lower weed biomass than mulched plots.

Table 5.3: Weed Biomass (g/m²) and weed density (number/m²) measurements taken 1.5 months (Oct.), 2.5 months (Nov.), and 3.5 months (Dec.) after tarp removal. Sudangrass (n=8, 7 for sudangrass mulch), solarization (n=12, 11 for non-solarized) and interaction effects determined using a split-plot ANOVA. Pairwise comparisons generated using protected Fisher's LSD (p=0.05.)

	Weed measuremnts (Oct-Dec)					
Treament	Biomass Oct (g/m²)	Density Oct (number/m²)	Biomass Nov (g/m²)	Density Nov (number/m²)	Biomass Dec (g/m²)	Density Dec (number/m²)
Sudangrass effect *Pr>F*	0.06	0.33	0.31	0.17	0.03	0.08
Mulched	2.02 a	9.14 a	18.3 a	3.61 a	74.3 b	7.92 a
Incoporated	22.5 a	8.08 a	116 a	11.9 a	192 a	35.3 a
No Sudangrass	29.5 a	17.0 a	93.0 a	16.3 a	135 ab	38.6 a
Solarization effect *Pr>F*	<0.01	0.01	0.02	0.04	0.02	0.10
Non-solarized	34.4 a	17.2 a	138 a	16.6 a	178 a	34.5 a
Solarized	1.67 b	5.30b	13.8 b	4.72 b	89.6 b	20.02 a
Interaction effect *Pr>F*	0.06	0.22	0.09	0.29	0.01	0.25

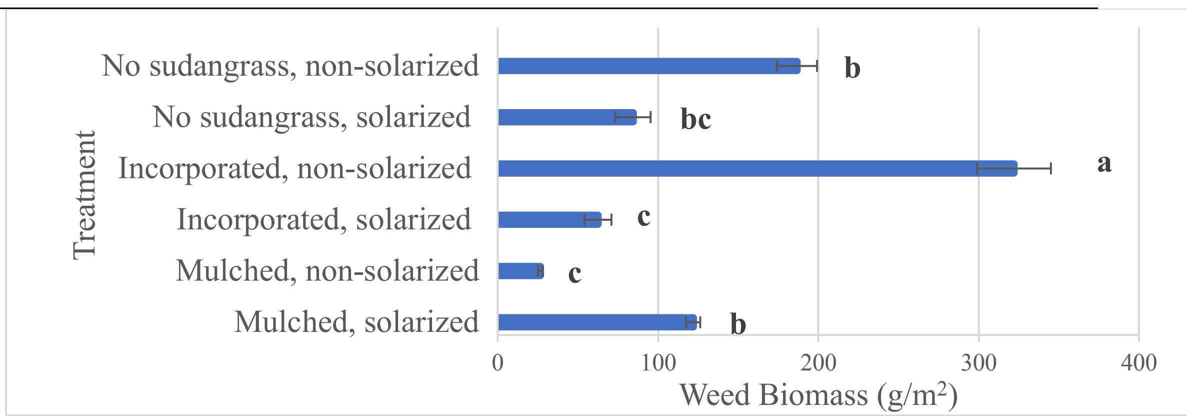

Figure 5.2. Weed biomass (g/m²) of each interaction treatment between sudangrass and solarization taken in December (p=.01, n=4, 3 for sudangrass mulch, solarized). Pairwise comparisons calculated using protected fishers LSD (p=0.05).

Relative species cover

At 1.5 and 2.5 months after tarp removal little mallow and annual sowthistle comprised significantly lower percent ground cover in solarized than in non-solarized plots (Table 5.4). At 3.5 months after tarp removal, percent ground cover for little mallow and annual sowthistle was not statistically different in solarized vs. non solarized plots (Table 5.4). Furthermore, little mallow species cover was 133% higher in solarized plots than non-solarized plots, whereas annual sowthistle cover was reduced by 65.4% in solarized plots. Common purslane cover was 241.7% higher in solarized plots than in non-solarized plots 6 weeks after solarization. Common purslane germinated under solarization tarps in some plots. However, common purslane populations decreased in November as the weather cooled off. Total weed cover was significantly reduced in solarized plots compared to non-solarized plots in October and November (Table 5.4). In December, solarized and non-solarized plots contained similar total weed cover.

Table 5.4: Relative ground cover of prominent weed species 1.5 months after tarp removal (13 Oct), 2.5 months after tarp removal (9 Nov) and 3.5 months after tarp removal (12 Dec) between solarized and non-solarized plots. (n=12, 11 for solarized plots). Pr>f values of less than of 0.05 indicate significant differences between solarized and non-solarized plots.

	Weed ground cover (%)								
	13-Oct			9-Nov			12-Dec		
Species	Non-solarized	Solarized	*Pr>F*	Non-solarized	Solarized	*Pr>F*	Non-solarized	Solarized	*Pr>F*
Little mallow	11.9	1.73	<0.01	35.5	9.83	<0.01	30.8	41.4	0.46
Annual sowthistle	12.8	0.03	0.04	21.9	1.00	0.02	34.2	11.8	0.10
Common purslane	0.96	2.32	0.33	0.83	1.00	0.95	0.00	0.00	n/a
Total	26.9	4.50	<0.01	58.3	23.8	<0.01	65.83	58.72	0.57

Cover crop treatments did not have a significant impact except for the total weed cover in October (*p*=0.009) and annual sowthistle populations in November (*p*=0.048), where mulched treatments had lower weed cover than no sudangrass or incorporated treatments. There was an interaction between sudangrass treatments and total weed cover during October, November, and December (Table 5.5). For non-solarized plots, total weed species cover was lower in mulched plots than incorporated or no sudangrass plots. In solarized plots, mulched plots had higher total weed cover than incorporated or no sudangrass plots.

Table 5.5 Interaction effect of sudangrass and solarization treatments of total weed cover (%) in weedy checks taken 1.5 months, 2.5 months, and 3.5 months after tarp removal (n=4, 3 for sudangrass mulch, non-solarized. Within each column Pairwise comparisons were done using protected Fisher's LSD test (p=0.05).

	Total weed cover (%)		
Treatment	Oct	Nov	Dec
Mulched, solarized	5.33 b	58.3 a	80.0 ab
Mulched, non-solarized	7.21 b	6.25 b	15.0 c
Incorporated, solarized	4.30 b	3.78 b	48.8 bc
Incorporated, non-solarized	33.7 a	90.0 a	88.8 ab
No sudangrass, solarized	4.08 b	9.28 b	52.8 abc
No sudangrass, non-solarized	39.7 a	78.0 a	93.8 a
Sudangrass*solarization *Pr>F*	<0.01	<0.01	0.01

5.4 *Verticillium dahliae* populations

Before soil solarization, *V. dahliae* populations were significantly lower in solarized vs non-solarized plots (Figure 5.3). After solarization treatments were conducted the difference became more pronounced. The largest difference in between solarized and non-solarized plots occurred in September, immediately after solarization. Post solarization, *V. dahliae* populations ranged from 1.5 to 5.1 CFU/g in solarized plots and 7.6 to 30.7 CFU/g in non-solarized plots. There were significantly lower populations of *V. dahliae* in September, November and June in solarized compared to non-solarized plots. In January, no differences were observed between solarized and non-solarized plots, although *V. dahliae* populations in solarized plots were 61.6% lower than non-solarized plots.

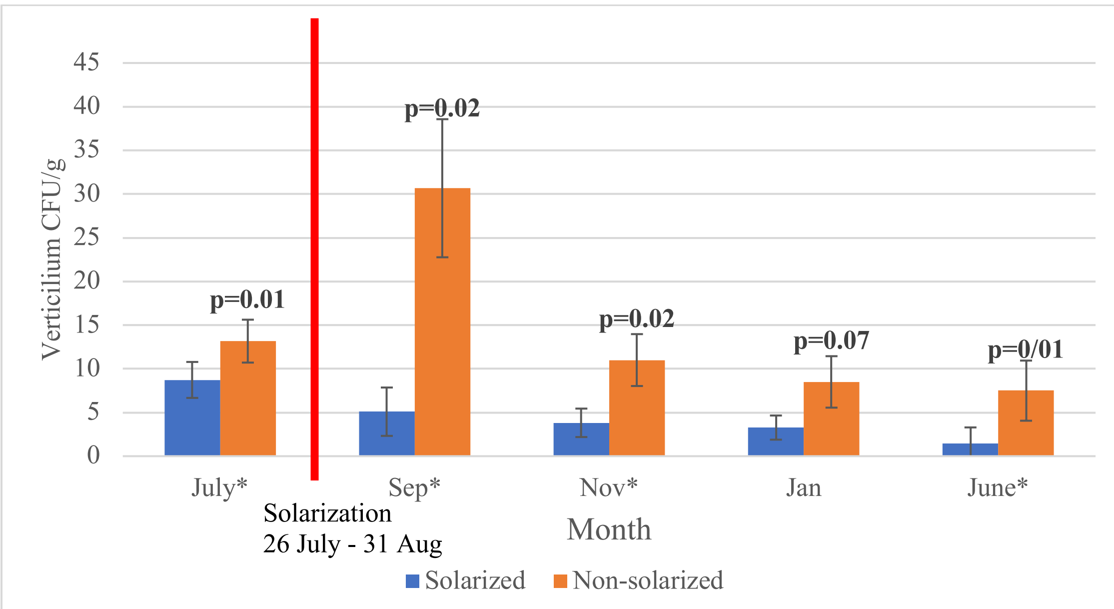

*Figure 5.3 Verticillium dahliae populations (Colony Forming units (CFU)/g) in solarized vs non-solarized plots taken from July 2018 (pre-solarization treatments) to June 2019 (end of harvest) (n=12,11 for solarized plots). P-value derived from a split plot ANOVA. *Denotes a significant difference between solarized and non-solarized plots using a protected Fisher's LSD test (p=0.05)*

Cover crop treatments had no significant effects on *V. dahliae* populations. However, some trends were observed in cover cropped plots. In mulched plots, a large jump in the *V. dahliae* population occurred in September, while the sudangrass was still actively growing. Levels decreased to pre-solarization levels in November after the cover crop was mowed twice and tarped. There were no significant interactions between sudangrass treatments and solarization treatments.

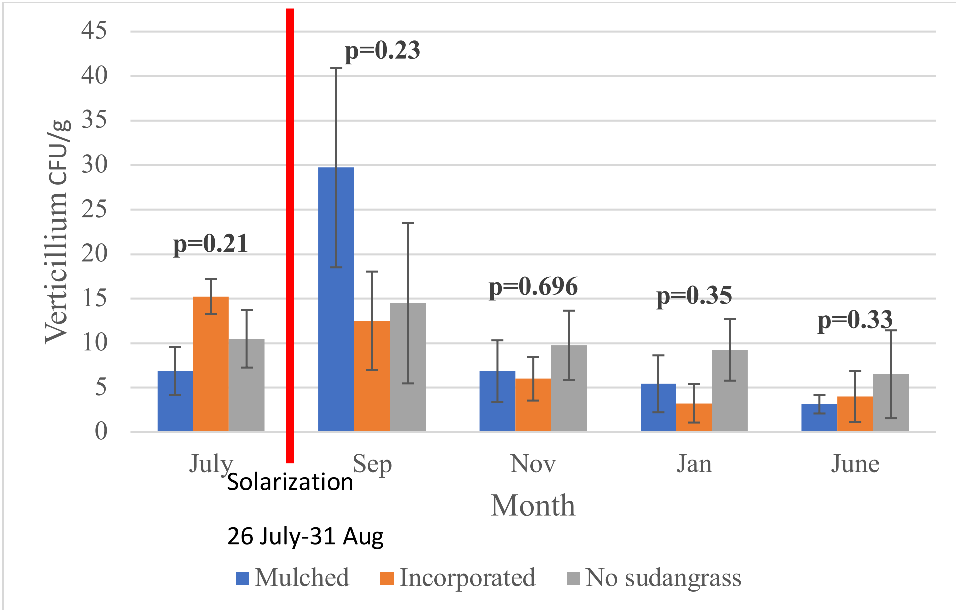

Figure 5.4 Verticillium dahliae populations (CFU/g) in sudangrass plots taken from July 2018 (pre-solarization treatments) to June 2019 (end of harvest) (n=8, 7 for mulched plots). P-value derived from a split plot ANOVA. No significant values were observed (p=0.05).

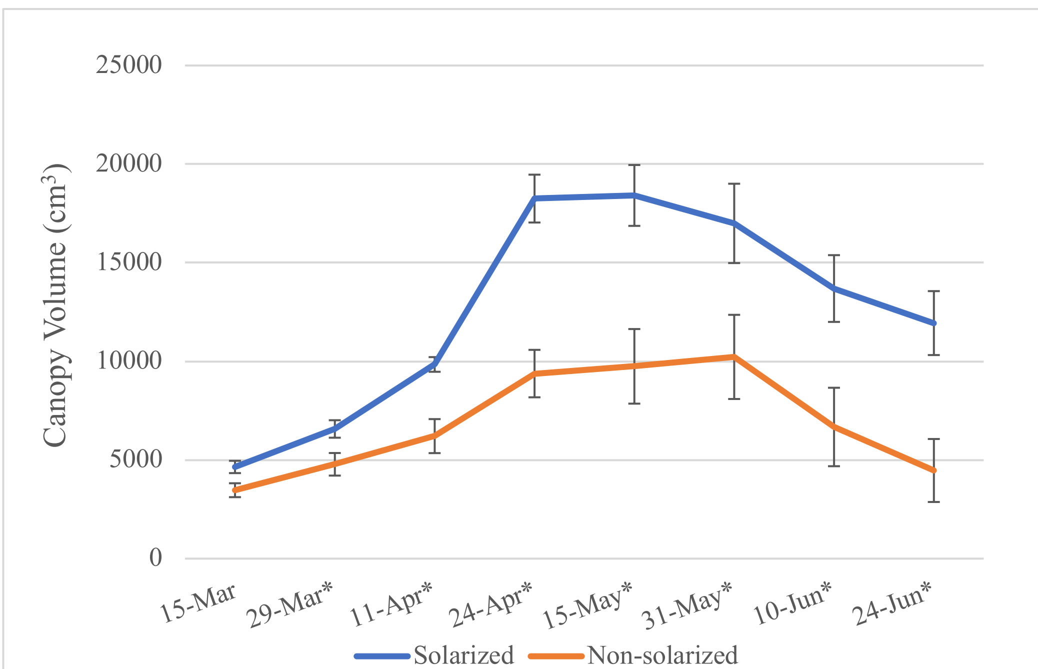

*Figure 5.5 Average canopy volume (cm3) measurements taken from five random plants per plot every two weeks during strawberry harvest (15 March to 30 June) in solarized vs non-solarized plots (n=12, 11 for solarized plots). *Denotes a significant difference between solarized and non-solarized plots using a protected Fisher's LSD test (p=0.05).*

5.5 Canopy volume

Canopy volume was used to determine the overall health of plants during the growing season. Canopy volume increased rapidly in March and early April, peaking in May during peak production season, and decreasing again in June as late-season disease stunted plants. The decrease in late season canopy volume can also be partially attributed to heat stress. Both solarization and sudangrass treatments influenced canopy volume. From 29 March until 24 June the solarized plots contained significantly higher canopy volume than the non-solarized plots (Figure 5.5). Solarization canopy volume peaked at 18,412.63 cm^3 on 15 May, while non-solarized plot's canopy volume peaked on 31 May at 10,226 cm^3.

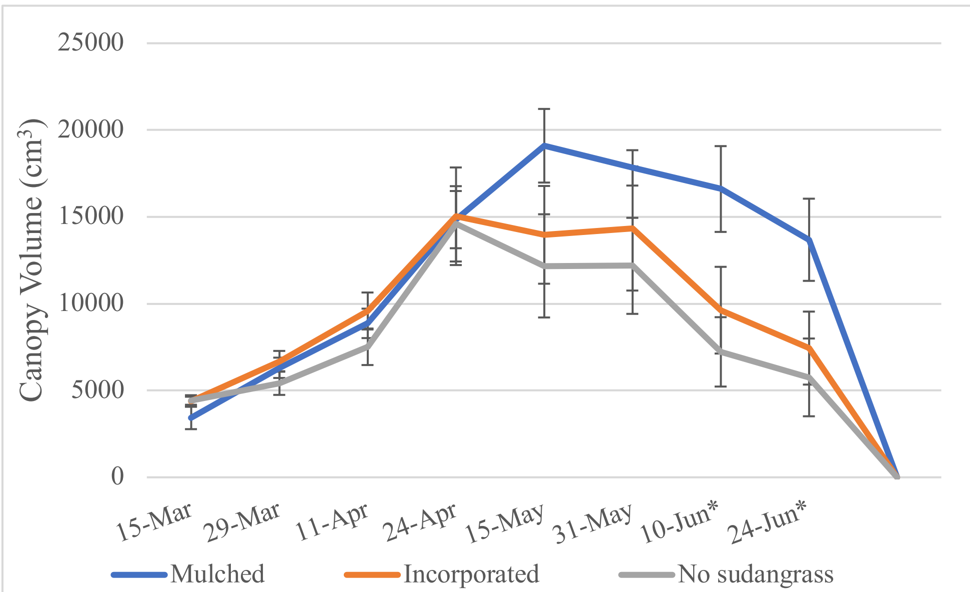

Figure 5.6 Average canopy volume (cm^3) measurements taken from five random plants per plot every two weeks during strawberry harvest (15 March to 30 June) in sudangrass treatments: mulched, incorporated, and no sudangrass (n=8, 7 for sudangrass mulch plots).*Denotes a significant difference between solarized and non-solarized plots using a protected Fisher's LSD test (p=0.05)

The effect of the cover crop factor was not significant until June (Figure 5.6). On 10 and 24 June, mulched treatments had significantly higher canopy volumes than the no sudangrass and incorporated treatments. Incorporated treatments tended to have a higher canopy volume than no sudangrass treatments. All cover crop populations saw decreases in canopy volume beginning in June correlating with disease severity. Canopy volume in the incorporated and no sudangrass treatments maxed out on 24 April at 15,036 and 14,600 cm^3. In the mulched treatments, the highest canopy volume occurred on 15 May at 19,097 cm^3.

5.6 Disease incidence

Both sudangrass and solarization factors had significant effects on disease severity (Figures 3.7 and 3.8). There were no interactions between the two factors. *V. dahliae* and *M. phaseolina* were isolated from diseased plants in high enough numbers to be determined as the causal agents of disease. *M. phaseolina* tended to occur more frequently in solarized plots (73.3% of isolations were in solarized plots) and *V. dahliae* occurred more frequently in non-solarized plots (67.8 of isolations were in non-solarized plots). However, not enough diseased plants were successfully identified to draw conclusions about effects of solarization and sudangrass residues on disease incidence of different pathogens.

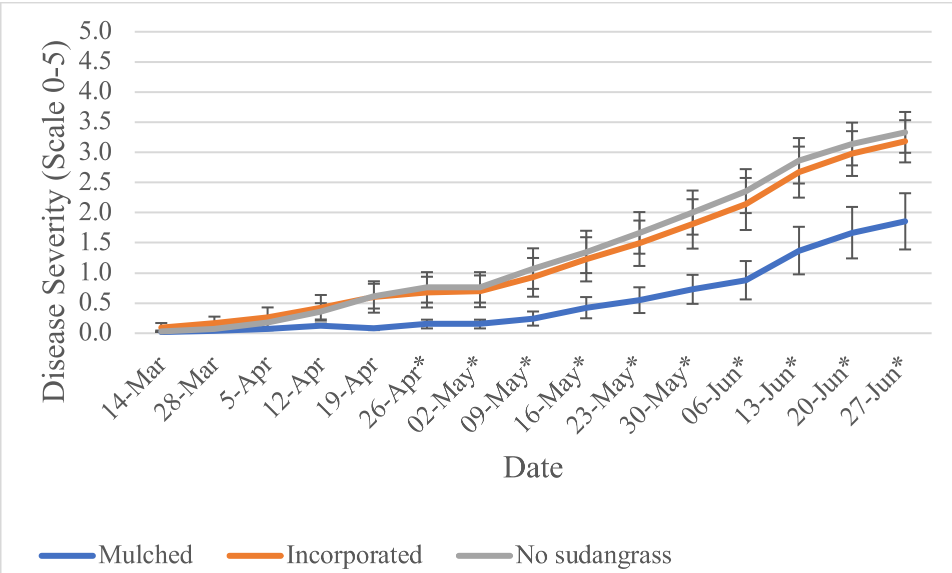

*Figure 5.7. Disease severity on a scale of 0 (no disease) to 5 (dead) of sudangrass treatments. (n=8, 7 for mulched plots). *Denotes a significant difference between solarized and non-solarized plots using a protected Fisher's LSD test (p=0.05).*

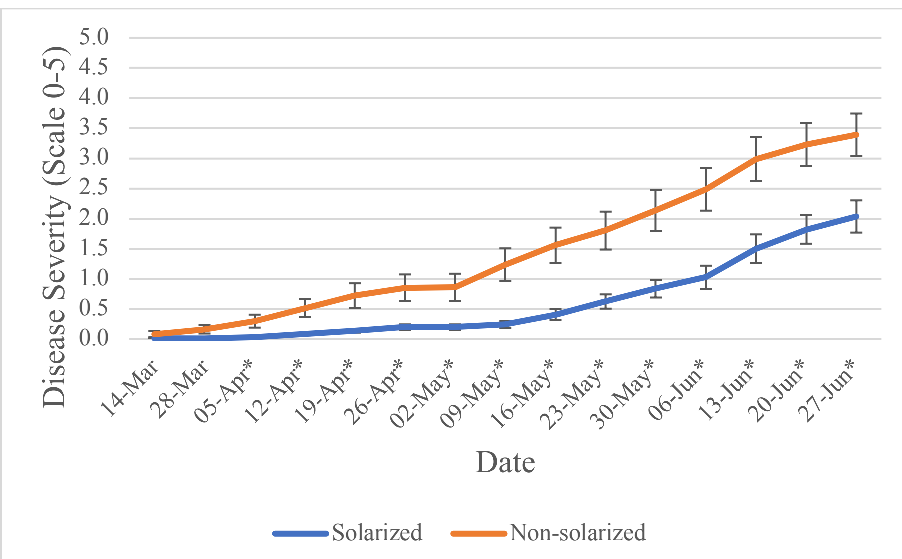

*Figure 5.8. Disease severity on a scale of 0 (no disease) to 5 (dead) in solarized vs non-solarized plots (n=12, 11 for solarized plots). *Denotes a significant difference between solarized and non-solarized plots using a protected Fisher's LSD test (p=0.05).*

Solarization and sudangrass treatments both had strong effects on disease severity. Starting on 5 April until the end of the experiment, solarized plots had significantly lower disease severity than non-solarized plots. Mulched plots had lower disease severity than both incorporated and no sudangrass plots starting on 26 April till the termination of the experiment. No interaction effects were observed for disease severity.

At the end of the experiment, solarized plots had significantly lower disease incidence than non-solarized plots (Table 5.6). Sudangrass treatments had no significant effect on disease incidence, however, mulched plots tended to have lower disease incidence than incorporated and no sudangrass treatments. No interaction effects were observed for disease incidence. Plant mortality was significantly lower in solarized than non-solarized plots (Table 5.6). Solarized plots reduced plants mortality by 54.9% over non-solarized plots. mulched plots had significantly lower plant mortality than both incorporated and no sudangrass plots (Table 5.6), reducing plant mortality from 64.9% to 66.2% over sudangrass incorporated and no sudangrass plots.

Table 5.6: Disease incidence (% of total infected plants) and plant mortality (% of dead plants)) measurements recorded at the end of harvest (June 28th) for sudangrass and solarization treatments. Sudangrass (n=8, 7 for sudangrass mulch), solarization, (n=12, 11 for non-solarized) and interaction effects determined using a split-plot ANOVA. Pairwise comparisons were generated using protected Fisher's LSD at p ≤ 0.05. Within a factor, values sharing the same letter are not significantly different.

	Disease Incidence (%)	Plant Mortality (%)
Sudangrass effect *Pr>F*	0.07	<0.01
Mulched	66.3	11.3 a
Incorporated	92.2	33.3 b
No Sudangrass	94.3	32.1 b
Solarization effect *Pr>F*	<0.01	<0.01
Solarized	77.9 a	16.0 a
Non-solarized	91.5 b	35.5 b
Interaction effect *Pr>F*	0.3879	0.2273

3.3.7 Yields

Solarized plots had roughly triple the yield of non-solarized plots. Solarized plots also had a significantly higher average fruit weight than non-solarized plots (Table 5.7). However, the °brix of strawberries in solarized plots was significantly lower than non-solarized plots as smaller fruit tended to be sweeter than larger fruit. Sudangrass management techniques did not have a significant effect on marketable yield. However, yield tended to decrease in the order: mulched > incorporated > no sudangrass. Mulched plots did have a significantly higher average fruit weight than incorporated or no sudangrass plots. However, fruit in mulched plots had significantly lower °brix than no sudangrass plots. There were no interaction effects for marketable yield, °brix and average weight.

Table 5.7: Marketable yield per 30 plants (g), °Brix (% sugar content) and average weight of marketable fruit for sudangrass and solarization treatments. Sudangrass (n=8, 7 for sudangrass mulch), solarization, (n=12, 11 for non-solarized) and interaction effects determined using a split-plot ANOVA. Pairwise comparisons generated using protected Fisher's LSD p=0.05.

	Marketable Yield per 30 plant (kg)	°Brix (% sugar content)	Average Weight (g)
Sudangrass effect *Pr>F*	<0.01	<0.01	0.02
Mulched	8.81 a	9.03 a	30.7 b
Incorporated	7.50 a	9.76 ab	25.1 a
No sudangrass	6.48a	10.4 b	25.3 a
Solarization effect *Pr>F*	<0.01	0.01	<0.01
Solarized	11.6 b	9.1 a	29.7 b
Non-solarized	3.84 a	10.4 b	24. a
Interaction effect	0.9781	0.0778	0.607

Large amounts of vertebrate pest damage occurred in the field (16.8% of total yield). Damage was similar across all treatments. Fruit with vertebrate pest damage were excluded from marketable yield. Small fruit of less than 10 grams were also excluded from marketable yield and was not included in average weight. Small fruit comprised 4.3% of the total yield (total yield = marketable yield + vertebrate pest damaged yield + small fruit) of mulched plots, 10.7% of the total yield of incorporated plots, and 12.3% of the total yield of no sudangrass plots. Small fruit comprised 4.2% of the total yield for solarized plots and 14.0% of the yield for non-solarized plots.

Conclusion and Discussion

Solarization was effective at reducing weeds, Solarization reduced *V. dahliae* populations by 80.7%, reduced plant mortality by 54.9%, and roughly tripled yields over non-solarized plots indicating its potential for use in organic strawberry production along California's central coast. Solarization's effect on weed reduction disappeared after 3.5 months and solarized strawberries suffered some late season reduction in yields due to late season pathogens. Weed and disease reduction could be of more importance to shorter season crops particularly those with growing seasons less than 3 months. Testing solarization vs other organic soil disinfestation techniques can better inform growers on the advantages and disadvantages of each technique. Additionally, it is important to determine the efficacy of solarization against different weeds and pathogens as sensitivity to heat differs between species. Sudangrass cover crops do not increase the impact of solarization. However, cover cropped plots tended to perform better than non-cover cropped plots. Cover crop mulch provided the best weed control and heathiest plants. Further research into cover crop mulches for organic strawberry production is warranted to verify reduction in weed population and improvements in plant health.

Outreach

The research plots were demonstrated to students in Cal Poly classes AEPS 203 and AEPS 315. Plots were also demonstrated to Cal Poly Organic Farm staff and visitors. One popular press article was published in Organic Farmer Magazine and the research project was featured in the same magazine.

1. Jacobs, T., Tubeileh A., Steinmaus, S., 2019. Effect of sudangrass cover crop residues and soil solarization on weed and *Verticillium dahliae* populations in organic strawberry production. 2019 American Society of Horticultural Science annual conference. Las Vegas, July 21-25, 2019.
2. Tubeileh A., Stephenson, G., 2019. Suppressing *Verticillium dahliae* through compost application. 2019 American Society of Horticultural Science annual conference. Las Vegas, July 21-25, 2019.
3. Jacobs, T., Tubeileh A., Tassinari, A., Steinmaus, S., 2019. Thermal death models simulating response of California weed seeds to soil solarization. 2019 American Society of Horticultural Science annual conference. Las Vegas, July 21-25, 2019.
4. Jacobs T., Tubeileh A., 2019. Organic soil disinfestation methods-Soil solarization and biosolarization. Organic Farmer. August 23, 2019. http://organicfarmermag.com/2019/08/23/organic-soil-disinfestation-methods-soil-solarization-and-biosolarization/

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Photos

A non-solarized plot showing dead or poorly growing strawberry plants.

A solarized plot showing healthy strawberry plants.