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Biosolarization: Harnessing the Sun and Organic Matter for Weed Control

Final Report

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Abstract

One of the most ubiquitous and challenging realities of organic farming is finding effective, ecological and viable ways of controlling weedy species. Organic producers are limited in the number of effective herbicides they are able to use both in number of available chemicals and scope of treatment, and sustainably minded conventional farmers are becoming more aware of the detrimental effects associated with chemical herbicides and fumigation. Volatilization and drift of herbicides have contaminated non-target crops and have exposed humans and the environment to these chemicals, resulting in economic losses and likely acute and chronic impacts on human health and the environment. Proving the efficacy of safe alternatives to weed management is essential to the progression and broader adoption of sustainable farming practices, which in turn will reduce exposure to people and minimize contamination to natural resources on which agriculture depends.

Biosolarization is a relatively new innovation in the realm of weed control. Similar to solarization, which uses clear plastic sheeting on moist soil to thermally terminate a variety of pest species, biosolarization includes the use of organic matter in the form of compost, cover crops, manure or other organic materials such as pomace or nut hulls. The addition of organic matter accelerates the process by encouraging anaerobic soil disinfestation. The carbon from organic material produces chemicals with bio-pesticidal activity. This results in the release of chemicals, which, when combined with the heat, acts like a fumigant during the solarization process.

The primary objective of the project was to measure the efficacy of biosolarization on weedy species present on five farms in northern California. Biosolarization will have achieved the objective if the plots with treatments have significantly reduced weed populations, both in absolute number, species present and duration of the treatment, compared to plain solarization and the control plots.

NCAT established the experiment on three separate farm properties. Each property had three test plots with three separate treatments within each plot: a solarized treatment, a biosolarized treatment using compost, and a control. The biosolarized treatment will take 8-10 days after incorporating the organic matter and the solarized sections treatment will take 32 days, which is the minimum recommended time for solarization in the Central Valley (Elmore et al., 1997).

Objectives

Our first objective was to test the relative effectiveness of solarization and biosolarization on weed suppression with control plots on organic farms in Northern California. NCAT worked with three farms to measure the effectiveness of the three treatments on weed seed germination and species mix.

Our second objective was to evaluate the amount of time required for biosolarization and solarization in the context of each farm's scheduled seeding or transplanting.

The third objective was to publicize the results. In working with three farmers, NCAT hoped to better understand the effects of biosolarization on three farms with different soils, cropping systems, and pest pressures. Considering the positive results, these localized trials will help to encourage the adoption of biosolarization in these regions and beyond. The results will be published and highlighted on our widely read sustainable farming website (www.attra.ncat.org). We also produced webinars in English and Spanish to highlight the results of this effort. Presentations at conferences were held to demonstrate the results of the project. We demonstrated how biosolarization can be added to the short list of effective sustainable weed control practices. Certainly, for smaller farmers, biosolarization might be an effective way to reduce weed pressure on smaller acreages. However, it can also be applied to non-cropped areas which require non-chemical weed suppression prior to planting, such as hedgerows, native plant restoration (along riparian areas), as well as beneficial habitat plantings (such as for NRCS practice, Conservation Cover 327).

Materials and Methods

NCAT's project took place on three different organic farms. In consultation with the farmers, we set apart a piece of land with weedy species present on each of these farms. Each farm included a total experimental area of 0.01 acres equivalent to 435 sq. ft. This measurement was chosen because it lends itself well to extrapolation primarily in terms of costs and application of organic matter.

Each treatment plot size was approximately 5' X 9.67', with nine plots this size (three plots per treatment) which combine to total 0.01 acres. Depending on the farm layout and equipment used on these farms there was between 2 to 5 feet between each treatment plot. Each property had nine test plots with three separate treatments randomly assigned: three plots for control with no treatment; three plots for solarization with plastic cover for 32 days; three plots for biosolarization with 5 tons/acre equivalent of compost and covered with plastic for 8-10 days. The research design was laid out in a randomized complete block design. The statistical test known as analysis of variance (ANOVA) was used to analyze the data drawn from results of the treatment's weed stands measured by canopy percentage on these plots.

The materials necessary for this project included clear U.V. resistant 1.5 mil plastic, soil temperature gauges, and compost. We used the farmers' equipment; the compost was purchased from a local supplier and was the same compost on all three farms. The compost was broadcast on top of the plots and lightly incorporated with a shovel and rake.

NCAT took soil samples from each treatment with a shovel at a depth of 6 to 8 inches. Samples were analyzed for soil organic matter (SOM) content as well as macro and micro-nutrient with A&L Labs of Modesto, CA. A phospholipid fatty acid (PLFA) test was conducted by Ward Labs of Kearny, NE.

Soil tests were conducted on all plots comparing treatments to the control. Ward Labs note that the PLFA test is, "conducted by analyzing phospholipid fatty acids, or PLFA. PLFA is a snapshot of soil community structure and abundance at the time of sampling. As environmental conditions such as temperature and moisture change so does the microbial community. Soil temperatures were recorded on the treatments at the surface, at 3 inches, and at 6 inches of the profile. During treatment periods, the farmers and NCAT personnel took soil temperatures two to three times a week. Weed germination was evaluated by comparing the control plot's canopy to the two treatment areas using the Canopeo mobile application which is a green canopy cover measurement tool developed by Oklahoma State University. This app tracks the growth of crops by calculating fractional green canopy cover through pictures or video. Its operation is based on calorimetry, offering real time results in a natural setting that are much more accurate than visual examinations. After a picture or video has been taken, the application displays the results on a smart phone. The image can be uploaded, filling out different data to identify the sample. The kind of weeds that emerge in the control were identified by genus and, when possible, species. Special attention focused on the type of weeds that survived the treatment plots.

The 2020 growing season was extraordinary and disrupted many of the farmer's practices. In addition to the COVID-19 pandemic, wildfires, labor availability and drought have affected many of the farms where these trials were located. The trials were executed on all the farms, but the subsequent planting and management changed on some of them. This will be detailed in the results and discussion section.

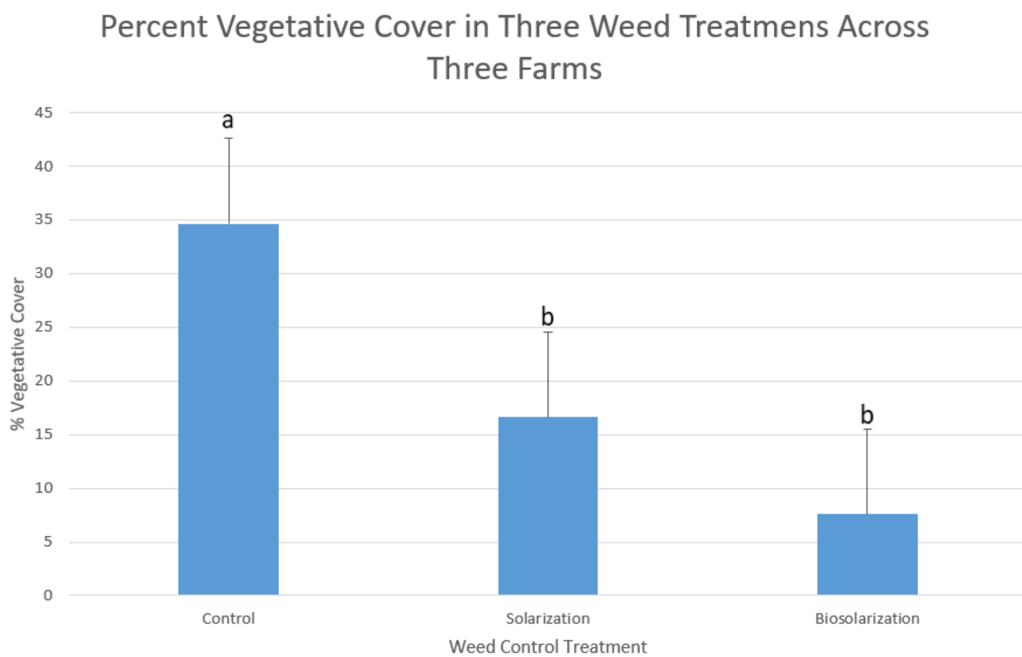
Results and Discussion

Statistical analyses were done to determine whether there were significant differences between biosolarization, solarization, and control treatments both within each individual farm, and across all farms.

When results from this study were compared across all three farms, a strong association between weed control treatment used and percent vegetative cover (weed germination) was found. A two-way ANOVA revealed that overall, the relationship between percent vegetative cover and type of weed control treatment across farms was significant, $F(2, 18) = 20.47$, $p = .0001$, partial $\eta 2 = .695$. However, farm location had a significant effect on the percent vegetative cover observed as well: $F(2, 18) = 80.195$, $p = .0001$, partial $\eta 2 = .899$, and the two-way ANOVA also revealed a significant interaction effect between farm location and weed control treatment $F(4, 18) = 12.27$, $p = .00001$, partial $\eta 2 = .732$, signifying that the effect of weed control treatment on percent vegetative cover was dependent upon the farm sampled.

Because farm location and weed control treatment both had a significant effect on percent of vegetative cover, and because there was a significant interaction effect between these two factors, we cannot extrapolate these findings beyond the farms that we sampled to arrive at general conclusions. However, we can conclude that for the three farms sampled in this study, weed control treatment did have a significant effect on the percent vegetative cover that we observed. Bonferroni post hoc tests revealed that plots receiving the control weed treatment (no weed control) had an average of 18% more vegetative cover than did solarized plots (95% CI, 6.69 to 29.44), which was a statistically significant difference ($p = .0001$). Plots receiving the control weed treatment (no weed control) had an average of 27% more vegetative cover than did biosolarized plots (95% CI, 15.701 to 38.425), which was also a statistically significant difference ($p = .0001$).

There was no significant difference in percent vegetative cover observed between solarized and biosolarized plots ($p = .153$), however, the reductions in percent vegetative cover achieved by biosolarization occurred in roughly a quarter of the time that it took for solarization to achieve. More studies are needed to determine under which landscape circumstances solarization and biosolarization are viable weed control practices, but our study suggests that biosolarization is indeed an effective and quick way to control weeds in a significant way.



Polestar Farm is a 12-acre organic orchard near Esparto, gateway to the Capay Valley. They produce a variety of stone fruits, citrus and figs. Biosolarization is of interest to the proprietors because of the possibility to grow strawberries and vegetables between the fruit trees to diversify their products. The pandemic postponed this project, but the trials continued for observation purposes. Located in an orchard, the treatments were shaded in the morning and afternoon, yet the temperatures were high enough to have an effect on the treatments. This farm was near wildfires that had days of hazy/smoky conditions during the trials.

Average temperature readings:

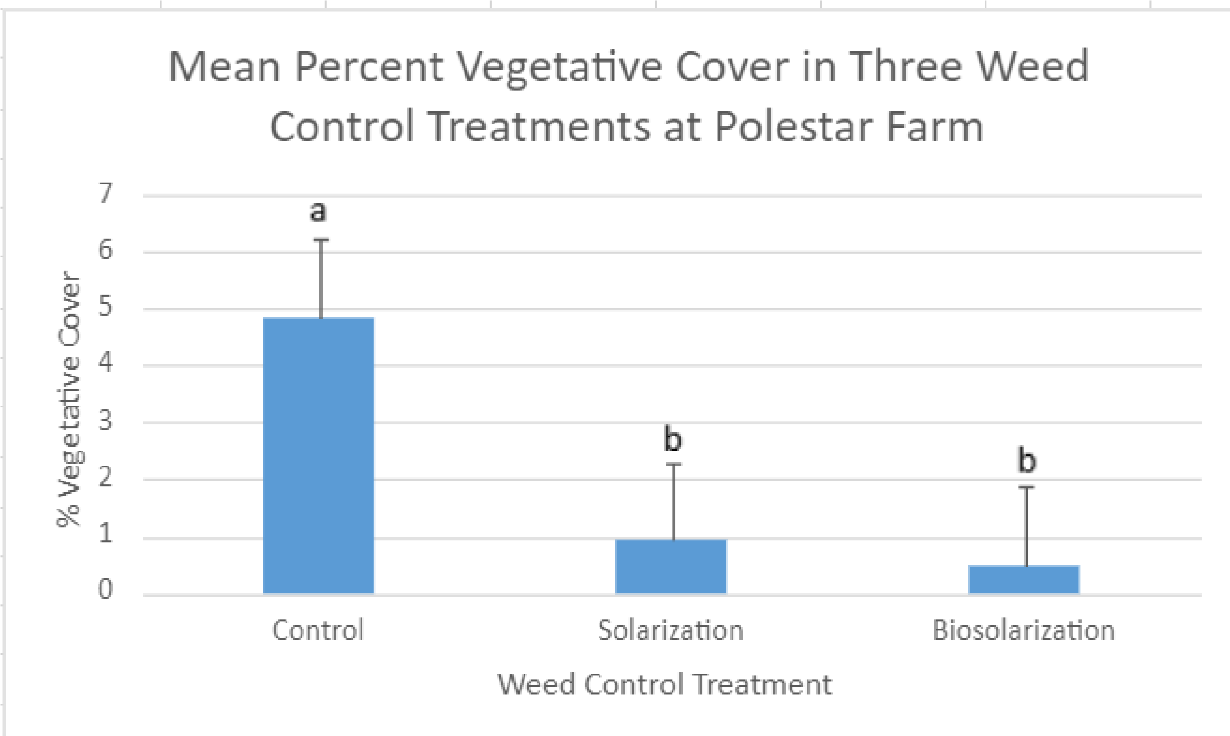
Treatment	Surface	3 Inches	6 Inches
Solarization (8-17 to 9- 14)	114^{o} F	106^{o} F	101^{o} F
Biosolarization (8-17 to 8-27)	114^{o} F	110^{o} F	107^{o} F

Weeds identified:

Common Name	Scientific Name	Family	Category
Persian Speedwell	***Veronica persica***	Scrophulariaceae	Broadleaf
Field Bindweed	***Convolvulus arvensis***	Convolvulaceae	Broadleaf
Hairy Vetch	***Vicia villosa***	Fabeae	Broadleaf

Trial results for Polestar Farm

At Polestar Farm, a strong association between weed control treatment used and percent vegetative cover (weed germination) was found; the one-way ANOVA revealed that the relationship between percent vegetative cover and type of treatment was significant, $F(2,6) = 12.67$, $p = .0071$. Post-hoc t-tests revealed that weed germination was significantly higher in the control treatment as compared to both plots treated with the solarization treatment ($p = 0.027$), and plots treated with the biosolarization treatment ($p = 0.019$). Plots treated with the biosolarization treatment were not significantly different from plots treated with solarization alone ($p = 0.103$).



Gauchito Hill Farm is a ten-acre certified organic farm located in Capay Valley, California. They grow a variety of organic fruit and vegetables, which can be found at several Bay area farmers' markets, grocery stores, online grocery retailers and restaurants. Due to the pandemic Gauchito farm altered their planting schedule and decided not to plant winter vegetables which included land where the trials were setup. Wildfires prevented access to the farm for a week and conditions were hazy and smoking during that time. The treatment was not irrigated after since vegetables were not being considered.

Average temperature readings

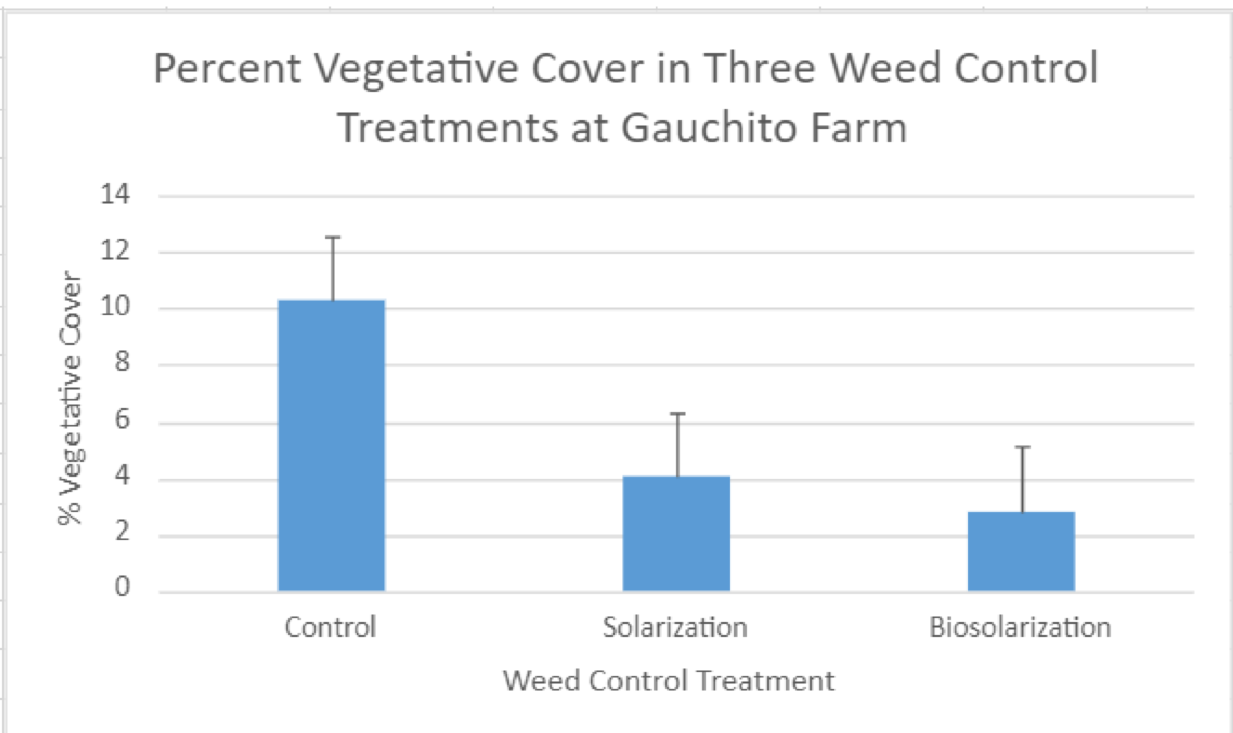
Treatment	Surface	3 Inches	6 Inches
Solarization (8-28 to 9- 25)	116° F	99° F	91° F
Biosolarization (8-28 to 9-7)	100° F	84° F	88° F

Weeds identified

Common Name	Scientific Name	Family	Category
Sow Thistle	Sonchus oleraceus	Asteraceae	Broadleaf
Field Bindweed	Convolvulus arvensis	Convolvulaceae	Broadleaf
Velvetleaf	Abutilon theophrasti	Malvaceae	Broadleaf
Redroot Pigweed	Amaranthus retroflexus	Amaranthaceae	Broadleaf

Trial results for El Gauchito Hill Farm

At Gauchito Hill Farm, no significant association between weed control treatment used and percent vegetative cover (weed germination) was found; the one-way ANOVA revealed that the relationship between percent vegetative cover and type of weed control treatment was not significant, $F(2,6) = 2.91$, $p = .131$.



Full Belly Farm is a well-known established organic farm in the Capay Valley. The field where the experiments were carried out was thought to be planted with flowers after the trials were conducted. It turned out it was seeded with a cover crop of Sudan grass, buckwheat and field peas. We decided to continue with the trials and treat the cover crop as weeds which if they are allowed to go to seed, they can be.

Average temperature readings

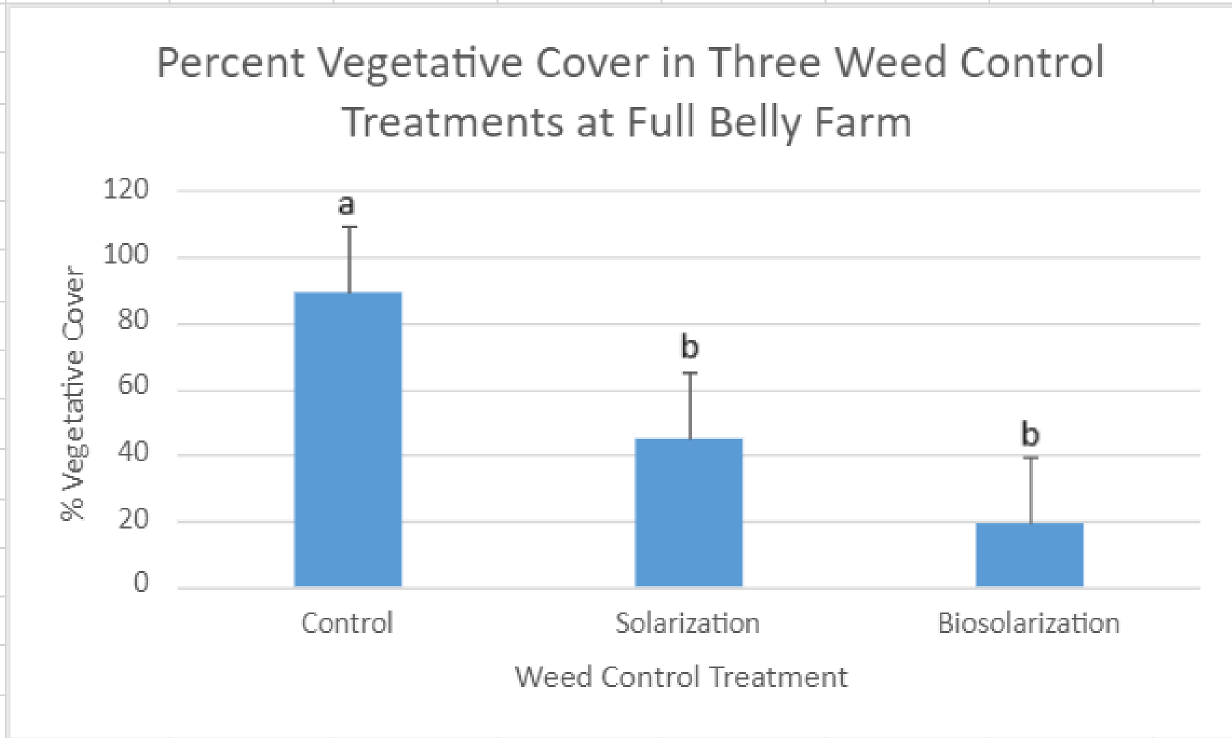
Treatment	Surface	3 Inches	6 Inches
Solarization (9-4 to 10- 2)	121^{o} F	109^{o} F	93^{o} F
Biosolarization (9-4 to 9-14)	123^{o} F	108^{o} F	90^{o} F

Weeds identified

Common Name	Scientific Name	Family	Category
Field Bindweed	***Convolvulus arvensis***	Convolvulaceae	Broadleaf
Sow Thistle	***Sonchus oleraceus***	Asteraceae	Broadleaf
Redroot Pigweed	***Amaranthus retroflexus***	Amaranthaceae	Broadleaf
Cheeseweed	***Malva parviflora***	Malvaceae	Broadleaf
Bristly Ox Tongue	***Picris echioides***	Asteraceae	Broadleaf
Yellow Starthistle	***Centaurea solstitialis***	Asteraceae	Broadleaf
Nutsedge	***Cyperus spp***	Cyperaceae	Sedge
Sudangrass	***Sorghum bicolor***	Poaceae	Grass
Buckwheat	***Fagopyrum esculentum***	Polygonaceae	Broadleaf
Field Pea	***Pisum sativum***	Fabeae	Broadleaf

Trial results for Full Belly Farm

At Full Belly Farm, a strong association between weed control treatment used and percent vegetative cover (weed germination) was found; the one-way ANOVA revealed that the relationship between percent vegetative cover and type of treatment was significant, $F(2,6) = 15.87$, $p = .004$. Post-hoc t-tests revealed that weed germination was significantly higher in the control treatment as compared to both plots treated with the solarization treatment ($p= 0.04$), and plots treated with the biosolarization treatment ($p= 0.00017$). Plots treated with the biosolarization treatment were not significantly different from plots treated with solarization alone ($p = 0.164$).



Soil Quality Results Across All Farms

Soil samples were taken from each treatment on each farm to measure the effect of biosolarization and solarization on soil quality metrics. A randomized complete block design one-way analysis of variance was undergone to determine if three different weed control methods had an effect on total biomass, diversity index, % bacteria, total bacterial biomass, total fungi %, total fungi biomass, fungi: bacteria ratio, nitrate levels (ppm), %K, and % OM throughout the various plots. No significant differences for any of the variables were found (p > .05 for all variables). Other research by Fernandez-Bayo et al. (2017) and by Achmon et al. (2020) found changes in bacterial and fungal soil microbiome components during biosolarization. For these trials, logistics in traveling to multiple farms, timing in sampling the treatments, accessibility to farms (wildfires), shipping to laboratories [cold shipment for phospholipid fatty acids (PLFA) tests] and time taken to analyze the sample at the lab may have affected the results.

Conclusions

This study found that, overall, across three experimental sites, solarization and biosolarization were very effective in reducing weed populations significantly as compared to control treatments. Across all farms, there were no significant differences between the percentage of weed germination within solarization and biosolarization treatments; however, the treatment time of one week for biosolarization compared to one month for solarization makes biosolarization a more efficient weed control method. Some perennial weeds like field bindweed and nutsedge were marginally controlled in some of the trials, indicating that they might be better addressed by other control methods. This could be a result of the way perennial weeds and their propagules spread to the edges of the relatively small treatment areas. Additional studies looking at flat treatments of larger areas rather than individual seed beds may address the effectiveness of these treatments on some perennial weeds. Larger treatment areas may reduce the need for seasonal treatment, since the furrows between the seedbeds would also receive treatment. Additionally, longer term studies of the succession of seasonal weed establishment are needed to determine how biosolarization affects the long-term lifecycle of summer annuals, winter annuals, biennials and perennials present in the treatment areas. More research is needed to determine which weeds can be effectively controlled by biosolarization and under what conditions, but the results of this study indicate that biosolarization may indeed be a time-efficient and effective way to control weeds organically.

Outreach

Due to Covid-19 restrictions on farm demonstrations and field days were cancelled and most outreach efforts was done through virtual workshops at four conferences, a podcast, a webinar, two videos and two updated tip sheets.

A presentation in Spanish with simultaneous English translation was done for the Tilth Alliance Conference on November 10, 2020. There were about 15 attendees at the conference and 22 views as of 7/12/21 on Tilth Alliance's You Tube page: https://www.youtube.com/watch?v=lvL2Y5DRIc0&list=PLvYjukikPLv7g2WP_eVOr4F9Spqz-e8Fk&index=4

On January 23, 2021, a Spanish presentation on Biosolarization was done for the Ecological Farming conference. There were about 12 attendees at the conference and 11 views as of 7/12/21 on the EcoFarm Vimeo site and 49 views on the ATTRA You Tube page: https://vimeo.com/515508969

A Spanish language presentation for the Latino Farmer Conference on February 11,2021; New Innovations in Weed Management featured a significant segment on Biosolarization as well as preliminary results from this research. Full conference webinar is at https://www.youtube.com/watch?v=KPxXDb0UfXU&t=4001s . Session on Weeds management starts at the 47 minute of the webinar. There were about 150 attendees for this session and as of 7/12/21 the webinar has had 39 views.

A presentation for the Small Farm Conference on February 15, 2021, title Biointensive Integrated Pest Management was conducted in Spanish and which also features a brief description of solarization and biosolarization and presented results of this research. About 10 attendees participated and as of 7/12/21 there have been 55 views on the ATTRA You Tube site. https://attra.ncat.org/el-manejo-integrado-biointensivo-de-plagas/

A webinar in English on biosolarization was presented on June 16, 2021, promoted by the National Center for Appropriate Technology (NCAT) through the ATTRA project. There were 600 registrants, 262 attendees and 164 views through ATTRA's You Tube channel. The webinar is accessible through the ATTRA webpage or ATTRA's YouTube channel. https://www.youtube.com/watch?v=vff_Udtbr5A

NCAT recorded a podcast with Alex Ellison of Castlerock Farm in Walnut Creek, California. The conversation includes a description of the Castlerock Farm operation as well as the initial results and challenges of Castlerock's trials in solarization and biosolarization. Found in the ATTRA website: https://attra.ncat.org/?s=biosolarization&cat=27

Two tip sheets on Soil Solarization and Biosolarization (English and Spanish) will be updated in 2022 with the results of the trials performed from this grant:
English: https://attra.ncat.org/product/solarization-tipsheet/;
Spanish: https://attra.ncat.org/product/solarizacion/

Two videos on biosolarization are in the process of development and will be posted on NCAT's ATTRA web page. They will demonstrate the installation of the trials and explain the principals behind the project. One of the videos will be presented in Spanish and one in English.

Leveraged Resources

NCAT received additional funding from Western Sustainable Agriculture Research and Education (WSARE) Project Number OW20-360 titled "Solarization and Biosolarization: Harnessing the Sun and Organic Matter to Control Weeds". The award was in the amount of $49,956.00 with the end period of performance for 5/31/22. This funding will allow NCAT to continue the research started with this project.

References

Achmon, Y., D.R. Harrold, J.T. Claypool, J.J. Stapleton, J.S. VanderGheynst, and C.W. Simmons, 2016. Assessment of major California fruit processing residues as soil amendments for biosolarization. Waste Management 48: 156-164.

Achmon, Y., J.D. Fernández-Bayo, K. Hernandez, D.G. McCurry, D.R. Harrold, J. Su, R.M. Dahlquist-Willard, J.J. Stapleton, J.S. VanderGheynst, C.W. Simmons. 2017. Weed seed inactivation in soil mesocosms via biosolarization with mature compost and tomato processing waste amendments. Pest Management Science, 73 (2017), pp. 862-873

Achmon Yigal, Joshua T. Claypool, Jesús D. Fernández-Bayo, Katie Hernandez, Dlinka G. McCurry, Duff R. Harrold, Joey Su, Blake A. Simmons, Steven W. Singer, Ruth M. Dahlquist-Willard, James J. Stapleton, Jean S. VanderGheynst, Christopher W. Simmons. (2020) Structural changes in bacterial and fungal soil microbiome components during biosolarization as related to volatile fatty acid accumulation. Applied Soil Ecology, Volume 153.

Butler, D.M., E.N. Rosskopf, N. Kokalis-Burelle, J. P. Albano, J. Muramoto, and C. Shennan. 2012. Exploring warm-season cover crops as carbon sources for anaerobic soil disinfestation (ASD). Plant and Soil 355:149-165.

Domínguez, P., Miranda, L., Soria, C. et al. 2014. Soil biosolarization for sustainable strawberry production. Agronomy for Sustainable Development 34, 821–829 (2014)

Elmore C. L., Stapleton J. J., Bell C. E., DeVay J. E. (1997). ***Soil Solarization, a Nonpesticidal Method for Controlling Diseases, Nematodes and Weeds.*** Oakland, CA: University of California.

Fernández-Bayo Jesús D., Emily A. Shea, Amy E. Parr, Yigal Achmon, James J. Stapleton, Jean S. VanderGheynst, Amanda K. Hodson, Christopher W. Simmons. 2020. Almond processing residues as a source of organic acid biopesticides during biosolarization, Waste Management, Volume 101, 2020, Pages 74-82.
https://www.sciencedirect.com/science/article/pii/S0956053X19306075

Fernández-Bayo, J.D., T.E. Randall, D.R. Harrold, Y. Achmon, K.V. Hestmark, J. Su, R.M. Dahlquist-Willard, T.R. Gordon, J.J. Stapleton, J.S. VanderGheynst, C.W. Simmons. 2018. Effect of management of organic wastes on inactivation of Brassica nigra and Fusarium oxysporum f.sp. lactucae using soil biosolarization Pest Management Science (2018).

Fernández-Bayo Jesús D., Yigal Achmon, Duff R. Harrold, Joshua T. Claypool, Blake A. Simmons, Steven W. Singer, Ruth M. Dahlquist-Willard, James J. Stapleton, Jean S. VanderGheynst, Christopher W. Simmons (2017). Comparison of soil biosolarization with mesophilic and thermophilic solid digestates on soil microbial quantity and diversity. Applied Soil Ecology, Volume 119, 2017, Pages 183-191.

Hestmark, K.V., J.D. Fernández-Bayo, D.R. Harrold, T.E. Randall, Y. Achmon, J.J. Stapleton, C.W. Simmons, J.S. VanderGheynst. 2019. Compost induces the accumulation of biopesticidal organic acids during soil biosolarization. Resources, Conservation and Recycling, Volume 143, 2019, P. 27-35.

Kanaan, Housam., Sammy Frenk, Michael Raviv, Shlomit Medina, Dror Minz. 2018. Long- and short-term effects of solarization on soil microbiome and agricultural production, Applied Soil Ecology, Volume 124, 2018, Pages 54-61.

López-Martínez N, Castillo S, Aguirre I, González-Zamora JE, Ávila C, López-Medina J (2006) Effect of biofumigation on typical weeds of strawberry fields. Acta Hort 708:193–196.

Momma, N., Biological soil disinfestation (BSD) of soilborne pathogens and its possible mechanisms. Japan Agricultural Research Quarterly (2008)
https://www.jstage.jst.go.jp/article/jarq/42/1/42_7/_article

Momma, N., Yamamoto, K., Simandi, P. et al. 2006. Role of organic acids in the mechanisms of biological soil disinfestation (BSD). J Gen Plant Pathol 72, 247–252 (2006).
https://doi.org/10.1007/s10327-006-0274-z

Stapleton, James J. , Ruth M. Dahlquist-Willard, Yigal Achmon, Megan N. Marshall, Jean S. VanderGheynst, and Christopher W. Simmons. "Advances in Biosolarization Technology to Improve Soil Health and Organic Control of Soilborne Pests". ***Proceedings of the Organic Agricultural Research Symposium, 2016. http://eorganic.info/sites/eorganic.info/files/u27/1.1.2-Stapleton-Biosolarization-Final.pdf***

Photos

Biosolarization and Solarization trials at Fiery Ginger Farms in West Sacramento, California.

Biosolarization and Solarization trials at Castlerock Farms in Walnut Creek, California

Setting up trials at Polestar Farm in Esparto California.