Optimization of steam soil disinfestation for healthy soils and communities around the ag-urban interface of coastal California

- *A new project to control soilborne diseases and weeds by developing and demonstrating alternatives to pre-plant soil fumigation in strawberry.*
- *Funded by CDFA to demonstrate a biologically integrated farming system (BIFS) for strawberry.*
- *The CSC and Cal Poly also contributed federal funds to the USDA ARS to support the building of the new self propelled strawberry soil steam applicator, thanks to support from US Congressmen Panetta and Carbajal.*

cdfa

CALIFORNIA STRAWBERRIES

USDA Agricultural Research Service

CAL POLY | Strawberry Center

Management Team

- Jenny Broome, UC Santa Cruz, Program manager, plant disease assessments.
- Steve Fennimore, Smart Steam Applications for Agriculture LLC, soil steam disinfestation machine fabrication and operation, weed impact assessment.
- Peter Henry, USDA ARS Salinas, soilborne pathogen quantification, USDA ARS fund manager for steam machine manufacturing.
- Bill Turechek, CSC statewide grower communication, research, outreach.
- Mark Bolda, UCCE SC, SB, Mont. on-farm demos, replicated trials, outreach.
- Oleg Daugovish, UCCE Ventura on-farm demons, replicated trials, outreach
- Nicholas LeBlanc, USDA ARS Salinas, soil microbiome analysis.
- Rachael Goodhue, UC Davis, cost/benefit analysis, grower surveys, focus groups.
- David Sanford, Santa Cruz CAC, regulatory & community
- Rod Koda, Shinta and Kawahara Farms, mentor grower
- Mike Stanghellini, Research collaborator, Trical Inc.

Main focus

- **Four main soilborne diseases:** Fusarium wilt (*Fusarium oxysporum* f. sp. *fragariae*) race 1 & 2, Macrophomina charcoal rot (*Macrophomina phaseolina*), Verticillium wilt (*Verticillium dahliae*), and Phytophthora root rot (*Phytophthora cactorum*).

- **Weeds** reduce strawberry yields by competition for nutrients and light. Annual weeds (little mallow, bur clover, sweet clover, filaree, hairy fleabane, annual sowthistle, common groundsel) and perennial (yellow nutsedge) weeds.

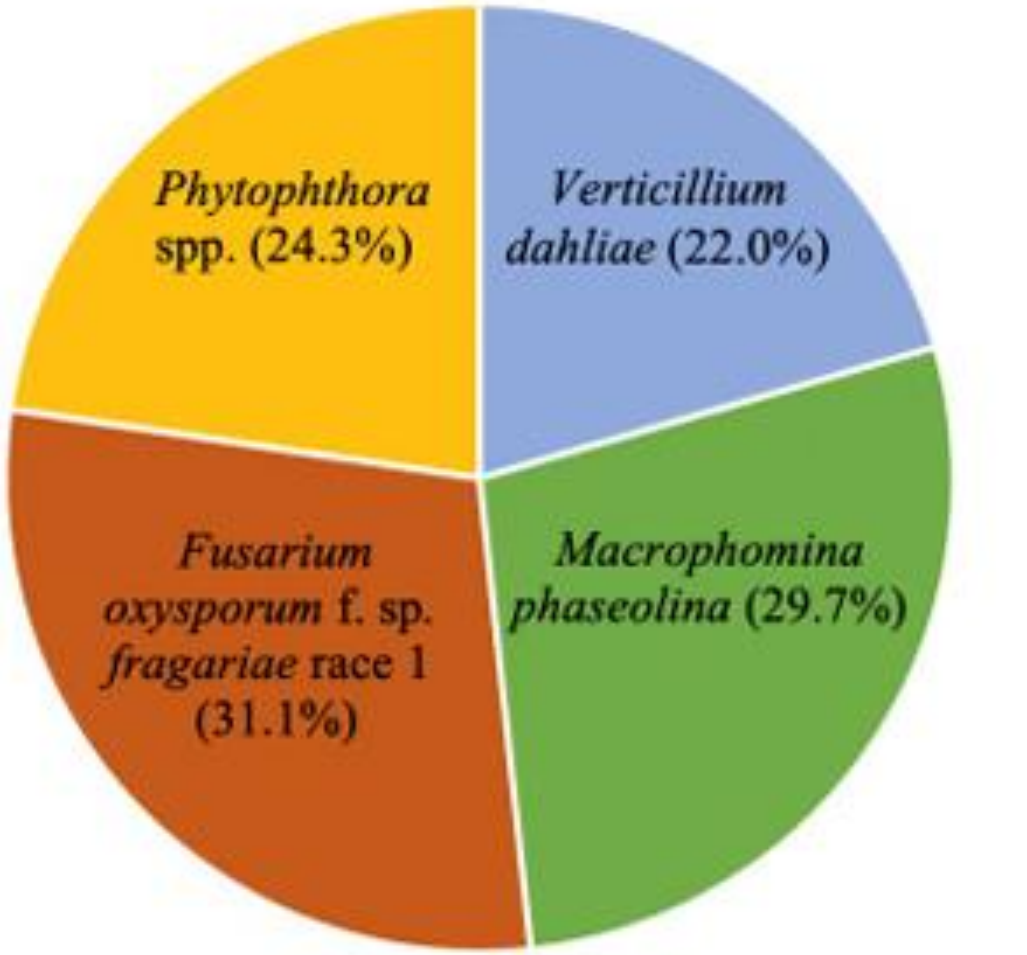
- **Costs:** $95,613/acre for conventional soil grown strawberries, and $103,445/acre for organic soil grown strawberry. Broadcast fumigation 1.5 to 2 acres per hour for a cost of $5,000/acre. Hand weeding costs in organic strawberry are $5,372/A per season (Bolda et al. 2024).

The 2025 California strawberry biologically integrated farming system

1. Use a field's disease history and rapid pre-plant soil pathogen quantification and assessment of beneficial microbial communities.
2. Use pre-plant soil steam disinfestation to reduce risk of crop loss on fields near sensitive sites (schools, daycare, eldercare facilities).
3. Plant the most appropriate disease resistant variety possible based on past disease and current pathogen(s) in a field and grower and shipper other priorities (yield, flavor, post harvest shelf life, etc.).
4. Increase biological diversity on farms through strategic rotations with broccoli and other beneficial crops based on a field's past disease history and soil pathogen profiles. Plant of non-crops (field edges, roads, etc.) where it is beneficial for pest management and resource conservation (water quality). Assess if any holdover effect of soil steam treatment for later crop rotation partners.

Watsonville-Salinas District soilborne pathogen survey, 2021 by the Cal Poly Strawberry Center

Macrophomina
Fusarium race 1
Verticillium
Phytophthora

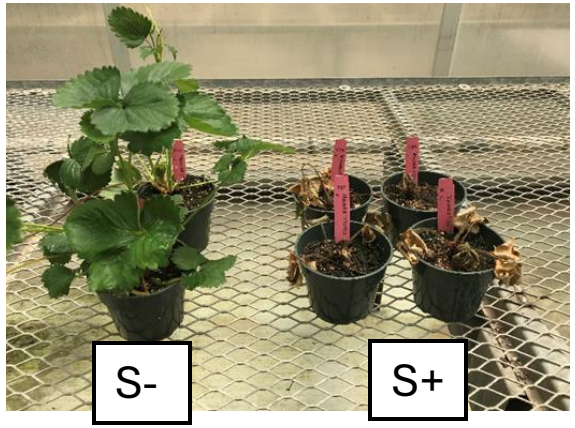


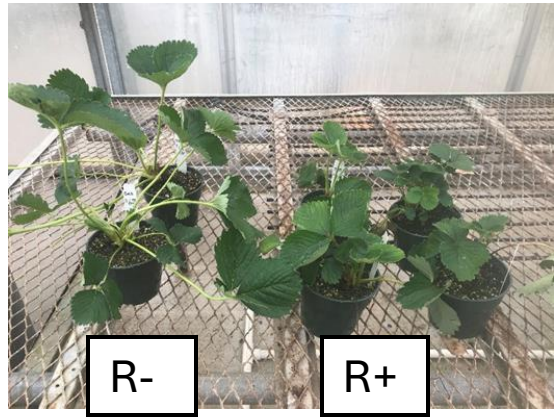
Watsonville-Salinas District (Aug - Oct 2021)

74 plant samples
33% of 2020 fall-planted acreage

UC Davis varieties and susceptibility to soilborne pathogens

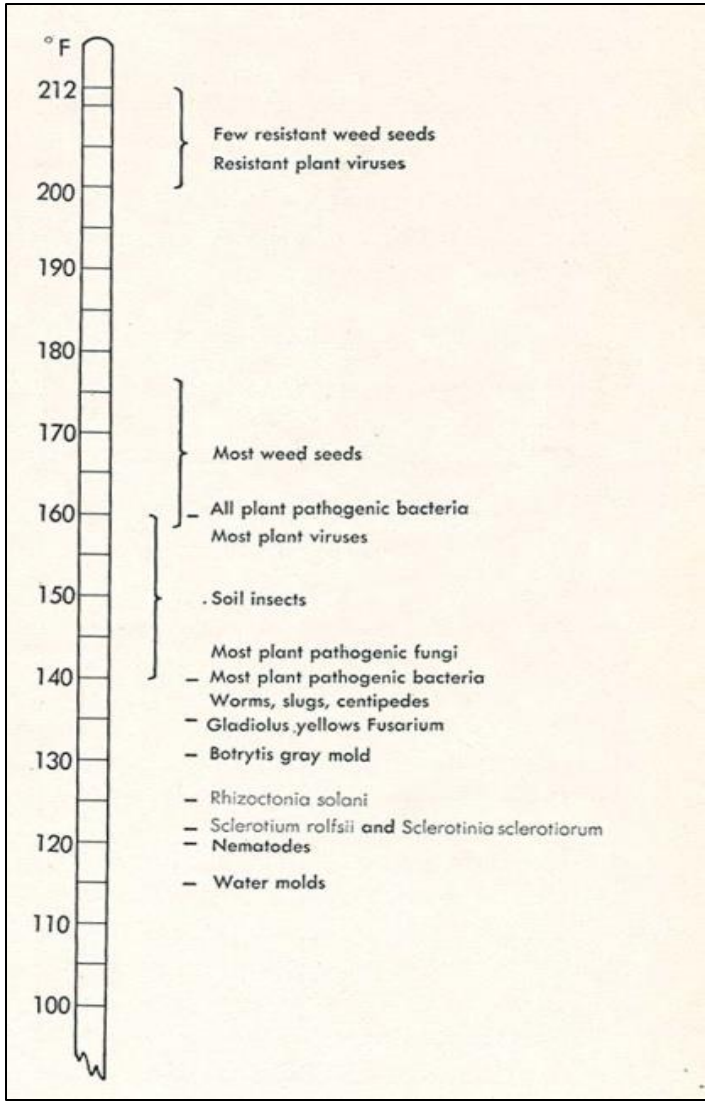
Variety	Type	Macrophomina	Verticillium	Fusarium	Phytophthora
Monterey	DN	4	3	4	3
Albion	DN	4	2	4	4
UCD Finn	EDN	4	3	4	2
Merced	SD	4	3	4	2
Cabrillo	DN	4	2	4	3
UCD Royal Royce	DN	3	2	4	3
UCD Valiant	DN	3	2	4	2
UCD Mojo	EDN	2	2	4	3
Petaluma	SD	3	2	3	3
UCD Moxie	DN	4	2	1	3
San Andreas	DN	4	2	1	3
Portola	EDN	4	3	1	2
UCD Victor	SD	3	3	1	2
UC Eclipse	EDN	4	2	1	2
UCD Warrior	SD	2	3	1	2
UC Monarch	SD	3	2	1	2
UC Keystone	DN	3	2	1	2
UC Golden Gate	DN	3	2	1	2
Fronteras	SD	3	2	1	2
UC Surfline	SD	3	2	1	1





Mobile soil steam pasteurization

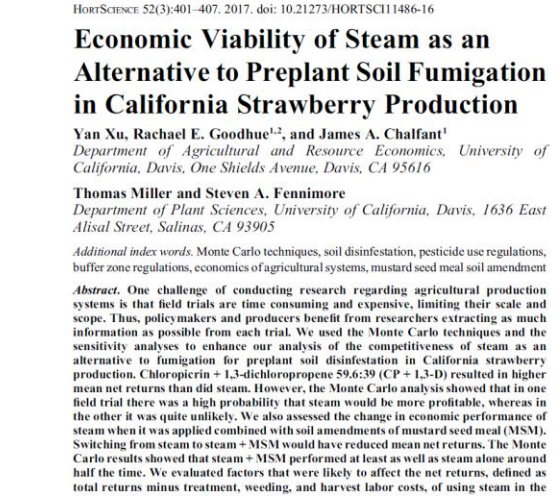
- Thermal death temperature for pests is known.
- It is soil pasteurization, NOT sterilization.
- Microbial re-colonization of simplified soil community with thermophilic species , many biocontrol/growth promoting organisms.
- Nitrogen release into soil is significant.
- Broadcast vs. bed vs. spike – effectiveness vs. efficiency
- Depth of treatment important for soilborne pests
- Speed, cost, carbon footprint.



K.F. Baker, 1957

Strawberry pre-plant trials – Soil steam disinfestation

- **TARGET:** 20 – 30 mins. at 65-70°C (149- 158°F) down to 12 inch (30 cm) = weed and pathogen kill. Cost $3,500 to $5,000/A, Speed 8 hr/A.
- Started in 2011-2012 with Steve Fennimore, UC Davis collaborating with Driscoll's Inc. and RAC's Nathan Dorn.
- **Prototype I.** Bed treating mobile marine boiler & steam shanked into soil and mixed by rototiller. Unit is pulled by tractor, fueled by propane, water held in tanks and drawn into boiler via hose. Blanket holds steam in beds.
- **Prototype II–** Bed treatment but with hot vapor/air, based on fracking technology, but **did not control weeds, abandoned**.
- **Prototype III** – Back to real steam, broadcast/flat treatment, focus on strawberry nursery use, also fruit production.
- **Prototype IV – Self-propelled steam applicator with ability to treat flat, bed and spike holes into beds.**



HortScience 52(3):401–407. 2017. doi: 10.21273/HORTSCI11486-16

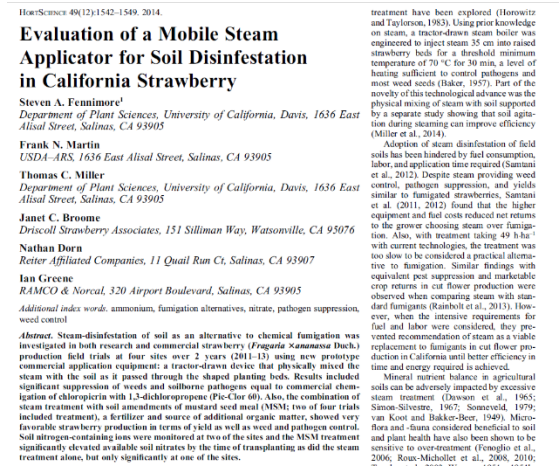
Economic Viability of Steam as an Alternative to Preplant Soil Fumigation in California Strawberry Production

Yan Xu, Rachael E. Goodhue[1,2], and James A. Chalfant[1]
Department of Agricultural and Resource Economics, University of California, Davis, One Shields Avenue, Davis, CA 95616

Thomas Miller and Steven A. Fennimore
Department of Plant Sciences, University of California, Davis, 1636 East Alisal Street, Salinas, CA 93905

Additional index words. Monte Carlo techniques, soil disinfestation, pesticide use regulations, buffer zone regulations, economics of agricultural systems, mustard seed meal soil amendment

Abstract. **One challenge of conducting research regarding agricultural production systems is that field trials are time consuming and expensive, limiting their scale and scope. Thus, policymakers and producers benefit from researchers extracting as much information as possible from each trial. We used the Monte Carlo techniques and the sensitivity analyses to enhance our analysis of the competitiveness of steam as an alternative to fumigation for preplant soil disinfestation in California strawberry production. Chloropicrin + 1,3-dichloropropene 59.6:39 (CP + 1,3-D) resulted in higher mean net returns than did steam. However, the Monte Carlo analysis showed that in one field trial there was a high probability that steam would be more profitable, whereas in the other it was quite unlikely. We also assessed the change in economic performance of steam when it was applied combined with soil amendments of mustard seed meal (MSM). Switching from steam to steam + MSM would have reduced mean net returns. The Monte Carlo results showed that steam + MSM performed at least as well as steam alone around half the time. We evaluated factors that were likely to affect the net returns, defined as total returns minus treatment, weeding, and harvest labor costs, of using steam in the**



HortScience 49(12):1542–1549. 2014.

Evaluation of a Mobile Steam Applicator for Soil Disinfestation in California Strawberry

Steven A. Fennimore[1]
Department of Plant Sciences, University of California, Davis, 1636 East Alisal Street, Salinas, CA 93905

Frank N. Martin
USDA–ARS, 1636 East Alisal Street, Salinas, CA 93905

Thomas C. Miller
Department of Plant Sciences, University of California, Davis, 1636 East Alisal Street, Salinas, CA 93905

Janet C. Broome
Driscoll Strawberry Associates, 151 Silliman Way, Watsonville, CA 95076

Nathan Dorn
Reiter Affiliated Companies, 11 Quail Run Ct, Salinas, CA 93907

Ian Greene
RAMCO & Norcal, 320 Airport Boulevard, Salinas, CA 93905

Additional index words. ammonium, fumigation alternatives, nitrate, pathogen suppression, weed control

Abstract. **Steam-disinfestation of soil as an alternative to chemical fumigation was investigated in both research and commercial strawberry (*Fragaria ×ananassa* Duch.) production field trials at four sites over 2 years (2011–13) using new prototype commercial application equipment: a tractor-drawn device that physically mixed the steam with the soil as it passed through the shaped planting beds. Results included significant suppression of weeds and soilborne pathogens equal to commercial chemigation of chloropicrin with 1,3-dichloropropene (Pic-Clor 60). Also, the combination of steam treatment with soil amendments of mustard seed meal (MSM; two of four trials included treatment), a fertilizer and source of additional organic matter, showed very favorable strawberry production in terms of yield as well as weed and pathogen control. Soil nitrogen-containing ions were monitored at two of the sites and the MSM treatment significantly elevated available soil nitrates by the time of transplanting as did the steam treatment alone, but only significantly at one of the sites.**

treatment have been explored (Horowitz and Taylorson, 1983). Using prior knowledge on steam, a tractor-drawn steam boiler was engineered to inject steam 35 cm into raised strawberry beds for a threshold minimum temperature of 70 °C for 30 min, a level of heating sufficient to control pathogens and most weed seeds (Baker, 1957). Part of the novelty of this technological advance was the physical mixing of steam with soil supported by a separate study showing that soil agitation during steaming can improve efficiency (Miller et al., 2014).

Adoption of steam disinfestation of field soils has been hindered by fuel consumption, labor, and application time required (Samtani et al., 2012). Despite steam providing weed control, pathogen suppression, and yields similar to fumigated strawberries, Samtani et al. (2011, 2012) found that the higher equipment and fuel costs reduced net returns to the grower choosing steam over fumigation. Also, with treatment taking 49 h ha^{-1} with current technologies, the treatment was too slow to be considered a practical alternative to fumigation. Similar findings with equivalent pest suppression and marketable crop returns in cut flower production were observed when comparing steam with standard fumigants (Rainbolt et al., 2013). However, when the intensive requirements for fuel and labor were considered, they prevented recommendation of steam as a viable replacement to fumigants in cut flower production in California until better efficiency in time and energy required is achieved.

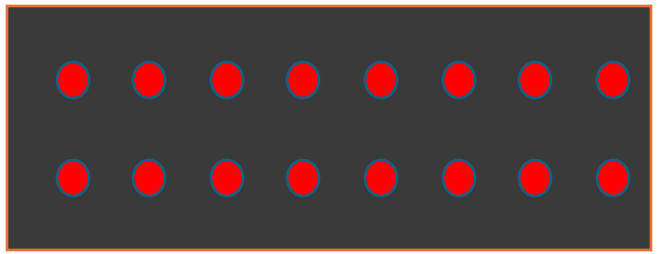
Mineral nutrient balance in agricultural soils can be adversely impacted by excessive steam treatment (Dawson et al., 1965; Simon-Silvestre, 1967; Sonneveld, 1979; van Koot and Bakker-Beer, 1949). Microflora and -fauna considered beneficial to soil and plant health have also been shown to be sensitive to over-treatment (Fenoglio et al., 2006; Roux-Michollet et al., 2008, 2010;

Steam patterns

Broadcast

Bed

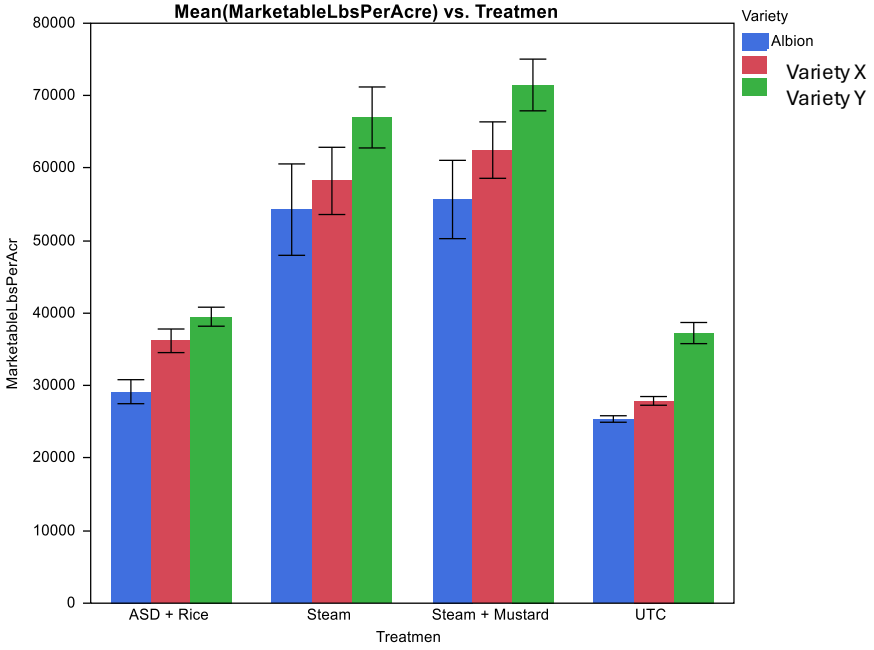
Band



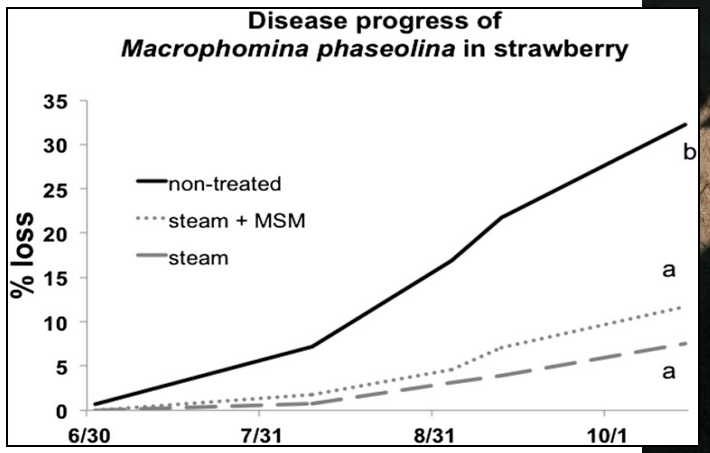
Spot

PROTOTYPE I - 2011-2016 - Bed injection

- Initial research by UC Davis with Reiter, Driscoll's and Valley Fabrication
- Tractor drawn, propane tanks on tractor and hose from water tank
- Yields increased, less disease, weeds



Trial 2012-13, Watsonville



Fennimore et al 2013, 2007-2013 in 13 field trials, steam & fumigants yielded 145-150% of untreated

PROTOTYPE III 2018-2020 – Broadcast injection - nursery & fruit

- Large, very heavy machine.
- Injected steam with a Northwest reverse tiller 10 ft (3 m) wide swath by 10-12 inches deep, 13.7 hr/A
- Target depth 30 cm (12 in)
- Costs $4,050/A

Nursery Plants:

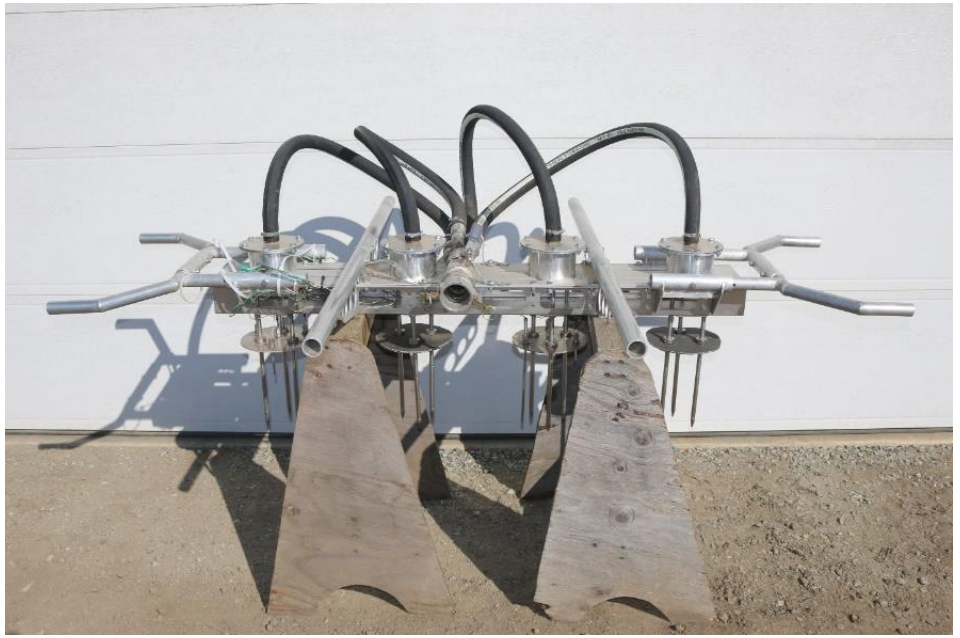
Treatment	Rate	Weed densities	Verticillium	Nematodes	Daughter plants
	G m^{-2}	Number/A	% viable	#/50 g	Number/A
MBPic 45:55	50	9308 a	0	10.8	348,026
MBPic 57:43	40	27518 a	2.5	2.0	267,089
Steam		16997 a	0	17.0	323,745

Fruit Yield & Disease:

- Yield increased 178% with steam over UTC
- 5% Macrophomina with steam vs. 28% UTC

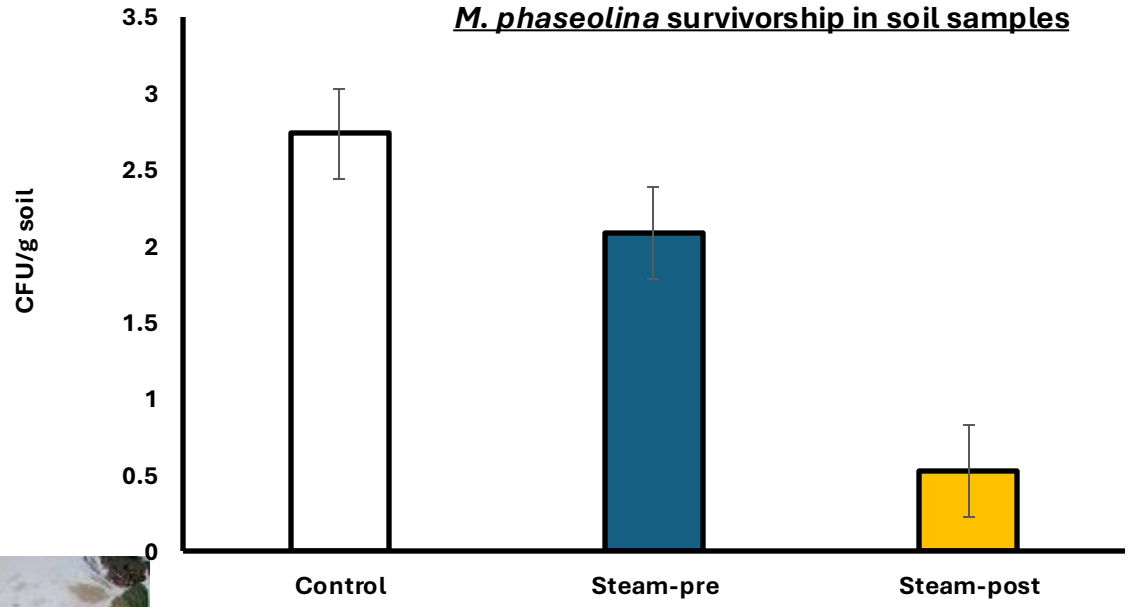
New precision spike steam injection through mulch into strawberry beds (**research unit**).

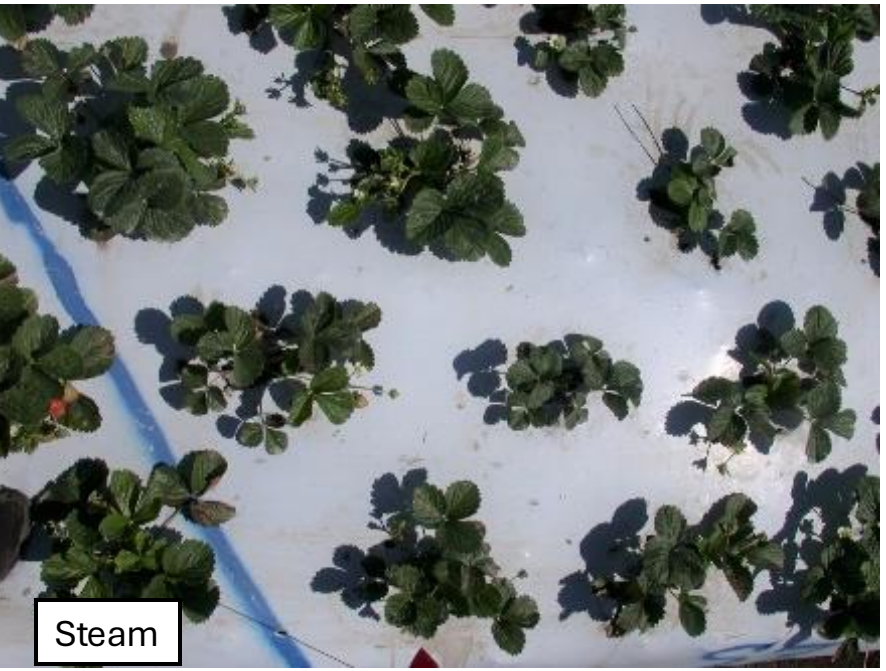
- Pre-plant soil steam disinfestation has shown impressive results.
- We need to make it faster and less expensive. **Now testing a "just enough" soil treatment = precision bed hole steaming = 8-inch diameter and 8-inch depth.**
- Started in 2022 with Reiter, Driscoll's Inc., UCCE, & USDA ARS with summer plant trial in Ventura County.
- Trialed in 2022-2023 winter plant in Santa Cruz and Monterey Counties, and in 2023-2024 in winter plant in Ventura County.



Pre-plant precision spike soil steam pasteurization through mulch

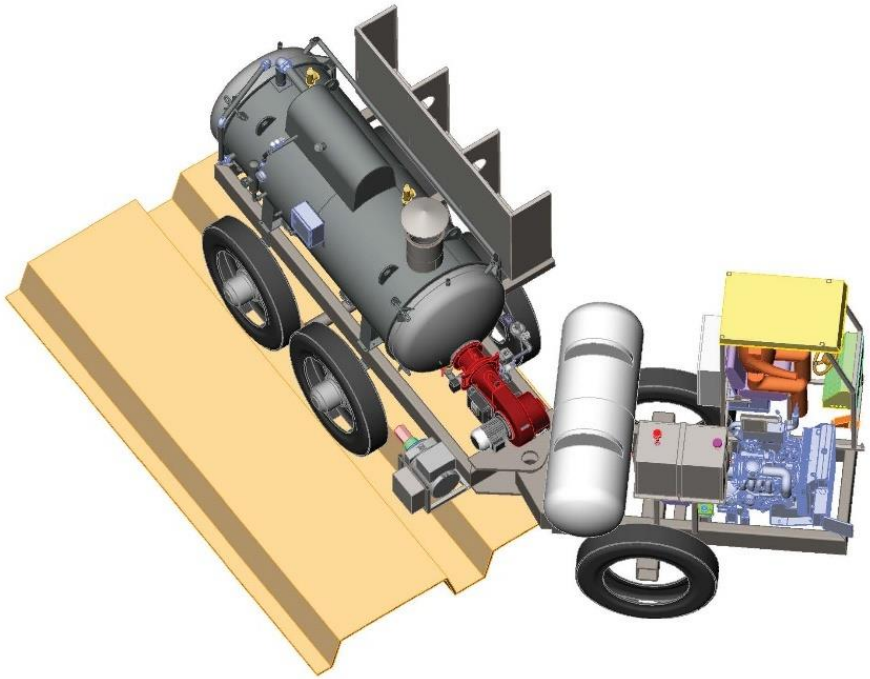
- Oxnard organic summer plant 2022
- **75% plant mortality in non-steamed plots and 17% in steamed plots due to Macrophomina**
- **Steamed plots yielded 20X higher** in grams of fruit per plot.





PROTOTYPE IV - New strawberry design, February 2025

- A self-propelled steam applicator being built to inject steam into the soil 3 ways - **bed, spike & broadcast.**
- Steam applicator has an articulated chassis on 6 wheels to clear strawberry beds.
- Mounted on the chassis is a Simox steam generator and a Kubota engine.
- Engine and steam generator fueled by propane.
- Propane and water carried on the applicator; enough to treat ½ an acre before refueling or adding more water.



Vegetable band steam applicator 2024 Monterey County trials

- Fennimore and collaborators built a self-propelled vegetable bed band applicator (4-in depth x 6-in width).
- In lettuce field with 1,420 ft runs the operation speed was 3.07 hours per acre & treated one 80” bed per pass
- Costs per acre:

Fuel	$319.41
Labor	$138.15
Machine	$150.09
Total	$607.65

- Steam suppresses Fusarium best at 90°C
- Steam suppresses weeds, lettuce drop & Verticillium
- Cost estimate can likely be reduced by more efficient water handling equipment and wider treatment width.

Crop rotation and cover crops

- Rotate out of strawberries for at least two seasons.
- Rotation with broccoli where you can harvest a crop, incorporate residues will help reduce *V. dahliae* inoculum.
- Incorporate cover crops, either grains (rye, barley) or mustards which can improve soil structure with dense stands to outcompete weeds.
- Long-term use of soil amendments can improve soil biology, soil structure, and drainage.

Chop, air dry and incorporate all plant residue left after harvest, can reduce microsclerotia by half.

How does steam influence the soil microbiome?

The soil microbiome can have beneficial effects on crop and soil health.

Suppress soilborne diseases

Mediate soil nutrient cycling

Increase crop growth and abiotic stress tolerance

Research will focus on how steam influences the soil microbiome and how these changes relate to strawberry health.

How fast does the soil microbiome recover post-steaming?

Does steam have positive or negative effects on beneficial microbes in the soil microbiome?

Is variation in the soil microbiome across California correlated with improved strawberry production?

Thank you for listening, please tell us what you think about this proposed work and help guide it.

- Questions or follow up please contact any of the collaborators you know, or myself at Jenny Broome, jabroome@ucsc.edu, 831 254 8962

Thank you to our funders:

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