CALIFORNIA LEAFY GREENS RESEARCH PROGRAM

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SOIL DISINFESTATION WITH STEAM FOR LEAFY GREENS

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ABSTRACT

Steam injected into soil so that temperatures reach 158°F for 15-20 minutes will control most soilborne pathogens and weed seed in the treated zone. We built and evaluated Band Steamer 2022 (second version of a band steam applicator) and verified the performance of the machine. Band steaming in lettuce reduced hand weeding times and suppressed *Fusarium* spp. Steam applied before planting is classified as a sanitation treatment for organic fields. Steam disinfestation of lettuce and spinach beds could reduce risk of loss due to soilborne diseases and lower hand weeding costs by over 80%. Steam treatment of soil causes no significant damage to beneficial soil microbial communities and favors beneficial organisms such as the Firmicutes.

OBJECTIVE

Evaluate soil disinfestation with steam in lettuce for control of soilborne diseases and weeds in the lettuce seedline.

PROCEDURES

Commercial evaluation

Three trials were initiated in 2023 with the primary objective of evaluating the impact of band steam treatment on weed control and soilborne pathogens in lettuce fields. Our focus was to assess the efficacy of the steam applicator as a potential alternative to fumigation for managing soilborne pests in lettuce fields.

Methods Band Steamer. Two treatments consisting of band steam and a no-steam control were evaluated in all trials. The Band Steamer 2022 used for the trials was built at the Keithly-Williams shop in Yuma, AZ (Fig. 1). Three trials were conducted in a single commercial field on three different Romaine plantings near Soledad, CA (Table 1). Steam was applied to six 4-inch wide bands on two 80 inch beds by 1,200 ft long at each trial date. Within each bed, two sections

30 ft long were not steamed to serve as control treatments. Weed counts for the three lettuce trials were collected two to three weeks after planting. Weed counts were recorded for every bed. Soil samples were collected before (pre-) and after (post-) steam application and subjected to a preliminary analysis of *Fusarium* density by soil dilution plating on Komada's semi-selective medium. This analysis is considered categorical (qualitative) because: i) fewer plates were used than standard dilution plating; and b) generic *Fusarium* spp. was assessed and not *F. oxysporum* f. sp. *lactucae.*

Figure 1. Version 2022 steam applicator treating soil at the Salinas Field Station June 2023.

Table 1. Critical dates for Soledad, CA trials.

Trial	Crop	Steam application	Planting	Weed density ratings	Pre Soil Sample	Post Soil Sample
1	Lettuce	6.16.23	6.25.23	7.19.23 7.31.23	6.16.23	6.17.23
2	Lettuce	6.30.23	7.5.23	7.19.23 7.27.23 7.31.23	6.29.23	6.30.23
3	Lettuce	6.28.23	7.7.23	7.31.23 8.7.23	6.28.23	6.29.23

Table 2. Weed densities at Soledad, CA one month after steam treatment.

Treatments	Lettuce trial 1[ii]	Lettuce trial 2[iii]	Lettuce trial 3[ii]
	(No. weeds/A)		
Steam	36.1 b	459.8 b	67.7 b
Control	381.5 a	2743.4 a	305.1 a
P Value	0.0002 *	<0.0001 *	0.0102 *

[i]Mean separation by Fisher's Protected LSDs. Means followed by the same letter within columns do not differ significantly at 5% level.

Table 3: Effect of steam on *Fusarium* spp. colony forming units (CFU/g) per gram of soil in Romaine plantings at Soledad.

Treatment	Trial 1	Trial 2	Trial 3
		CFU/g	
Pre-Steam	5597.0 a	3952.6 a	3502.2 a
Post-Steam	337.7 b	168.9 b	402.9 b
Treatment Prob (F)	0.001	0.001	0.001

Analysis of the data in lettuce trials 1, 2, and 3 showed that steamed plots had lower weed densities (Table 2). Marketable yield was obtained from trial 2, and although yield was numerically higher yield in the steam treatment (33.3 tons/acre) compared to control (29.1 tons/acre), this difference ($P = 0.1030$) was not statistically significant. Steam reduced generic Fusarium spp. CFU/g of soil by 89 to 96% (Table 3). No Fusarium wilt symptoms were observed in the field.

Evaluation of band dimensions

The width and depth of the band steam zone were evaluated August 2023 at the Hartnell College field site near Salinas. Band zone treatments were (width x depth in inches): 1) 4W x 3D; 2) 4W x 5D; 3) 5W x 3D; and 4) 5W x 5D. Plots were one 40" bed by 120 ft., and arranged in a randomized complete block design with four replications. Steam was applied on August 29, and 30, 2023, using Band Steamer 2022 (Fig. 1). Soil temperatures were monitored using Hobo temperature recorders placed within 30 seconds after steaming at a depth of 4 inches. Romaine was seeded on August 31, 2023. Soil samples were collected and analyzed for impact on beneficial soil microorganisms. Weed densities and hand weeding times were measured in the treated bands on Sept. 19, and 21, 2023, respectively. Lettuce was harvested November 14 and 20, 2023. Data were analyzed in Agricultural Research Manager.

Soil Sampling. Soil samples were gathered from the steam treatments a day before steaming then 1 and 30 days after steaming for 16S sequencing. Soil samples were taken from the top 4 inches of the soil to determine the abundance of bacterial diversity. Two subsamples were collected from two points in the lettuce bed, 40 and 80 feet from the plot's perimeter, and then compositing them into a single bag, with a total of 4 soil samples for both control and steam treatments. The enzyme assays analyzed all soil samples for all three time points.

Enzyme Analysis. The Enzyme Activity Protocol involves preparing soil samples for enzyme analysis by determining soil water content and pH, and selecting appropriate buffers. Substrate and standard solutions are prepared and stored with precautions to prevent light exposure. On the first day, soil slurries are created and distributed into labeled deep well plates. Standards and substrates are pipetted into wells and incubated at room temperature for 3 hours. Post-incubation, samples are centrifuged, transferred to black 96 well plates, and fluorescence is measured using a

fluorometer. Data analysis involves calculating enzyme activity based on fluorescence readings, incubation time, and soil dry weight, with results expressed in nmol/g dry soil/hr.

Results. Soil temperatures were significantly higher when injected 5 inches deep than at 3 inches (Fig. 2). Overall, weed densities were significantly lower in the steam treated beds compared to the non-treated beds (P = 0.001) (Table 4). Hand weeding times in the steam treatments were similar, but significantly lower than the Kerb and control treatments (Table 4). Lettuce vigor in the 4W x 5D, 5W x 3D and 5W x 5D treatments was higher than the other treatments. There were no differences in lettuce yields. Our preliminary results suggest that for lettuce, steam should be injected 5 inches deep for best results in holding temperatures at critical levels.

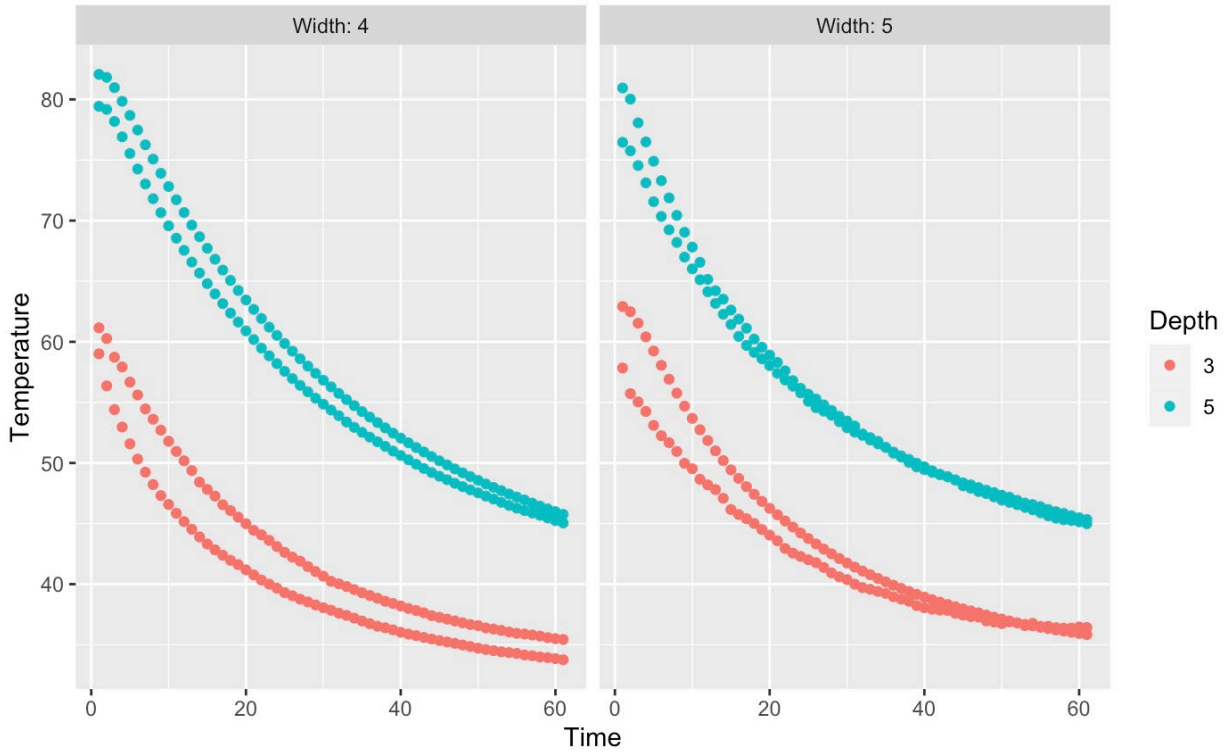

Figure 2. Plots of the soil temperatures when steam was injected in band widths of 4 or 5 inches at depths of 3 inches (red) or 5 inches (blue) at the Hartnell College plots August 29 and 30, 2023.

Table 4. Weed densities, hand weeding times and lettuce vigor estimates.

Treatment	Rate	Weeds #/ft.^{2}	Hand weed Hour/A	Vigor 1=poor, 10=good
Control		67 a	121 a	7.5 c
Kerb	3.5 pt./A	29 b	68 b	7.6 c
Steam	4”W x 3”D	6 c	23 c	7.6 c
Steam	4”W x 5”D	3 c	26 c	8.8 ab
Steam	5”W x 3”D	4 c	23 c	8.4 b
Steam	5”W x 5”D	2 c	18 c	9.1 a

While some beneficial microbes were negatively affected by the steam treatment, there were also increases in other beneficial microbes. These results highlight the dynamic responses of soil microbial communities to steam treatments and the potential for recovery over time. More timepoints would clarify whether there is potential for close to full recovery of soil microbiome. Next steps are to graph the functional diversity of the soil microbiome to investigate if ecosystem stability is maintained after steam treatments.

Conclusions. The band steam applicator reduced pathogens in the soil and weed densities as well as hand weeding times compared to the no steam control. Steam bands 4 inches wide by 5 inches deep provided the best combination of weed and disease control. Where disease pressure is high as we saw in 2021, then we see yield benefits from steam. Some beneficial soil microorganisms such as the Firmicutes were enhanced by steam treatment. Steam does not appear to cause damage to the beneficial soil microbial community.