SOIL DISINFESTATION WITH STEAM IN CALIFORNIA STRAWBERRY PRODUCTION

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Summary Reported here are weed and pathogen control results with steam as well as fruit yields over four strawberry production seasons (2011/12, 2012/13, 2013/14 and 2014/15). Steam was applied by a proto-type tractor towed steam machine with a Clayton steam generator. We discuss the efficacy of steam compared to chemical and non-chemical soil disinfestation methods in California. Steam controls weeds and soil borne pests and strawberry yields usually increase with steam up to 20 % compared to common non-chemical pre plant soil disinfestation treatments in CA. Our results suggest that these steam induced benefits are due to combined effects of extra nutrient release and reduction of pathogen pressure. We are currently separating those effects in controlled experiments. Furthermore we investigate steam induced changes in soil microbial community and the utilization of steam in combination with allyl isothiocyanate (AITC) and cover crops as management tool. A commercial flat field steam applicator is being manufactured in cooperation with industry.

Methods From 2011 – 2014, steam was applied with a prototype steam applicator (tractor-towed wagon with a propane-fueled Clayton 100 HP steam generator, Figure 1). This prototype was built to treat shaped beds and is able to increase soil temperatures to ca. 70 °C. Steam was injected and mixed into the soil through a bed shaper equipped with two rototillers, each with 24 steam injection tines. All field trials were conducted in a randomized complete block design with minimum four replications. To assess the efficacy on weed control, weed densities were assessed in all field trial. To assess pathogen control, *Verticillium dahliae* or *Pythium ultimum* (depending on field trial) levels were assessed before (pre) and after (post) treatments. Yield data were gathered throughout the season.

Field trials 2011/12: a. Salinas, CA (Spence): steamed on 12. and 13. Oct 2011 *b.* Watsonville, CA (MBA): steamed on 25. Oct. Following treatments were installed at both sites: (1) Steam, (2) Pic-Clor 60 (280/392 kg/ha Spence/MBA respectively), (3) Non-treated. Pic Clor 60 was applied at 280/392 $kg \cdot ha^{-1}$ in Salinas/Watsonville, respectively.

Field trial 2012/13: a. Watsonville, CA (TCR): Steam was applied on 6. and 7. Sep 2012. Following treatments were installed: (1) Steam, (2) Steam + MSM (3000 lbs/a) (3) Anaerobic Soil Disinfestation (ASD) + Rice Bran (9 tons/a), (4) Non-treated.

Field trial 2013/14: a. Salinas, CA (Mc Fadden): Steam was applied on 28. and 29. Sep 2013. Following treatments were installed: (1) Steam, (2) Steam +

Mustard Seed Meal (MSM) (3000 lbs/a), (3) Steam + Crab Meal (2000 lbs/a), (4) MSM (3000 lbs/a), (5) Crab Meal (2000 lbs/a), (6) ASD, (7) Non-treated.

Field trials 2014/15: a. Salinas, CA (Spence): Steam was applied on 26., 29. and 30. Sep 2014. Following treatments were established: (1) Steam, (2) Steam + MSM (2000 lbs/a), (3) Non-treated. *b.* Salinas, CA (Fuji): Steam was applied on 4. and 6. Oct 2014. Following treatments were established: (1) Steam + MSM (2000 lbs/a), (2) Rice bran (9 tons/a), (3) ASD + Rice bran (9 tons/a), (4) Non-treated. *c.* Watsonville, CA (TCR): Steam was applied at 10. and 12. Oct 2014. Following treatments were established: (1) Steam + MSM, (2) Non-treated.

Results We compare weed/pest control efficacy and yield of selected steam field trials conducted in the strawberry production seasons 2011/12 – 2014/15 in the Salinas/Watsonville area in California. We focus on comparison between treatments of steam, shank applied Pic-Clor 60, anaerobic soil disinfestation (ASD) and mustard-seed-meal (MSM).

Weed control (Table 1): Weed seedbank viability decreases in response to increasing temperature of the soil (Figure 2). When critical temperatures are reached, steam can provide similar weed control to Pic-Clor 60 applications. Steam combined with MSM does not affect weed control significantly. However, when critical temperatures are not reached (at Spence 2014/15), no effects on weeds were observed (Table 1).

Pathogen control (Table 2): Steam provided a significant better control of *Verticillium dahliae* in soil compared to ASD (Fuji 2014/15) and *Pythium ultimum* (TCR 2013/14). Also disease progress of plants affected by *Macrophomina phaseolina* was significantly reduced by steam (TCR 2012/13, data not shown). However, where critical temperatures were not reached, no pathogen control effects were observed (Spence 2014/15, Table 2).

Yield (Table 3): Beds disinfested with steam provide similar fruit yields compared to soils disinfested with Pic-Clor 60 (Spence 2011/12). Steam provides higher (Fuji 2014/15, TCR 2012/13) similar (Steam + MSM, Mc Fadden 2013/14) yields compared to ASD + Rice Bran and higher yields than MSM alone (Mc Fadden 2013/14) (Table 3).

Conclusions Previous and current investigations show that steam has to be considered as alternative soil disinfestation method for California strawberry production. Depending on field conditions, steam shows similar or better pest and weed control efficacy than common chemical and non-chemical soil disinfestation methods. However, it is critical that constant soil temperatures are achieved throughout the treatment.

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Figure 1: Tractor towed steam soil disinfestation machine prototype with Clayton 100 HP steam generator (Watsonville, CA Sept. 2012).

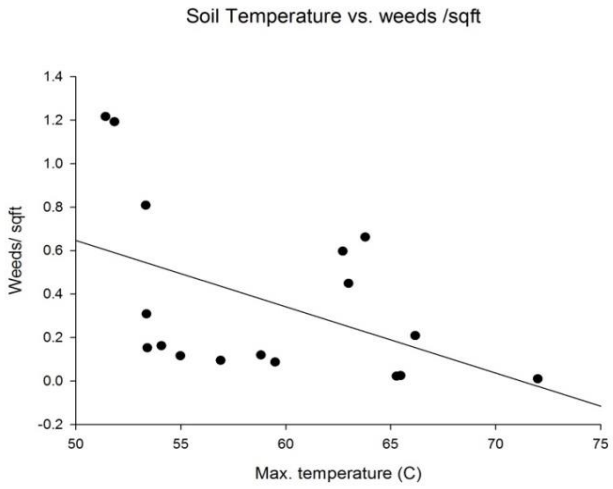

Figure 2: Maximum soil temperatures vs. the weed densities (Nov-Mar). Data are shown for the three field sites of 2014/15 (Spence, Fuji, TCR). Weed emergence decreases with response to increased soil temperatures.

Table 1: Cumulative weed density (n/sqft). Shown are means values. Mean separations are calculated after ANOVA (P=0.05) with Fisher's LSD test.

	Steam compared to Pic-Clor		**Steam compared to ASD**	**Steam combined with MSM**	
Trial and Season	*MBA 2011/12*	*Spence 2011/12*	*Fuji 2014/15*	*TCR 2012/13*	*Spence 2014/15*
Non-treated	0.4a	0.833a	0.46a	2.32a	0.158 ns.
Steam	0.02b	0.165b	-	0.047b	0.233 ns.
Pic-Clor-60	0.03b	0.39b	-	-	-
ASD	-	-	0.25ab	2.98a	-
MSM	-	-	-	-	-
Steam+MSM	-	-	0.03b	0.138b	0.229 ns.

Table 2: Soilborne pathogen control (% reduction). Shown are mean values. Mean separations are calculated after ANCOVA (P=0.05) with Duncan's multiple range test.

	Steam compared to ASD		**Steam combined with MSM**	
Trial and Season	*Fuji 2014/15**	*TCR 2012/13***	*TCR 2012/13****	*Spence 2014/15****
Non-treated	12.5% a	14.5 % a	48.1 % b	72.7 % ns.
Steam	45.8 % b	1.5 % b	89.3 % a	86.7 % ns.
Pic-Clor-60	-	-	-	-
ASD	25% ab	15.1 % a	50,1 % b	-
MSM	-	-	-	-
Steam+MSM	-	2.8 % a	96.4 % a	81.2% ns.

**Verticillium dahliae* (% reduction in microsclerotia per g soil, assessment pre and post treatment)
** ***Macrophomina phaseolina* (% of diseased plants)**
****Pythium ultimum* (% reduction in propaguels per g soil, assessments pre and post treatment)

Table 3: Yield (marketable Lbs/a; in % relative to non-treated). Shown are mean values. Mean separations are calculated after ANOVA (P=0.05) with Duncan's multiple range test.

	Steam compared to Pic-Clor		**Steam compared to ASD & MSM**			
Trial and Season	*MBA 2011/12*	*Spence 2011/12*	*Fuji 2014/15*	*Mc Fadden 2013/14*	*TCR 2012/13*	*Spence 2014/15*
Non-treated	24,401 ns.	16,887 b	100 % c	33,411 b	23,028 b	100 % b
Steam	32,320 ns.	19,876 a	-	38,134 ab	49,207 a	126 % a
Pic-Clor-60	29,492 ns.	21,169 a	-	-	-	-
ASD	-	-	121.5 % b	42,972 a	29,175 b	-
MSM	-	-	-	39,335 ab	-	-
Steam+MSM	-	-	144 % a	42,455 a	50,479 a	125 % a
Yield to	*9/6/12*	*9/15/12*	*8/15/15*	*10/11/14*	*10/19/13*	*8/15/15*