DIRECT-FIRED STEAM AND HOT AIR TO CONTROL WEEDS AND PATHOGENS IN STRAWBERRY

M. Hoffmann[1], M Ganci[2], J. Broome[2], M. Stanghellini[3], A. Asche[3], G. Vargas[3], R. Goodhue[4] and S. Fennimore[5]

[1]Department of Horticultural Science, North Carolina State University, Raleigh, NC; [2]Driscoll's Strawberry Association, Watsonville, CA; [3]TriCal Inc. Hollister, CA; [4]Department of Economics, UC Davis, Davis CA; [5]Department of Plant Sciences, UC Davis, Salinas, CA.

Summary: Farmland impacted by buffer zones requires new approaches to control pathogens and weeds, currently controlled by fumigants. Steam has long been used to control weeds, nematodes and pathogens in greenhouses and on small-scale farms. Previous results have shown effective pathogen and weed control in strawberry field trials with a prototype steam applicator. A commercial-scale mobile steam/hot air applicator built in 2015 was evaluated for soil disinfestation in strawberry. Two trials initiated in commercial strawberry fields in October 2016 were assessed for fruit yields as well as weed and pathogen control. Several tests were conducted with the mobile steam/hot air applicator to attempt to improve heat retention and distribution in the soil between February to October 2016. First results indicate that the prototype steam/hot air applicator can control weeds and pathogens. However, steam and hot air provide challenges in belowground heat trapping and results were not comparable to fumigant standard Pic-Clor 60.

Introduction: Conventional strawberry producers have traditionally relied on preplant soil fumigation for control of soilborne pathogens (CDPR 2015, 2016). Strict fumigation regulations and buffer zones result in valuable farmland where fumigants cannot be applied. Steam has been used for over a century to control soilborne diseases, nematodes and weeds in greenhouses and on small-scale farms (Baker 1957; Baker 1962; Luvisi et al. 2008; Barberi et al. 2008). Previous field trials with a prototype steam applicator demonstrated efficient pathogen and weed control for strawberry fields in California (Samtani et al. 2012; Fennimore et al. 2014; Hoffmann et al. 2016). However, the prototype was too small for commercial use in California. We built a new mobile steam/hot air applicator in 2015 with the goal of developing a commercial-scale applicator. This applicator utilized a direct-fire steam/hot air generator that does not require a pressure boiler. The objective of the work was to evaluate the new steam/hot air applicator.

Material and Methods: The steam/hot air generator used was a 5 MM BTU Johnson Gas CurePak direct-fire steam/hot air generator (Fig. 1). The CurePak produces steam/hot air by injecting water into a hot air stream, heated by a propane flame in a horizontal cylinder.

Optimization field tests took place during February 2016 to October 2016. Measurement of soil temperatures were made at 6 and 12 inch depths with HOBO data loggers (Onset, Bourne, MA) immediately following steam/hot air injection. Main focus of the optimization was to (1) minimize heat loss by capturing as much heat in the soil as possible and (2) to assure that the soil reaches critical temperatures of 65-70˚C for at least 20 minutes.

Field trials were conducted in October 2016 (Salinas, CA and Watsonville, CA). In Salinas 2016 and Watsonville 2016, steam/hot air was applied using 50 feet long mats for insulation. The mats were towed directly behind the steam/hot air injection bar. Steam/hot air was injected at both 6 and 12 inch depths.

<u>Salinas 2016:</u> The test field is located southeast of Salinas, CA at the USDA Spence Farm. Three treatments with four replicates each were established: (1) Non-treated control, (2) steam/hot air and (3) Pic-Clor 60. Steam/hot air was applied on the flat field on October 4 and 5, 2016. Steam/hot air was injected 6 and 12 inches deep and temporarily covered with 50 feet long insulation pads towed behind the injectors. Beds were shaped on October 25, 2016 and Pic-Clor 60 was applied October 26, 2016 at a rate of 350 lbs/a. Strawberry 'Monterey' was transplanted Nov. 11, 2016.

<u>Watsonville 2016:</u> The test field is located east of Watsonville, CA at the Driscoll's research site. Three treatments were established: (1) Non-treated control, (2) cover crop and (3) cover crop + steam/hot air. A summit wheat cover crop was planted in April 2016 and was cut and plowed under in September 2016. Steam/hot air was applied on the flat field October 7, 2016. Steam/hot air was applied and covered with 50 feet long mats for heat trapping and two injection depths (6 and 12 inches) at a speed of 300 ft./hour. Beds were shaped one week after steam/hot air application and strawberry was transplanted November 21, 2016.

<u>Weed Control Efficacy:</u> In all field trials, weed densities were assessed at regular intervals between January and May. Additionally, at the Salinas 2016 trial, weed control was assessed by artificially introduced weed seed samples and post treatment viability assessments (according to Hoffmann & Fennimore 2017, Baalbaki et al. 2009). At the Salinas 2016 site, the seeds of burning nettle, common purslane, common knotweed and yellow nutsedge tubers were used in the assays. Ten tubers of yellow nutsedge were put into seed bags with 25 seed of the three other species. Prior to loading the seed bags, subsamples of the seeds were tested for their viability using a Tetrazolium assay. **Tetrazolium Assay.** Seeds of burning nettle, common purslane and common knotweed were tested for viability using the tetrazolium assay (Baalbaki et al. 2009). **Yellow Nutsedge Sprouting Assays.** The viability of yellow nutsedge tubers were assessed by sprouting assays. Tubers were placed in separate pots, filled with sand and placed in a greenhouse (24 °C, 14h/12h d/n cycle). After 4 weeks, numbers of sprouted tubers were counted.

Pathogen Control Efficacy:
Pythium ultimum: At the Salinas 2016 site, pre- and post treatment levels of soilborne natural *P. ultimum* were assessed, using a wet plating method on semi-selective medium.
Macrophomina phaseolina: At the Watsonville 2016, pre- and post treatment levels of soilborne natural *M. phaseolina* were assessed, using dry plating on semi-selective medium.

Yield: By the time of this abstract, yields were still assessed.

Statistics: Weed control and pathogen data were analyzed by a multi factorial ANOVAs (fixed effect model III; $\alpha = 0.05$). MANOVAs were conducted for each study and weed species separately. In case of significances, Fisher LSD post-hoc tests ($\alpha = 0.05$) were performed on each data set. All statistics were performed with R 3.3.0 (https://www.r-project.org).

Results:

Steam/hot air generator: The applicator consisted of a Johnson Gas® direct-fire steam/hot air generator (Figure 1), mounted on a trailer and four noble plows, covering a swath of 14 feet. The noble plows are attached to a tool bar and towed by a tractor. Steam/hot air was delivered through hoses from the steam/hot air generator to the noble plows.

Salinas 2016 (Table 1): Pic-Clor 60 treatments controlled weeds and *Pythium ultimum* populations. However, only the viability of artificially introduced burning nettle seeds was significantly reduced by the steam/hot air treatment. Steam/hot air treatments didn't control any other weed seeds, artificially introduced *V. dahliae* or natural *P. ultimum* populations. Yield will be assessed through September 2017.

Watsonville 2016 (Table 2): Weed populations were controlled by steam/hot air in combination with summit cover crop, but not in the summit cover crop stand-alone treatment. Natural *M. phaseolina* populations were controlled by steam/hot air on this field side. Yields will be assessed through September 2017.

Discussion:
The setup of the CurePak direct-fire steam/hot air generator leads to lower water vapor saturation per air volume, compared to a normal steam generator (personal communication Dan Hodel, Johnson Gas Inc.). About 65% of the volume of gasses injected into the soil by the applicator are hot air and 35% water vapor. The CurePak is in reality a hot moist air generator, not a steam generator and this is a key reason our results are different than our earlier prototype which used a pure steam generator (Clayton Sigma Fire). When 100% (pure steam) steam is injected into the soil, it condenses on the soil particles releasing heat energy into the soil, heating

the soil and killing soil pests. When steam condenses, the volume decreases exponentially because liquid water takes up much less volume than steam. The hot moist air injected by the CurePak does not condense like steam. Unlike steam, the volume of air is relatively constant. Therefore continuous injection of hot moist air into the soil creates a backpressure because the air must escape. This backpressure makes it difficult to trap the heat in the soil, and this is why we think the CurePak did not perform as well as previous steam application equipment. Our recommendation is that the focus of future work be on pure steam rather than steam air mixtures.

Conclusions:

The direct-fire steam technology provides challenges in its' application for soil pasteurization. Although in Watsonville 2016, steam/hot air injections provided weed and pathogen control, due to discussed challenges in belowground heat and energy distribution and trapping, we recommend to focus future work on pure steam rather than steam/air mixtures.

Literature:

Baalbaki R, Elias S, Marcos-Filho, McDonald MB (2009) Seed vigor testing handbook. Contr. 32, Handbook of Seed Testing. Ithaca NY: Association of official Seed Analysts. 341pp

Baker, K.F. (ed). 1957. The U.C. system for producing health container-grown plants through the use of clean soil, clean stock, and sanitation. Univ. CA Div. Agricultural Sci. Agriculura; Expt. Sta. – Ext. Serv.

Baker, K.F. 1962. Principles of heat treatment of soils and planting material. J. Austral. Inst. Agricultural Sci. 28:118-126.

Barberi, P., Moonen, A.C., Peruzzi, A., Fontanelli, M. & Raffaelli, M. 2008. Weed suppression by soil steaming in combination with activating compounds. *Weed Research* **49**: 55-66.

California Department for Agriculture (CDFA) 2015. California Agriculture Statistics Review 2014-2015. 126pp.

California Department of Pesticide Regulations (CDPR). 2016. Summary of Pesticide Use Report Data 2014 Indexed by Chemical. 789pp.

California Department of Pesticide Regulations (CDPR). 2015. Field Fumigation Methods Allowed by Geographic Area. 8pp.

Fennimore, S.A., Martin, F.N., Miller, T.C., Broome, J.C., Dorn, N. & Greene, I. 2014. Evaluation of a Mobile Steam Applicator for Soil Disinfestation in California Strawberry. *HortScience* **49**(12): 1542-1549.

Hoffmann, M., Barbella, A., Miller, T.C., Broome, J.C., Martin, F.N., Koike, S.T., Rachuy, J., Greene, I., Dorn, N., Goodhue, R. & Fennimore, S. 2016. Weed and Pathogen Control with Steam in California Strawberry Production. *Acta Horticulturae* (accepted).

Hoffmann, M. & Fennimore, S.A. 2017. A Method to Evaluate Weed Seed Survival in Soil Disinfestation Trials. *Weed Technology* (accepted).

Luvisi, A., Materazzi, A. & Triolo,E. 2008. Control of soil-borne diseases in tomato by use of stream and exothermic reaction. *Advanced Horticulture Science* **22**(3): 174-181.

Samtani, J.B., Gilbert, C., Weber, B., Subbarao, K.V., Goodhue, R.E. & Fennimore, S.A. 2012. Effect of Steam and Solarization Treatments on Pest Control, Strawberry Yield, and Economic Returns Relative to Methyl Bromide Fumigation. *HortScience* **47**(1): 64-70.

Table 1: Weed control and pathogen control in Salinas 2016. Letters indicate significance levels according to Fisher LSD post-hoc test (P = 0.05).

Weed seed bioassay viability percentages (Means)

Treatment	**Purslane (%)**	**Knotweed (%)**	**Nettle (%)**	**Malva (%)**
NTC	41.9 a	71.7 a	75.2 a	90.7 a
Steam/hot air	39.8 a	68.3 a	57.8 b	97.0 a
Pic-Clor 60	0.0 b	0.0 b	0.0 c	60.0 b

***Pythium ultimum* populations pre and post treatment (pgg soil) (Means)**

Treatment	**PRE**	**POST**
NTC	1007 a	853 a
Steam/hot air	797 a	989 a
Pic-Clor 60	947 a	0 b

Weed density per acre (Means)

Treatment	**Weeds (n/acre)**
NTC	1,888 a
Steam/hot air	1,242 ab
Pic-Clor 60	391 b

Table 2: Weed control and pathogen control in Watsonville 2016. Letters indicate significance levels according to Fisher LSD post-hoc test (P = 0.05).

***Macrophomina phaseoina* populations pre and post treatment (ms/g soil) (Means ± SEM)**

Treatment	**PRE**	**POST**
NTC	7.2 ± 1.2 a	1 ± 0.5 a
Cover Crop	5.75 ± 1.3 a	0.5 ± 0.8 a
Steam/hot air + Cover Crop	5.5 ± 1.1 a	0.5 ± 0.8 a

Weed density per acre (Means ± SEM)

Treatment	**Weeds (n/acre)**
NTC	14,715 ± 4,500 ab
Cover Crop	18,390 ± 6,029 a
Steam/hot air + Cover Crop	8,643 ± 2,839 b

Figure 1: (October 2016: 50 feet heat trapping mats and 12 and 6 inch injection points are used for the field trials in Salinas 2016 and Watsonville 2016.

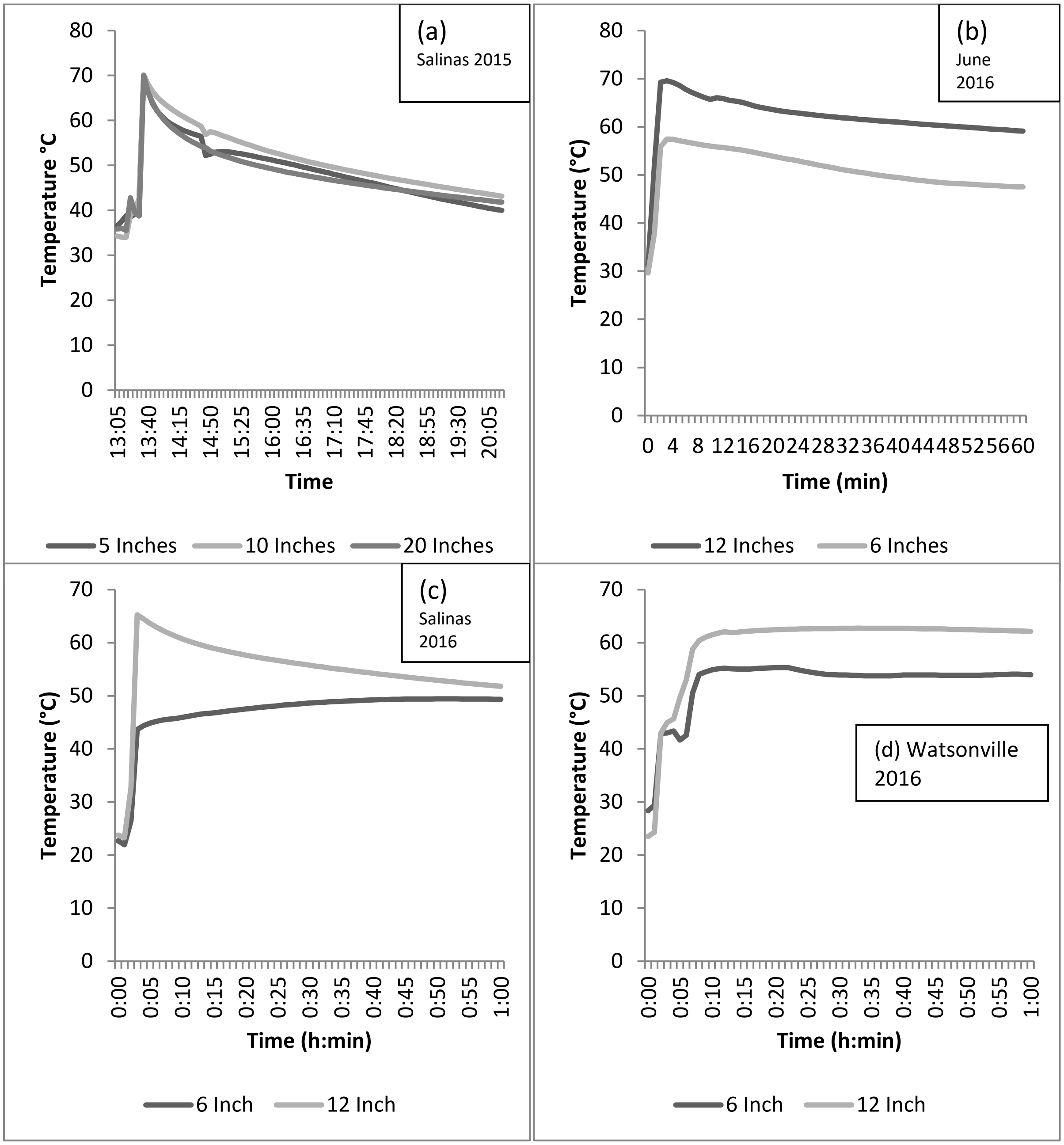

Figure 2: (a) Salinas 2015: Maximum temperatures at one measurement station. All other measurements were below 60 °C **(b)** June 2016: Mean temperatures of field test. **(c)** Salinas 2016: Mean temperatures of all measurement stations **(d)** Watsonville 2016: Mean temperatures of all field stations.