Optimizing Anaerobic Soil Disinfestation for California Strawberries

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Abstract

Anaerobic soil disinfestation (ASD), a biological alternative to soil fumigation, can control soilborne pathogens and nematodes in numerous crop production systems. To optimize ASD for California strawberries, a series of field and pot experiments have been conducted since 2003. Overall, ASD treatment was shown to be consistently effective at suppressing *Verticillium dahliae* and obtaining comparable yield with fumigant control in coastal California when 20 t ha^{-1} of rice bran (RB) was pre-plant incorporated and at least 75 mm of irrigation was applied in sandy-loam to clay-loam soils. However, due to economic and high nitrogen application issues associated with use of 20 t ha^{-1} RB, there is interest in examining alternative C sources used in ASD. In the 2012-2013 season, we conducted non-replicated demonstration trials at 4 local farms in which sugarcane molasses (Mol) 20 t ha^{-1} alone or in combination with RB (Mol 10 t ha^{-1} + RB 10 t ha^{-1}) were tested. Although Mol has advantages over RB in terms of ease of application and lower N content, the anaerobic condition created by Mol did not last long and split applications were needed. Further, cumulative marketable fruit yield from Mol 20 t ha^{-1} plots were as low as 70% of fumigated controls, whereas RB 20 t ha^{-1} and Mol 10 t ha^{-1} + RB 10 t ha^{-1} plots had similar yields as the control. Lack of effectiveness

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in Mol-based ASD may be related to uneven distribution of Mol across the bed profile and low soil temperatures at trial sites. We also evaluated the potential for eliminating pre-plant fertilizer application when using RB-based ASD at one site. Pre-plant fertilizer increased fruit yield only ~5%, suggesting a possibility of reducing pre-plant fertilizer at ASD fields. Future studies should examine other C-sources including summer cover crops combined with a low rate of RB or Mol in ASD.

INTRODUCTION

Anaerobic soil disinfestation (ASD), a biological alternative to soil fumigation developed in Japan (Shinmura, 2000; Momma, 2008) and The Netherlands (Blok et al., 2000; Lamers et al., 2010), can control soilborne pathogens and nematodes in numerous crop production systems. ASD integrates principles behind solarization and flooding to control soilborne pests in situations where neither is effective or feasible. To optimize ASD for California strawberries, a series of field trials and pot experiments have been conducted since 2003. Overall, planting-bed ASD treatment was shown to be consistently effective in suppressing *Verticillium dahliae* and marketable yields from ASD plots were generally equal to or higher than Pic-Clor 60 plots, and significantly greater than untreated controls in coastal California when 20 t ha^{-1} of rice bran (RB) was pre-plant incorporated and at least 75 mm of irrigation was applied to sandy-loam to clay-loam soils (Shennan et al., 2013). Following this success, some berry growers in California started to implement ASD in commercial fields; total ASD-treated acreage in California was 50 ha in the 2012-2013 season, and increased to 170 ha in the 2013-2014 season (Farm Fuel Inc. pers. commun.). However, due to economic factors (cost ~$ 6,000 per ha as compared with ~$ 4,400 for PicChlor 60) and high nitrogen application issues (~400 kg-total N ha^{-1}) associated with use of 20 t ha^{-1} RB, there is interest in examining alternative C-sources or reducing the amount of RB used in ASD. Molasses has been used successfully as a C-source for ASD in Japan (Shinmura, 2004) and Florida (Butler et al., 2012). Although the cost is not much different from RB, Mol has advantages over RB in ease of application and its low N content (0.5%). Here we report the results of demonstration trials in which ASD was conducted using sugarcane molasses (Mol) alone or in combination with RB. We also evaluated the potential for eliminating pre-plant fertilizer application when using RB-based ASD at one demonstration trial.

MATERIAL AND METHODS

Non-replicated large-scale ASD demonstration trials were conducted at 4 sites in Watsonville, Salinas, and Santa Maria, California during the 2012-2013 growing season (Table 1). At the Watsonville site, RB 20 t ha^{-1} and RB 10 t ha^{-1} + Mol 10 t ha^{-1} plots were established at a conventional field and at an organic field in September 2012. Each plot was further divided to establish with or without pre-plant fertilizer treatment plots (Table 1). RB 20 or 10 t ha^{-1} was broadcasted to the assigned plots and rototilled to a depth of 15 cm. Beds were formed, drip tapes and plastic mulch applied, and the first irrigation began two days from the RB application. Mol was diluted with water at 1:2 to 1:5 in a water tank prior to application, then 6.5 t ha^{-1} of Mol was applied through drip tapes to assigned plots. Seven days later, the balance of Mol (3.5 t ha^{-1}) was applied in the same manner. All plots were intermittently drip irrigated for three weeks from the first irrigation, with total irrigation amount of 60-75 mm.

For the remaining sites, grower collaborators chose to attempt Mol-based ASD; in September-October 2012 (Table 2), 20 t ha^{-1} of Mol was split applied as described above except the second Mol application was conducted 3 to 7 days after the first application. Soil Eh, an indicator of anaerobisis, (all sites) and soil temperature (Watsonville and Salinas 1) at 15 cm depth was monitored during the three week treatment period. Strawberry plants (*Fragaria ananassa*) were transplanted in November 2012 at all sites. Marketable fruit yield was surveyed either at 4 to 6 harvest stations with 20 or 40 plants at each station (Watsonville, Salinas 1, and Santa Maria) or at the entire plot (Salinas 2) during the harvest season in 2013. At all conventional sites, marketable fruit yield at adjacent fumigated fields were also monitored and used as controls. There was no known history of soilborne diseases at any of the sites.

RESULTS AND DISCUSSION

Watsonville Site

A strong anaerobic condition was created in all ASD plots in both conventional and organic trials (Fig. 1, left for the conventional trial). Average cumulative Eh under 200 mV, an indicator of anaerobisis intensity, reached over 100,000 mV h in these sandy soils (Table 2) easily exceeding the 50,000 mV h threshold required to kill *V. dahliae* microsclerotia in soil at 25°C (Shennan et al., 2010). Soil temperature during ASD treatment averaged 21 (organic) to 23°C (conventional) (Table 2).

At the conventional trial, cumulative marketable fruit yields from ASD plots were as high as 90-97% of the methyl bromide/chloropicrin control when pre-plant fertilizer was added (Table 3, Fig. 2, left), and 85-93% without pre-plant (Fig. 2, left). ASD with RB 20 t ha^{-1} plots had 8% higher yield than ASD with RB 10 t ha^{-1} + Mol 10 t ha^{-1} plots on average at the conventional site (Fig. 2, left) though such differences were not found at the organic trial (Fig. 2, right). Pre-plant fertilizer did not significantly influence fruit yield at both conventional and organic trials at this location; the average increase in fruit yield in response to pre-plant fertilizer at RB-based ASD plots was ~5% (Fig. 2).

Salinas 1 Site

The initial molasses application quickly created strong anaerobic conditions, however, it was of short duration; soil Eh increased after 2-3 days. Interestingly, the second molasses application made at 4 days after the first application reduced soil Eh again resulting in a strong to moderate anaerobic condition that persisted for approximately 2 weeks (Fig. 1, right). This provided 82,780 mV h of cumulative Eh under 200 mV (Table 2). Due to the late October to November application, the average soil temperature during ASD treatment was <20°C (Table 2). Although it created a significant anaerobic condition, fruit yield at ASD Mol plot was rather low; it was only 67% of the adjacent fumigation plot (Table 3).

Salinas 2 and Santa Maria Sites

ASD with molasses did not create strong enough anaerobic conditions (Table 2) though the treatment was conducted using methods almost identical to that employed at the other trial sites. Marketable fruit yields at ASD plots relative to fumigated plots were as low as 71 (Santa Maria) to 73% (Salinas 2), a yield level similar to that attained in ASD Mol plot at the Salinas 1 site (Table 3).

Overall, molasses-based ASD was not as effective as rice bran-based ASD; it provided only ~70% of marketable fruit yield attained in the fumigated controls. Although its ease of application is attractive to growers, bed application of molasses may not consistently create a uniform distribution of the C-source across the bed profile, hence its effect may be limited. Further, regions where molasses has been successfully used as a C-source for ASD (e.g., Japan and Florida) experience much warmer temperatures than central coastal California (greater than 30°C at 15 cm depth). We are currently examining interactions between temperatures and C-sources on pathogen control by ASD in a greenhouse study. To reduce N inputs from C-sources, use of summer planted cover crops (Butler et al., 2011; Blok et al., 2000) together with a reduced amount of rice bran or molasses as C-sources warrants further studies.

The effect of pre-plant fertilizer on fruit yield under ASD was not clear in the Watsonville trial suggesting a possibility of eliminating or reducing pre-plant fertilizer with rice bran-based ASD. However, data from another conventional site found a stronger positive effect of pre-plant fertilizer application on yields following ASD, so we are testing this again in an on-going field trial.

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Tables

Table 1. Large-scale demonstration trials on anaerobic soil disinfestation (ASD) in the 2012-2013 season.

Location	C-source[z]	Size (ha)	Management	Soil type
Watsonville	20 t ha^{-1} RB or 10 t ha^{-1} RB+10 t ha^{-1} Mol +/- preplant fertilizer[y]	0.4	Organic	Sandy loam
	20 t ha^{-1} RB or 10 t ha^{-1} RB+10 t ha^{-1} Mol +/- preplant fertilizer[x]	0.2	Conventional	Loamy sand
Salinas 1	20 t ha^{-1} Mol	0.2	Conventional	Loam
Salinas 2	20 t ha^{-1} Mol	0.4	Conventional	Clay loam
Santa Maria	20 t ha^{-1} Mol	0.2	Conventional	Loam

[z] RB: rice bran, Mol: sugarcane molasses.

[y] Preplant fertilizer for organic site: feather meal 12-0-0, 1,122kg ha^{-1}.

[x] Preplant fertilizer for conventional site: slow release coated fertilizer 18-6-12, 673kg ha^{-1}.

Table 2. Cumulative Eh mV hours under 200 mV and soil temperature at 15 cm depth at ASD demo trials.

Location	ASD period in 2012	Cumulative Eh mV h[z]	Soil temp (°C) Ave. (min.-max.)[y]
Watsonville (conventional)	Sep.12-Oct.4	186,606[x]	22.5 (18.1-31.3)[x]
Watsonville (organic)	Sep.15-Oct.4	117,400[x]	21.2 (17.5-27.4)[x]
Salinas 1	Oct.19-Nov.9	82,780	18.8 (15.0-22.9)
Salinas 2	Oct.2-Oct. 23	30,300[w]	Not measured
Santa Maria	Sep.26-Oct.15	28,200[w]	Not measured

[z] Our incubation study indicated that more than 50,000 mV h below 200 mV is needed to kill *V. dahliae* microsclerotia in soil at 25°C (Shennan et al., 2010).
[y] During ASD period at 15 cm depth.
[x] Average of 4 ASD plots. Conventional trial used clear plastic mulch with herbicide whereas organic trial used black plastic mulch.
[w] Estimate from Eh data measured daily by a handheld meter. Eh data of other sites were measured every 30 s by an automated data logger.

Table 3. Cumulative marketable fruit yield at ASD and fumigation plots at conventional sites.

Location[z]	Cultivar	Harvest period	Cumulative marketable yield ($t\ ha^{-1}$)		ASD/fum. yield (%)
			ASD	Fumigation (fumigant)	
Watsonville	Albion	Mar.-Oct.	57[y]	59 (Mb/Pic)[w]	97
	Albion	Mar.-Oct.	53[x]	59 (Mb/Pic)	90
Salinas 1	Albion	Apr.-Oct.	35	52 (Pic-Clor60)	67
Salinas 2	Monterey	May-Oct.	48	66 (Pic-Clor60)	73
Santa Maria	BG1975	Mar.-Jun.	50	70 (Chloro)[w]	71

[z] Plant density (plants per ha): Watsonville; 46,500, Salinas 1; 45,200, Salinas 2; 40,400, Santa Maria; 75,100.
[y] RB 20 $t\ ha^{-1}$ ASD + pre-plant fertilizer.
[x] RB 10 $t\ ha^{-1}$ + Mol 10 $t\ ha^{-1}$ ASD + pre-plant fertilizer.
[w] Mb/Pic; methyl bromide/chloropicrin, Chloro; chloropicrin.

Figures

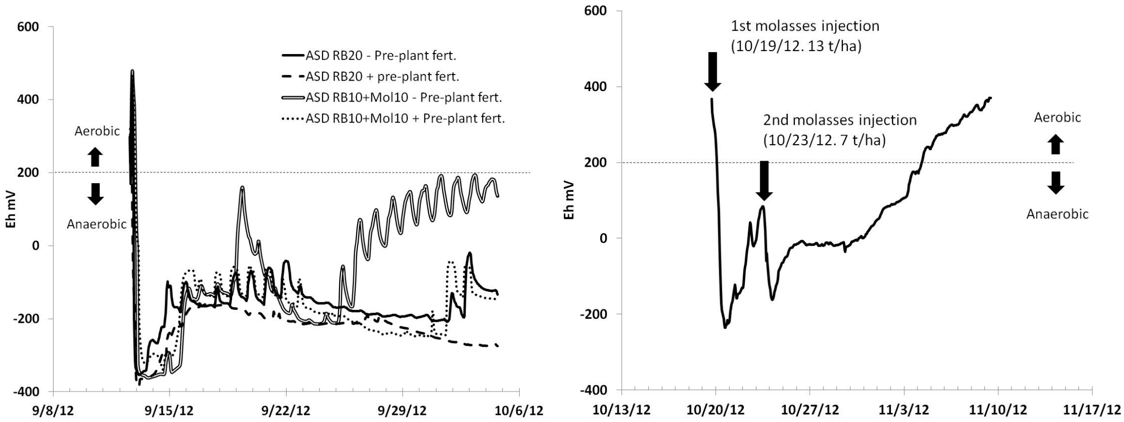

Fig. 1. Changes in soil Eh at 15 cm depth during ASD treatment at the Watsonville conventional site (left) and the Salinas 1 site (right).

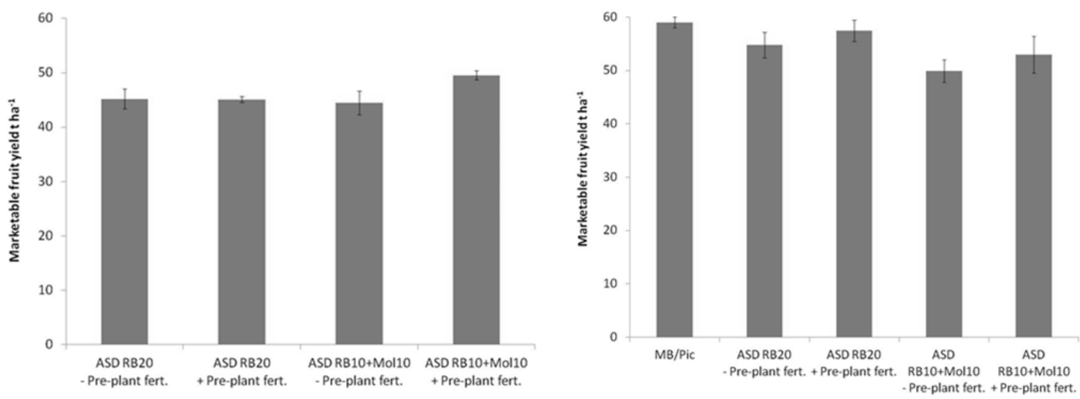

Fig. 2. Cumulative marketable fruit yield at the conventional demo trial (left) and the organic demo trial (right) in the Watsonville site. Mean ± SEM (n=4 harvest stations within each plot). MB/Pic: methyl bromide/chloropicrin, RB20: rice bran 20 t ha^{-1}, RB10+Mol10: rice bran 10 t ha^{-1} and molasses 10 t ha^{-1}.