Evaluating IPM Methods to Control Apple Replant Disease

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When apple replant disease occurs, it can cost orchardists $70,000 to $150,000 in reduced returns during just the first four years of production. Washington growers generally fumigate using 1-3 Dichloroproprene, Chloropicrin to try to prevent the complex of pathogens which cause replant. But fumigation generally only provides short term benefits. Growers asked for alternatives that may provide longer term benefits and higher returns allowing them to maintain their organic status.

Current study

In 2017 we initiated three studies looking at anaerobic soil disinfestation and bio-renovation using *Brassica* seed meal treatments that have worked well at a small scale and in field applications in strawberries. To see if these treatments are ready for field application, we used large field plots of one to twelve-acres where we could look at variability across a field and use field scale equipment. Studies were conducted in three locations with 4 to 5 replications.

Bio-renovation using mustard seed meals releases volatile compounds produced by the interaction between the mustard plant compound glucosinolate with a plant enzyme (myrosinase). Volatiles suppress soil-borne disease organisms and can select for beneficial microorganisms that directly parasitize plant pathogens and induce plant defense. ***See Figure 1 (at right)***.

Anaerobic soil disinfestation (ASD) is a process where organic carbon sources are added to the soil and then the soil is flooded using irrigation and covered by a gas impermeable plastic film. During anaerobic decomposition microbes release volatile compounds which are toxic to plant parasites and pathogens. ***See Figure 2 (pg. 2)***.

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Step 1. Apply *Brassica* seed meal when soils are warm.

Pescadero Gold Mustard meal (1:1 formulation of B. *juncea* and S. *alba*) was applied using a Whatcom spreader at 0.4 lb per ft^2 to the 4 ft wide tree row (3.5 tons/orchard A).

Step 2. Incorporate mixing well.

Material was incorporated using a rototiller to 10 in.

Step 3. Totally impermeable film.

Totally impermeable film (TIF; 1.2 ml) was laid within 30 min of incorporation to trap volatile gases. Plastic should be tight to soil.

Step 4. Treatments for 3 weeks.

Leave TIF in place for 3 weeks.

Step 5. Aerate soil 3 weeks or more.

Remove TIF and allow soil to aerate. Volatile compounds from bio renovation are phytotoxic. Bio renovation was performed the fall before planting.

Figure 1. Steps to *Brassica* seed meal bio-renovation.

Step 1. Carbon source from grass cover crop or hay 8 to 10 ton per acre.

At Othello the carbon source was triticale seeded at 100 lbs/A with a seed drill. Triticale was terminated at anthesis. Standing biomass of 3.5 ton/A was cut and windrowed to form 10 t/A applied biomass.

At Rock Island and Tonasket sites timothy hay was applied at 8 ton/A to the 4-ft wide tree row.

Step 2. Chop carbon material into small pieces.

Material was chopped with multiple passes of a flail mower to form small bioavailable pieces.

Step 3. Incorporate.

Biomass was incorporated using a rototiller to 10 in.

Step 4. Tarp with TIF.

Rows were tarped with totally impermiable film (TIF) 1.2 ml black or clear.

Step 5. Maintain soil wet.

Soil moisture was brought up to and maintained above 30% VWC using a double drip line under TIF.

Step 6. Remove TIF and aerate.

Soil was allowed to aerate 3 weeks. Compounds released during anaerobic conditions can be phytotoxic.

Figure 2. Methods for anaerobic soil disinfestation (ASD) employed at three field sites in WA.

A fumigated control (1,3-*Dichloropropene*, *Chloropicrin*) and a no-treatment control were included in each site.

We planted trees the spring following summer/fall soil treatments. Orchards were planted to cv WA38 on G41 in Othello (spring 2018), cv TC2 on Bud 10 Rootstock in Tonasket and cv WA38 on G41 and M9.337 in Rock Island (spring 2019).

New Findings

Did treatments change the soil biology?

Bio-renovation treatments can initiate successive changes to the soil microbiome. For example, during ASD when the soil goes anaerobic bacterial communities generally progress from dominance by *Bacillus* and *Paenibacilus* groups to dominance by anaerobic bacteria including *Clostridium. Clostridium* produce a variety of chemistries such as volatile fatty acids which inhibit fungi and dimethyl disulfide which is nematocidal and fungicidal. Volatile compounds reduce the numbers of pathogens in the soil and ideally the shift in the soil microbiome is more stable than that observed in response to fumigation where communities often quickly revert to high parasite/ pathogen levels.

We measured the soil biology three weeks after soil treatments using Terminal restriction fragment length polymorphism (T-RFLP) analysis. The soil bacterial and fungal communities in the *Brassica* seed meal treatment were different than the no-treatment control and the fumigated control in all three sites. In the anaerobic soil disinfestation treatment bacterial and fungal populations were different than in the no-treatment control in Rock Island and Tonasket but not in Othello. Lack of soil biology transformation in Othello ASD treatments was likely because those soils did not stay wet enough to become anaerobic when we used sprinkler irrigation. When treatments were performed again in Othello using drip vs sprinkler irrigation application microbial communities did shift in ASD. We looked at microbial communities again the fall after trees were planted using high-throughput DNA sequencing of soil in the root rhizosphere (***Figure 3***). A year after treatment bacterial communities were still different in *Brassica* seed meal treated soil compared to non-treated soil in Tonasket and Rock Island as well as two years later in Othello.

Figure 3. Rhizosphere soil is the soil directly influencing plant roots. See the small clods of soil adhered to and tangled in fine plant roots above.

Figure 4. Researchers sampling rhizosphere soil 1 year after planting in anaerobic soil disinfestation (right) and *Brassica* seed meal (left) treatments in Rock Island, WA.

Impacts on tree growth

Cost-benefit over the first five years will tell us whether treatments were successful. To give you a sneak peak let's look at initial tree growth. Tree growth in *Brassica* seed meal treatments was greater than or equal to tree growth in fumigated plots at all sites during first year growth as well as in second year growth in Othello (**Figure 5**). The anaerobic soil disinfestation treatment was more variable. In Tonasket anaerobic soil disinfestation tree growth was greater than the no-treatment control but less than the fumigated control. In Rock Island anaerobic soil disinfestation tree growth on M.9 and G.41was as good as the fumigated control and greater than the no-treatment control. In Othello the anaerobic treatment was fumigated in order to avoid risking four acres of grower trees after anaerobicity was not achieved and thus impacts are not reported here.

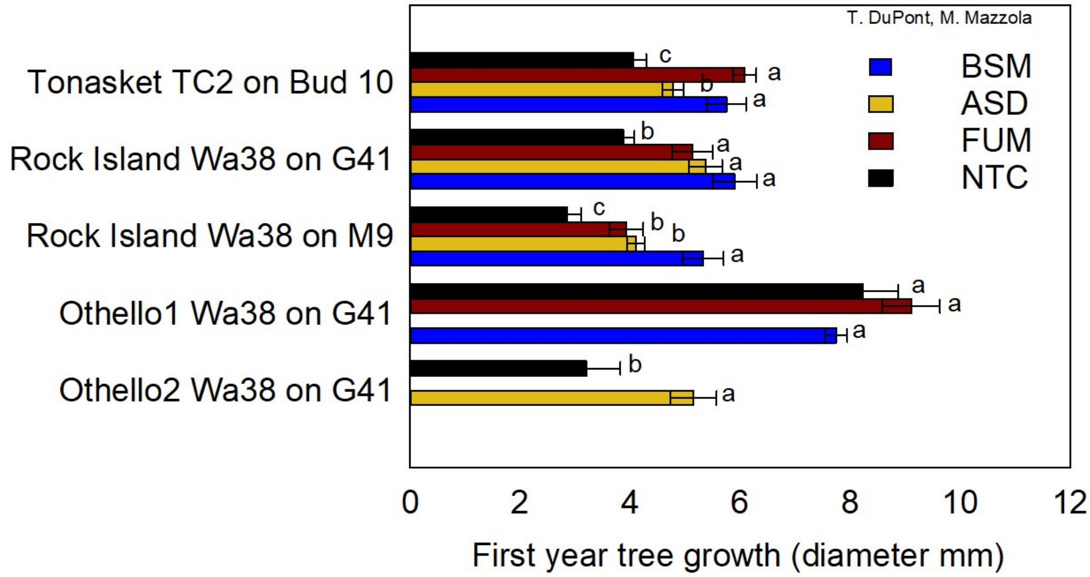

Figure 5. Effect of replant management strategies on tree growth 1 year after treatment. *Brassica* seedmeal bio-renovation (BSM), Anaerobic soil disinfestation (ASD), fumigated control (FUM), no-treatment control (NTC).

Tips for Growers

Brassica seed meal bio-renovation is looking promising as an alternative to fumigating with 1,3-Dichloropropene, Chloropicrin. If you are considering this option keep in mind that not all brassica seed meals are equal. The seed meal used here was a 1:1 formulation of B. juncea and S. alba (Mazzola 2015). Seed meals are often processed at different temperatures and with different grinding methods which affect the quantity of active chemistry that is released. Tests should be conducted to determine the type and quantity of glucosinolate contained in the seed meal that you intend to use. To date in the US the Brassica seed meal we used is labeled only as a fertilizer. Until products have the appropriate labels as a soil fungicide/ nematicide, application for this use is not legal. Remember that soil temperature and moisture are important. These are biological processes where moisture and temperature affect the activity of soil biology and the movement through the soil of the compounds they produce. For Brassica seed meal, treatment soil should be warm (above 70° C) and moist. Last, application rate is important.

Anaerobic soil disinfestation resulted in significant changes in composition of the rhizosphere microbiome and tree growth that was better than the no-treatment control in three of four experiments but not always greater than the fumigated control. It will be essential to keep soil wet (above 30% moisture) and reach anaerobic conditions for success. In sites with high pratylenchus nematode populations higher carbon inputs and longer incubation times might be necessary for success.

Next steps

We plan to follow these plots for at least three more seasons to have five years of tree growth and three years of harvest data. Returns from packed fruit over the long-term compared to costs will let us track success. Additional work is also needed to further improve the practical application of treatments.

For further information

For videos of bio-renovation procedures visit

treefruit.wsu.edu/videos

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Appendix 1. Field Operations Othello

Anaerobic soil disinfestation application			
Operation	**Implement/Equipment**	**Details**	**Date**
Fertilize			April 2017
Tillage	John Deer 7200/ 15 foot disc		April 2017
seed triticale	John Deer 7200/Great Plains seed drill	95 lbs per acre	April 19, 2017
Irrigation	Hand lines (R33 sprinklers)	6 gal per min, 0.28 in per hr	May-Jun 2017
cut and swath	John Deere R450 swather	4 ft windrow	June 28, 2017
chop	Pak flail	0.7 mi per hr	July 3, 2017
Incorporation	John Deer 7200/ Celli rototiller	8 in depth	July 4, 2017
Tarping	Kubota M8540 / Mulch layer Mechanical Transplanter Co Model 90		July 7, 2017
***Brassica* seed meal application**			
Operation	**Implement/Equipment**	**Details**	
Pre-irrigation	Hand lines (R33 sprinklers)	6 gal per min, 0.28 in per hr	July 15, 2017
Mustard meal application	John Deer 5083/ Whatcom mulch spreader	Settings: 4 low, 1700 rpms, belt 5, floor 4, gate 12.5 in	July 19, 2017
Incorporation	John Deer 7200/ Celli rototiller	8 in depth	July 19, 2017
Tarping	Kubota M8540 / Mulch layer Mechanical Transplanter Co Model 90	N/A	July 19, 2017

Appendix 2. Field Operations Rock Island WA

Anaerobic soil disinfestation application			
Operation	**Implement/Equipment**	**Details**	**Date**
Pre-Irrigation	Sprinkler system (R5 sprinklers)/ Big gun system (8 mm nozzle)	1.5 acre-inches applied	July 2-4, 2018
Hay distribution	By hand	8 ton per acre	July 4, 2018
Hay chopping	Flail mower		July 4, 2018
Incorporation	Mascchio Rototiller	8 in depth	July 5, 2018
Tarping	Mechanical Transplanter	N/A	July 5, 2018
Saturation	Drip irrigation to flood soil	0.44 acre-inches per hour	July 6-27, 2018
***Brassica* seed meal application**			
Operation	**Implement/Equipment**	**Details**	**Date**
Mustard application	Whatcom compost spreader 750	2 for belt and 2 for floor	July 6, 2018
Incorporation	Mascchio Rototiller	8 inch depth	July 6, 2018
Tarping	Mulch layer Mechanical Transplanter Co Model 90	Within 20 min of mustard incorporation.	July 6, 2018

Appendix 3. Field Operations Tonasket WA

Anaerobic soil disinfestation application			
Operation	**Implement/Equipment**	**Details**	**Date**
Pre-Irrigation	Big gun system (8 mm nozzle)	5 acre-in applied in 12 hr sets	Aug 2-6, 2018
Hay distribution	By hand	8 ton per acre	Aug 8, 2018
Hay chopping	Flail mower		Aug 8, 2018
Incorporation	Mascchio Rototiller	8 in depth	Aug 8, 2018
Tarping	Mulch layer Mechanical Transplanter Co Model 90	N/A	Aug 8, 2018
Saturation	Drip irrigation to flood soil	0.44 acre-in per hr	Aug 8-29, 2018
***Brassica* seed meal application**			
Operation	**Implement/Equipment**	**Details**	**Date**
Mustard meal application	Mill Creek mulch spreader	1.7 lbs per tree row ft Settings: 4 floor; 4 belt	Aug 9, 2018
Incorporation	Mascchio Rototiller	8 in depth	Aug 9, 2018
Tarping	Mulch layer Mechanical Transplanter Co Model 90	Within 20 min of meal incorporation.	Aug 9, 2018

Appendix 4. Treatment Costs

Anaerobic Soil Disinfestation (ASD) - Carbon grown in place.				
Field activity		**hrs/A**	**$/hr**	**$/A**
tillage		0.25	$40	$10
move irrigation triticale		4.0	$13	$52
seeding triticale		0.25	$40	$10
cut and swath triticale		custom		$50
flail		1	$40	$40
hay rake		custom		$7
hand rake		2.8	$13	$36
move irrigation for ASD		4.0	$13	$52
lay plastic		2.0	$40	$80
Supplies	**$/unit**	**unit**	**unit/A**	**$/A**
triticale seed	0.32	lb	100	$32
Totally impermeable film	0.06	ft	4200	$252
Equipment	**equip**	**yrs amortized**	**A/year**	**$/A**
hand lines	$650	10	50	$1.30
flail	$4,000	10	50	$8
plastic layer	$2,300	10	50	$5
seed drill				
Total cost				***$635***
Anaerobic Soil Disinfestation (ASD) - Hay carbon source				
Field activity		**hrs/A**	**$/hr**	**$/A**
pre-irrigate		3	$14	$41
apply hay		16	$14	$213
flail hay to chop		1	$40	$40
place drip lines		5.25	$14	$71
lay plastic		2	$40	$80
Supplies	**$/unit**	**unit**	**unit/A**	**$/A**
hay	$100	ton	8	$800
hay shipping	$500	ea	1	$500
drip line	$0.07	ft	8400	$546
drip couplings	$3.63	ea	20	$73
Totally impermeable film	$0.06	ft	4200	$267
Equipment	**equip**	**yrs amortized**	**A/year**	**$/A**
flail	$4,000	10	50	$8
plastic layer	$2,300	10	50	$5
Total cost				***$2,642***
Brassica seed meal bio-renovation				
field activity		**hrs/A**	**$/hr**	**$/A**
irrigation		4	$13	$52
mustardmeal application		2	$13	$26
incorporation		2	$13	$26
tarping		2	$13	$26
Supplies	**$/unit**	**unit**	**unit/A**	
mustard meal*	$0.85	lb	6720	$5,712
Totally impermeable film	$0.06	ft	4200	$267
Equipment	**equip**	**yrs amortized**	**A/year**	**$/A**
mulch spreader	$22,000	10	100	$22
plastic layer	$2,300	10	50	$5
Total cost				***$6,135***
Fumigation				
Field activity		**hrs/A**	**$/hr**	**$/A**
Total cost		custom		***$900***

*1.6 lbs per tree-row-foot for 4 ft wide tree strips

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