FINAL PROJECT REPORT

Project Title: Implementation of alternative methods to control replant disease

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Other funding sources

Agency Name: USDA Crop Protection

Amt. awarded: $195,713

Notes: USDA Crop Protection Grant # 2017-70006-27267 funded two additional sites. Thank you to in kind support from Gold Crown Nursery, Cameron Nursery, Progene Seed, Trident Ag Products, Farm Fuel Inc and generous support of labor, materials and equipment from orchardists Mike Robinson, Jim Baird and Sam Godwin.

Total Project Funding: **Year 1:** $60,577 **Year 2:** $34,163 **Year 3:** $35,248

Budget History:

Item	Year 1: 2017	Year 2: 2018	Year 3: 2019
WTFRC expenses			
Salaries	$19,800	$20,592	$21,416
Benefits	$6,283	$6,534	$6,795
Wages			
Benefits			
Equipment			
Supplies	$33,457	$6,000	$6,000
Travel	$1,037	$1,037	$1,037
Plot Fees			
Miscellaneous			
Total	$60,577	$34,163	$35,248

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OBJECTIVES

1. Conduct field scale experiments to test the efficacy of bio-renovation and anaerobic disinfestation as alternatives to soil fumigation for the control of apple replant disease. At each on-farm site four treatments (mustard seed meal bio-renovation, anaerobic soil disinfestation, fumigated control and non-fumigated control) will be applied in randomized strips in each of four blocks (four replicates each). Plant response to treatments will be assessed by measuring trunk cross sectional area and yield. In addition, microbial analysis of roots and soil will be conducted to determine treatment effects on target replant pathogens and overall composition of the microbiome including potential beneficial microbes.
2. Use field scale experiments to demonstrate to growers the steps to bio-renovation and anaerobic soil disinfestation. Each step will be documented with photos and video to create Extension factsheets explaining the process and lessons learned. Conducting trials at a large plot scale will allow us to use the same equipment growers would use, develop practical expertise, and work out the inevitable kinks with a new technique.

SIGNIFICANT FINDINGS

- Brassica seed meal treatments (BSM) successfully altered soil microbial communities and were associated with apple tree growth that was as great or greater than fumigated controls across all three study locations in year one.
- Anaerobic soil disinfestation (ASD) resulted in significant changes in composition of the rhizosphere microbiome and tree growth in year one that was better than the no-treatment control in three of four experiments but not always greater than the fumigated control.

RESULTS AND DISCUSSION

Brassica seed meal treatments (BSM) successfully altered soil microbial communities and were associated with apple tree growth that was as great or greater than fumigated controls across all three study locations in year one. In bioassays, BSM soil amendment lowered *P. penetrans* nematode numbers recovered from apple seedling roots (Table 1) and shifted post treatment microbial composition as assessed by T-RFLP analysis (Fig. 1). In field trials, changes to the microbial community were maintained in concert with lower *P. penetrans* populations in apple roots one-year post-treatment. Significant differences in the apple rhizosphere microbiome and *P. penetrans* root populations were evident between BSM and both the no-treatment and fumigated controls one-year post treatment in Tonasket and Rock Island and two years post-treatment in Othello1 (Fig.2; Table 1). Root pathogens *Illonectria robusta* (all sites) and *Rhizoctonia* spp. (Rock Island) were significantly diminished in the rhizosphere of BSM treated soil compared to the control and several fungal genera with potential biocontrol activity including *Talaromyces*, *Chaetomium*, *Gelasinospora* and *Hypocrea/Trichoderma* were present at significantly ($P < 0.05$) greater relative abundance in rhizosphere soil from the BSM than control treatment. Suppression of plant pathogens and nematodes corresponded with tree growth greater than or equal to the fumigated control at all sites in year 1 (Fig. 3; Table 2).

Anaerobic soil disinfestation (ASD) resulted in significant changes in composition of the rhizosphere microbiome and tree growth in year one that was better than the no-treatment control in three of four experiments but not always greater than the fumigated control. At Rock Island, Tonasket and Othello2, but not Othello1, ASD treated soils attained 50,000 mVhr oxidation reduction potential indicating anaerobic conditions. Post treatment bioassays showed low (comparable to pasteurized control) *P. penetrans* levels g^{-1} root in plants grown in ASD treated soil for Rock Island and Tonasket. At Othello1 and Othello2 sites *P. penetrans* were still present at levels (167 g^{-1} root and 285 g^{-1} root, respectively) significantly higher than the pasteurized control (Table 1). Bulk soil microbial communities assessed by T-RFLP analysis were transformed significantly in response to ASD at the Rock Island and Tonasket orchards but not Othello1 (Fig. 1). One-year post-treatment, rhizosphere microbial communities from ASD treated plots possessed fewer OTUs that differed in relative abundance from the fumigated and no-treatment control than did BSM treated soil. Bacteria belonging to the Clostridiales and Bacilliales within the Firmicutes, as well as Actinobacteria and Bacteroidetes shifted to an increased abundance in response to ASD at Rock Island and Othello2. Amplification of Firmicutes (Mowlick *et al.*, 2013; Liu *et al.*, 2016; Hewavitharana *et al.*, 2019) and Bacteroidetes (van Agtmaal *et al.*, 2015; Mazzola *et al.*, 2018) abundance in soil and the rhizosphere has been documented in response to application of ASD in other crop production systems and was associated with enhanced yields. A progression in composition of the Firmicutes community was correlated with the production of metabolites that possessed antimicrobial, and potentially disease suppressive, activity (Hewavitharana *et al.*, 2019). In this study, sites that exhibited significant rhizosphere bacterial community shifts in response to ASD, such as at Rock Island, Tonasket, and Othello2, correspondingly exhibited a significant increase in tree growth relative to the control in year one (Figure 3).

Tree growth and yield measurements of second (and third leaf Othello1) trees showed the early impacts of soil treatments over time. At Othello1 trees grown in BSM treated soil had significantly smaller tree diameter than both the no-treatment and fumigated controls according to repeated measures analysis of variance (Figure 4). Trees at Othello1 in all treatments were large at 33 to 35 mm diameter. At Othello2 trees grown in ASD treated soil were significantly larger than no-treatment controls. At Rock Island cv WA38 trees on G.41 rootstock trees grown in ASD and BSM treated soils were significantly larger than no-treatment and fumigated controls with no difference between ASD and BSM and a significant difference between no-treatment and fumigated controls. At Rock Island cv. WA38 trees on G.41 rootstock trees had significant differences between all treatments but a significant treatment by date interaction. Trees in BSM treated soils were the largest, larger than both no-treatment and fumigated controls. WA38 trees on G.41 trees in ASD treated soils were larger than no-treatment controls but not fumigated controls. At Tonasket tree size was greatest in BSM and fumigated control trees until 14 months after treatment. At month 16 BSM tree size was smaller than those in fumigated control soils. Trees in ASD treated soils were larger than those in no-treatment controls but not fumigated controls. At Othello1 fruit yield in bins per acre in trees grown in BSM treated soil was intermediate for both second and third leaf trees where yield in fumigated control soil trees was greater than that in no-treatment controls. Across sites in second (and third leaf Othello1) trees BSM treated trees were larger than no-treatment control in three of four experiments. Second (and third leaf Othello1) trees in ASD treated soils were larger than those in no-treatment control soils in four of four experiments but smaller than trees in fumigated control soils in two of three experiments.

At Othello1 the combination of a vigorous scion WA38 on a vigorous rootstock G.41 may have contributed to overall large trees and limited differences between treatments at that site. Additionally, no-treatment control plots at Othello1 were small 45 tree plots nested within large approximately one-acre plots. Bioassays of soil across the twelve-acre field site (data not shown) found large within field variability in replant pressure at the site which may not have been captured in small no-treatment control plots.

Table 1 Density (number gram^{-1} root) of Pratylenchus penetrans recovered from tree roots as influenced by soil treatment at the respective orchard field trials. Roots were sampled in October of the first growing season (Tonasket and Rock Island) or the first two growing seasons (Othello1).

	Tonasket†				Rock Island†				Othello1‡ 2018				Othello1‡ 2019			
BSM§	5	±	3	a#	10	±	7	a	363	±	129	a	130	±	38	a

ASD	2 ± 1 a	38 ± 13 b	NA	NA
FUM	9 ± 4 a	44 ± 13 b	1933 ± 449 b	352 ± 45 b
NTC	142 ± 46 b	197 ± 33 c	997 ± 31 b	294 ± 53 b
P value	0.003	<.0001	0.004	0.004

[†]Analysis performed on log (1+ *P. penetrans*/ gram root)
[‡]Analysis performed on log (*P. penetrans*/ gram root)
[§]Treatments: BSM = *Brassica juncea:Sinapis alba* (1:1) seed meal; ASD = anaerobic soil disinfestation; FUM = soil fumigation; NTC = no treatment control
[#]Means in the same row followed by the same letter are not statistically different (*P* > 0.05).

Table 2. Effect of soil treatments on increase in tree diameter (mm) at 20 cm above the graft union.[†]

	Tonasket cv. TC2 r. B10	Rock Island cv. Wa38 r. M9	Rock Island cv. Wa38 r. G41	Othello1 cv. Wa38 r. G41	Othello2 cv. Wa38 r. G41
First year growth					
BSM[§]	5.8 ± 0.4 a	5.3 ± 0.4 a	5.9 ± 0.4 a	7.7 ± 0.2 a	NA
ASD	4.8 ± 0.2 b	4.1 ± 0.2 b	5.4 ± 0.3 a	NA	5.2 ± 0.4 a
FUM	6.1 ± 0.2 a	3.9 ± 0.3 b	5.1 ± 0.4 a	9.1 ± 0.5 a	NA
NTC	4.1 ± 0.2 c	2.9 ± 0.2 c	3.9 ± 0.2 b	8.2 ± 0.6 a	3.2 ± 0.6 b
P value	<0.001	<0.001	0.007	0.2	0.06
Second year growth					
BSM	6.4 ± 0.5 a	7.2 ± 0.4 b	7.1 ± 0.4 a	5.8 ± 1 a	NA
ASD	8 ± 0.3 b	7 ± 0.2 b	7.8 ± 0.2 a	NA	7.5 ± 1 a
FUM	8 ± 0.2 b	8.3 ± 0.3 c	8.1 ± 0.2 a	6.9 ± 0.3 a	NA
NTC	6.4 ± 0.7 a	5.5 ± 0.3 a	7.9 ± 0.3 a	7.2 ± 0.2 a	8 ± 2.1 a
P value	0.049	<0.001	0.11	0.34	0.68
Third year growth					
BSM				4.1 ± 0.4 a	
ASD				NA	
FUM				3.9 ± 0.2 a	
NTC				4.1 ± 0.1 a	
P value				0.83	

[†]Means in the same column followed by the same letter are not statistically different (*P* > 0.05).
[§]Treatments: BSM = *Brassica juncea:Sinapis alba* (1:1) seed meal; ASD = anaerobic soil disinfestation; FUM = soil fumigation; NTC = no treatment control

Table 3. Effect of soil treatments on fruit yield (bins/acre).

	Tonasket 2nd leaf	Othello1 2nd leaf	Othello1 3rd leaf
BSM[§]	1.3 ± 0.5 a	12.6 ± 1.6 ab	18.8 ± 1.3 ab
ASD	0.9 0.3 a	NA	NA
FUM	2.2 ± 0.1 a	16.6 ± 0.7 b	20.6 ± 0.5 b
NTC	1.4 ± 0.5 a	9.1 ± 2.3 a	15.6 ± 2.2 a

[§]Treatments: BSM = *Brassica juncea:Sinapis alba* (1:1) seed meal; ASD = anaerobic soil disinfestation; FUM = soil fumigation; NTC = no treatment control

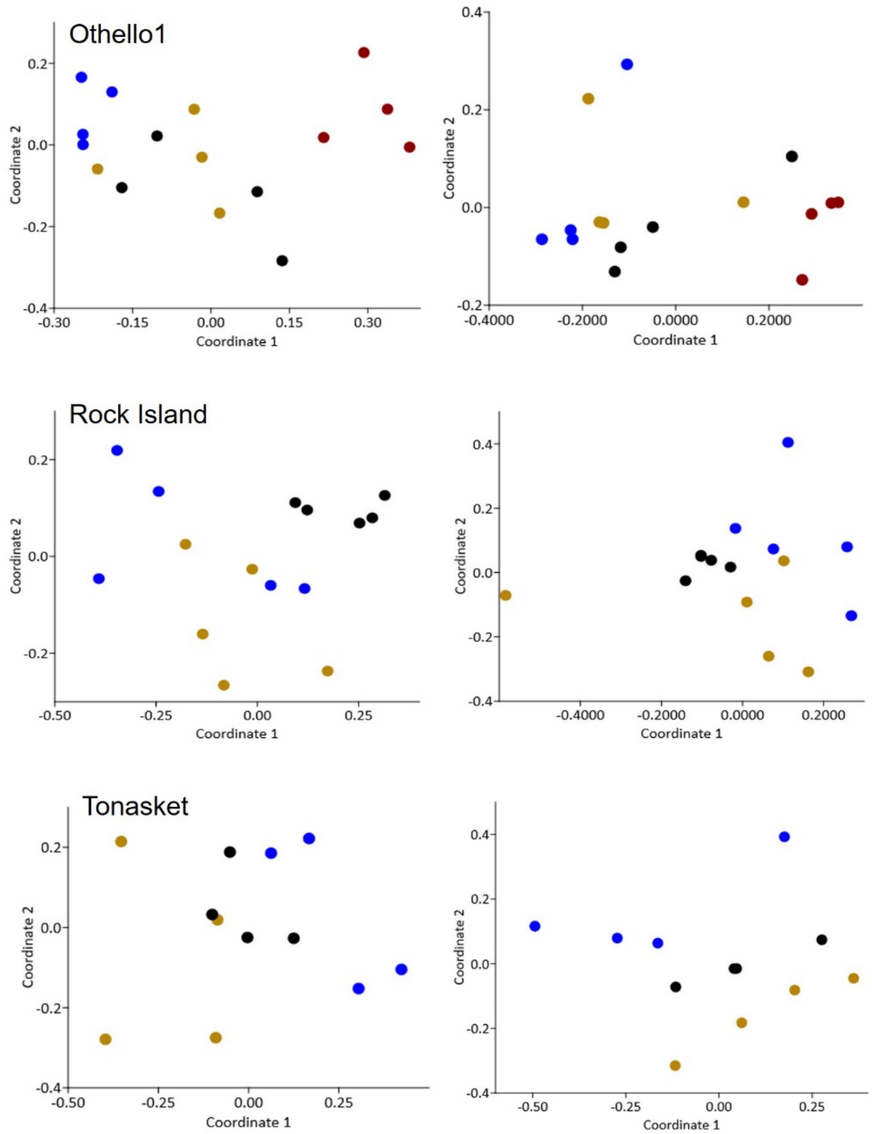

Figure 1 Effect of soil treatment on bulk soil bacterial and fungal community composition at three weeks post-treatment application as assessed by non-metric multidimensional scaling of terminal restriction fragment length polymorphism derived data using the Dice similarity index. Left panels represent bacterial data and right panels represent fungal data. Brassica juncea:Sinapis alba (1:1) seed meal = blue; Anaerobic soil disinfestation = gold; Fumigation = red.

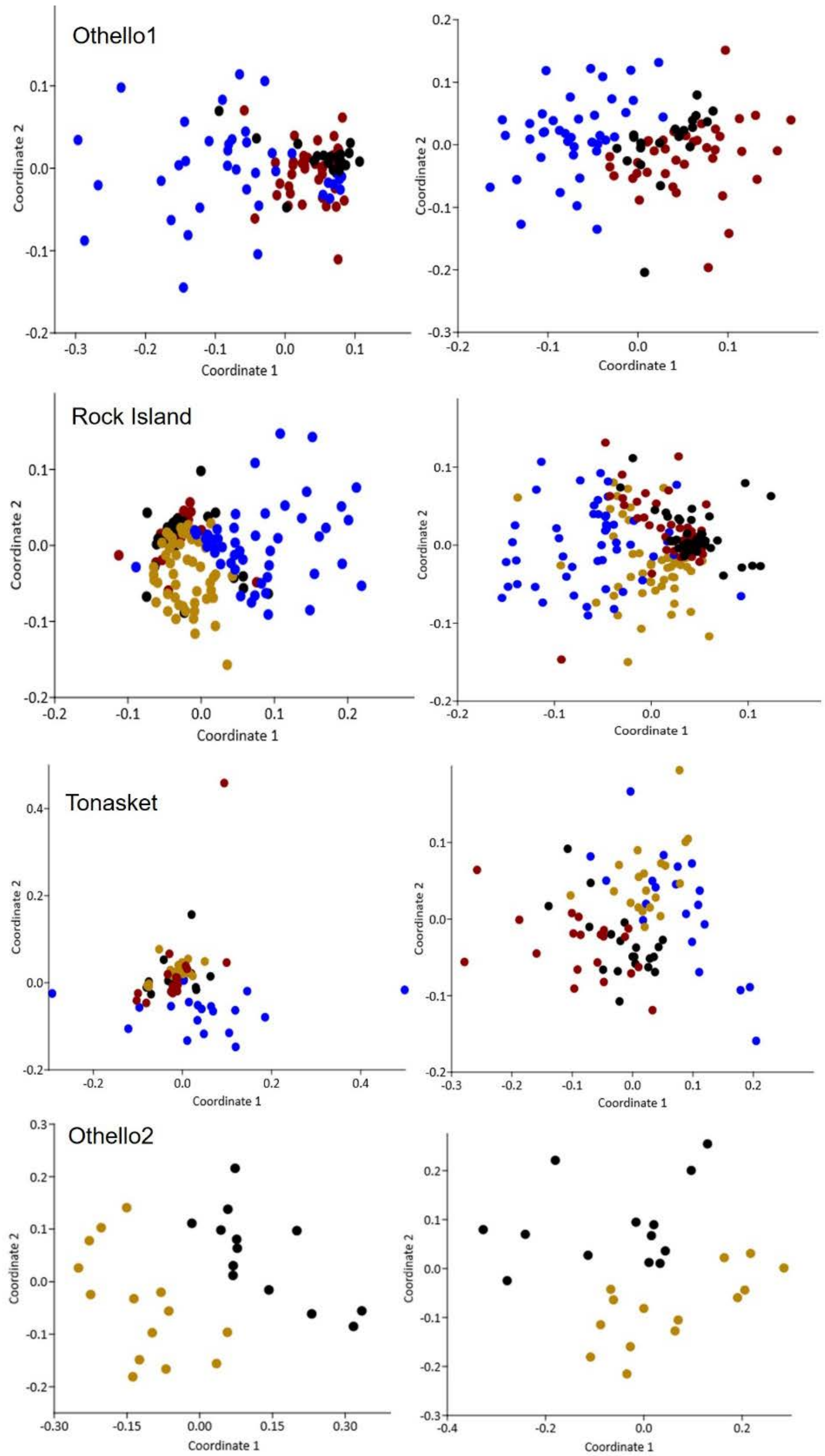

Figure 2. Influence of soil treatment on composition of microbial communities detected in the rhizosphere of apple cultivated in orchard replant soils. Ordination was conducted by non-metric multidimensional scaling (NMDS) of operational taxonomic units (OTUs) using the Bray-Curtis similarity index. Data describe the communities as detected in rhizosphere soil collected one year after treatment application. For all orchards, panels in the left column and right column represent the bacterial and fungal community, respectively. Treatments: Brassica seed meal = blue; anaerobic soil disinfestation = gold; 1,3-dichloropropene/chloropicrin fumigation = red; control = black.

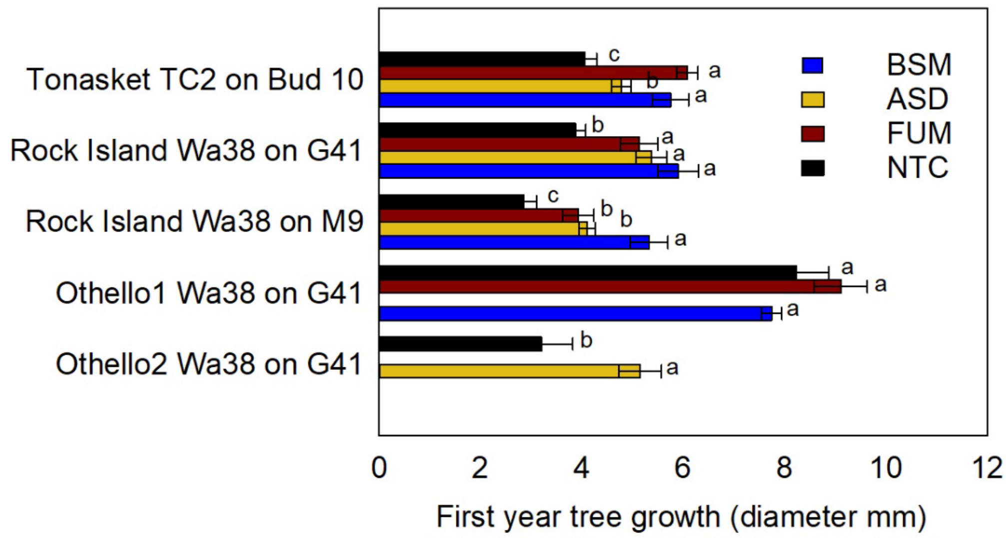

Figure 3. Effect of soil treatments on tree growth in the first year after planting measured as change in trunk diameter (mm) at 20 cm above the graft union. Brassica seedmeal (blue), fumigated control (red), no-treatment control (black).

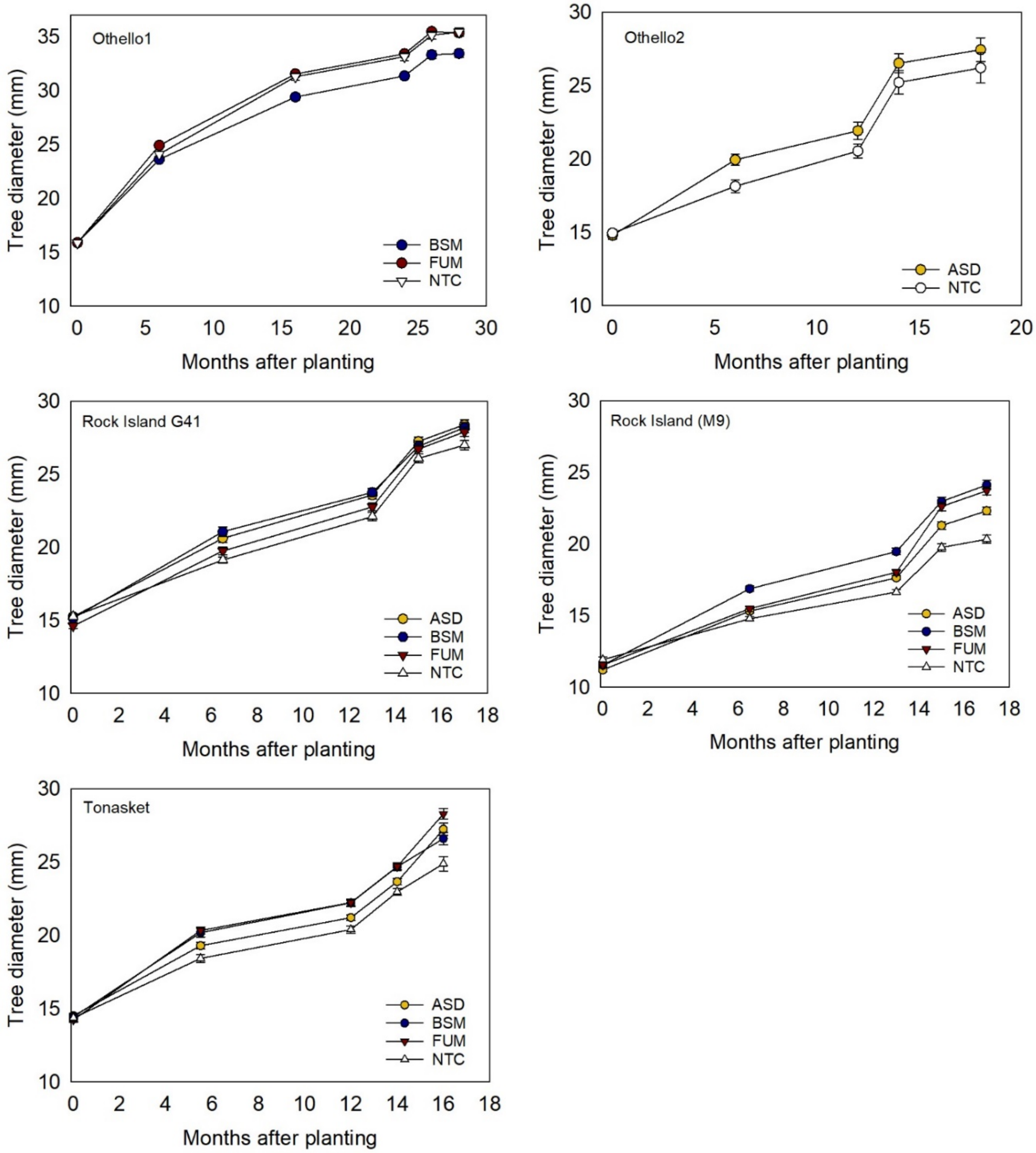

Figure 4. Effect of soil treatments on tree diameter (mm) at 20 cm above the graft union. [§]*Treatments: BSM = Brassica juncea:Sinapis alba (1:1) seed meal; ASD = anaerobic soil disinfestation; FUM = soil fumigation; NTC = no treatment control.*

Application Considerations

Brassica seed meal bio-renovation appears promising as an alternative to fumigating with 1,3-Dichloropropene, Chloropicrin. If considering this option growers should remember that not all brassica seed meals are equal. The seed meal used in this trial was a 1:1 formulation of *B. juncea* and *S. alba*. 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 growers 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.
It is also critical to 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. Application timing is critical. If used, orchardists will need to consider application timing to avoid phytotoxicity. A previous study demonstrated that applications made in the autumn prior to planting did not yield phytotoxic effects whereas spring applications resulted in tree death in some cases (Mazzola *et al*., 2015). Recent studies have shown that reduced applications rates (1/3 of current study) can result in the same level of disease control and also resulted in no phytotoxicity when spring applications were made (Wang and Mazzola, 2019). Application rate is important. The rate used in this trial was 0.4 lb per sq ft. Further studies at a large scale are needed to confirm whether reduced rates can be used. Additionally, at rates used in this trial (0.4 lb per sq ft), BSM applications including materials and labor cost approximately $5,900 per acre compared to $900 per acre for fumigation with 1,3-dichloropropene-chloropicrin a cost which may be prohibitively expensive depending on long term benefits (Appendix 4).

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. Lack of disease suppression obtained with the ASD treatment at Othello1 can likely be attributed to insufficient moisture, with a resulting failure to achieve anaerobicity and consequent absence of necessary changes to the soil microbiome (Hewavitharana et al. 2019). It will be essential to keep soil wet (above 30% moisture) and reach anaerobic conditions for success. Variable success in disease control obtained between sites in these orchard trials may also be influenced by the differences in composition of the replant disease pathogen complex. In sites with high *Pratylenchus* nematode populations higher carbon inputs and longer incubation times might be necessary for success. Previous studies have shown that grass carbon sources at a target rate of 8 ton per acre were most consistent for the specific apple replant disease pathogen complex present in Washington state (Hewavitharana and Mazzola, 2016) and were used in this study. However, carbon source quality and quantity may need to be adjusted based on the pathogen complex present at any specific orchard site to yield optimal disease control.

Changes in pesticide registration and additional research to refine application rates, methods and timings at a field scale are needed for widespread adoption of anaerobic soil disinfestation or *brassica* seed meal biorenovation. Product registrar Farm Fuels is working with the USDA IR4 program to complete the pesticide registration process. After registration specific use recommendations can be prescribed. Two opportunities for cost effective/practical brassica seedmeal applications include reduced rate spring applications and spot treatment for individual tree replants. Wang and Mazzola, 2019 provide good evidence of the potential of reduced rate applications that can be tested at the field scale. More efficient applications methods for ASD carbon sources such as the use of a bail chopper to apply hay carbon sources should be explored. Additionally, refining target moisture levels so that irrigation can be cycled will be key as continuous drip irrigation for three weeks is not practical when water resources are limited. Yield measurements from current plots on third and fourth year trees will provide more robust return on investment comparisons between treatments.

Extension

Results of research trials were shared with growers and consultants through field days, presentations, newsletter and popular press articles in addition to research reviews. Four field days with 130 total participants were conducted on August 7, 2019 as part of the WSU Sunrise Orchard Field Day and October 27,28,29 at research sites in Tonasket, Rock Island and Othello using social distanced mini-groups. Due to Covid19 events had to be adapted and attendance was limited. Four presentations were made to grower/stakeholder organizations with 260 participants (see below). Of participants surveyed 95% learned a good or great deal and 97% said they were likely to try biorenovation in the future (N=37). Fruit Matters article to be released in February/ March 2020 with publication of peer reviewed article contains application costs, suppliers and application considerations as well as research trial results (contact tianna.dupont@wsu.edu for a pdf prior to publication date). The pesticide label for the *brassica* seed meal product is still pending. Until the product is labeled WSU cannot give recommendations.

Presentations

2020. Alternative Controls for Replant Disease. APAL Australian Growers Association. Webinar. *(invited)*

May 14, 2020. IPM Methods to Control Replant Disease of Tree Fruit. DuPont, S.T., Mazzola, M., Hewavitharana, S. Western Integrated Pest Management Center. Annual Meeting. Webinar.

January 21, 2020. Orchard Biorenovation. DuPont, S.T., Mazzola, M., Hewavitharana, S. GS Long Organic Grower Meeting. Yakima, WA. *(invited)*

February 6, 2020. Replant Disease Project. DuPont, S.T., Mazzola, M., Hewavitharana, S. Northwest Wholesale Grower Meeting. Royal City. WA. *(invited)*

Articles and websites

DuPont, S.T., S. S. Hewavitharana, M. Mazzola. Evaluating IPM Methods to Control Apple Replant Disease. Australian Fruit Growers Magazine. V. 14. Issue 3. Spring 2020.

DuPont, S.T., S. S. Hewavitharana, M. Mazzola. Evaluating IPM Methods to Control Apple Replant Disease. WSU Fruit Matters. March 2021. http://treefruit.wsu.edu/article/replant_trials/

DuPont, S.T., S. S. Hewavitharana, M. Mazzola. Field scale application of *Brassica* seed meal and anaerobic soil disinfestation for the control of apple replant disease. Applied Soil Ecology. Submitted September 26, 2020.

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
Brassica seed 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**
Brassica seed meal 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**
Brassica seed 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 for 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
Total cost				***$635***
Anaerobic Soil Disinfestation (ASD) - Hay carbon source				
Field activity		**hrs/A**	**$/hr**	**$/A**
pre-irrigate		3	$14	$41
apply grass hay (timothy)		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
grass hay (timothy)	$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
Brassica seed meal application		2	$13	$26
incorporation		2	$13	$26
tarping		2	$13	$26
Supplies	**$/unit**	**unit**	**unit/A**	
Brassica seed 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

Hewavitharana, S.S., Mazzola, M., 2016. Carbon source dependent effects of anaerobic soil disinfestation on soil microbiome suppression of Rhizoctonia solani AG-5 and Pratylenchus penetrans. Phytopathology 106, 1015–1028.

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Liu, L., Kong, J., Cui, H., Zhang, J., Wang, F., Cai, Z., 2016. Relationships of decomposability and C/N ratio in different types of organic matter with suppression of Fusarium oxysporum and microbial communities during reductive soil disinfestation. Biological Control 101, 103–113.

Mazzola, M., Hewavitharana, S.S., Strauss, S.L., 2015. Brassica seed meal soil amendments transform the rhizosphere microbiome and improve apple production through resistance to pathogen reinfestation. Phytopathology 105, 460-469.

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EXECUTIVE SUMMARY

Project title: Implementation of Alternative Methods to Control Replant Disease

Key words: replant disease, mustard meal, biorenovation, soil microbiome

Abstract:

Apple replant disease causes stunting and reduced yields when apples are planted in locations previously cropped to tree fruit. Anaerobic soil disinfestation and bio-renovation using mustard seed meals may provide an alternative to fumigation controlling plant pathogens and leading to beneficial long-term changes in soil microbial communities. One-to-twelve acre trials were conducted in Othello, Rock Island and Tonasket to examine alternative techniques at the field scale and to track impacts on tree growth, yield and profits over time. Brassica seed meal treatments (BSM) successfully altered soil microbial communities and were associated with apple tree growth that was as great or greater than fumigated controls across all three study locations in year one. Anaerobic soil disinfestation (ASD) resulted in significant changes in composition of the rhizosphere microbiome and tree growth in year one that was better than the no-treatment control in three of four experiments but not always greater than the fumigated control.