FINAL REPORT ON
PROJECT FUNDED BY THE SOUTHERN REGION SMALL FRUIT CONSORTIUM

SRSFC PROJECT #: 2019-R-03

PROJECT TITLE: INTEGRATED SYSTEMS FOR MANAGING SOIL-BORNE DISEASES IN STRAWBERRY PRODUCTION IN NORTH CAROLINA

NAME, MAILING AND EMAIL ADDRESS OF PRINCIPAL INVESTIGATOR(S): Frank J. Louws[1], and Tika Adhikari[2], [1]Department of Horticultural Science, Campus Box 7609; Shipping: 2721 Founders Dr; 118 Kilgore Hall, and [2]Department of Entomology and Plant Pathology NC State University, Raleigh, NC, 27695-7609. E-mail: frank_louws@ncsu.edu, and tbadhika@ncsu.edu.

PUBLIC ABSTRACT

Strawberries constitute one of the most widely grown fruit crops in the United States (USDA, National Agricultural Statistics Service). In the SEUS (and north of Florida) 4643 acres of plasticulture strawberries are grown for a total of 92.6 million lbs and a gross farm gate value of $95.6 million. In the Southeast, strawberries are grown as an annual crop. Over the last 15 years, we have conducted extensive work, including widespread on-farm-research with strawberry growers (Louws 2009; Welker et al. 2008) to enable them to transition away from the ozone-depleting fumigant, methyl bromide. Many growers in the SEUS have adopted Pic-Clor60, a combination of 60% chloropicrin and 40% 1,3 dichloropropene. However, these chemicals are also biocide gases and recent very strict fumigation mitigation efforts and management plans required by EPA have shifted growers toward seeking alternative production systems (Tutor et al. 2010) that do not depend on fumigants. In addition, the intensive systems with low carbon inputs into the soils, lack of rotation, and high fumigant dependency has led growers to report that their soils are getting "poor". A farming systems approach is rooted in the core premise that biologically based solutions and different types of farming system approaches can be developed (Grabowski 2001) and economically implemented and assessed (Rysin et al., 2015; Sydorovych et al., 2006). Management systems that we have evaluated and continue to develop include the utility of compost, cover crops, crop rotations, amendments with beneficial microbes, biofumigation/amendment of soils with a mustard meal, and the use of anaerobic soil disinfestation (ASD) methods (Louws et al., 2000; Schonbeck and Morse, 2004; Schroeder-Moreno M. 2010. Shennan et al., 2009; 2016). We also have advanced novel biological control agents (BCAs) as potential products for use in strawberry production systems (Leandro et al. 2007a,b; Torres-Barragan et al. 2013) and in the long-term, these will be integrated into biologically-based production systems.

This final report highlights our work conducted in the 2018-2019 season. However, hurricane Florence deposited 32 inches of rain at the experimental site after most treatments were installed, forcing the abandonment of the study. In 2019-2020, COVID19 emerged just as the final plant parameter data and fruit harvest data were to be secured. We were able to collect total yield (managed by the on-site station personnel), plant growth, and soil measurement parameters (also sampled by station personnel but processed in the NC State Labs) under special permission. In this study, different carbon sources also had a dramatic effect on the soil health metrics and pH values

soon after application (~3 weeks) as measured at planting time. ASD treatments and the fumigant also increased yield by 17% to 27%. The yield was fostered by superior plant growth as measured by crown and leaf growth. Thus, our results illustrate the potential for gains in productivity through investment ASD and improvement of soil biological health.

RESEARCH OBJECTIVE: Our main objective was to advance strawberry production systems and to manage these BRR pathogens is through a farming systems approach that preserves soil quality and health.

MATERIALS AND METHODS

Treatments evaluated are included inTable 1. Summer legume/grass (Cowpea : Pearl Millet, 100:10 lb/A) was field-sown in late June. The summer cover was managed for optimum growth until the 19 September and then flail mowed to allow cut residue distribution evenly on the cover crop plots. Compost (12 Tons/A), produced using the Controlled Microbial Compost (CMC) system, was amended to these plots just before seeding. The cover crop and compost were soil incorporated 8 to12 inches deep using a PTO driven rototiller. Beds were pulled and covered with totally impermeable film (TIF) with two drip tape buried 2 to 4 in deep and spatially distributed in the bed. Cover crop residues were left under these conditions until strawberry plants were transplanted (3 weeks later). The cover crop was highly labile upon incorporation and plastic beds pulled well. In this study, the cover crop + compost plots were also flooded with water.

Table 1. Ten treatments were used in field experiments for 2018-2019 and 2019-2020.

Table of treatments applied				
1		PicClor-60		175 lbs/A PicClor 60
2		No fumigation/amendments		None
3		Cover crop + compost		see text
4		ASD carbon source 1	Molasses full rate	5000 lbs/A
5		ASD carbon source 2	Molasses half rate	2500 lbs/A
6		ASD Carbon source 3	Mustard meal half rate	1000 lbs/A
7		ASD clear plastic carbon source 1	Molasses full rate	5000 lbs/A
8		Clear plastic only	No fumigation	None
9		Mustard meal	Mustard meal Full Rate	2000 lbs/A
10		Mustard meal + carbon source 1	Mustard meal half rate/Molasses half rate'	As above

ASD beds were established 18-20 September 2019. Drip irrigation was applied (via the two buried lines) within 16-24 hours to saturate the beds and induce anaerobic conditions in the topsoil. Redox electrodes hooked up to Campbell Scientific dataloggers were used to assess real-time changes in the redox potential (anaerobic state) of the soil. Carbon treatments included molasses (5000 lbs/A; full rate) or half rate (2500 lbs/A) and Mustard Meal (Biofence) applied at 2000 lbs/A (full rate) or half rate (1000 lbs/A). An additional treatment consisted of half rate of each. In addition, molasses at the full rate was covered with clear plastic. The most common commercial fumigant, Pic-Clor60 was used as a control and injected into the beds during the bed formation process at 300lbs/treated A (positive control). Untreated controls included beds overlain with TIF or clear plastic but without a fumigant or amendments.

Strawberry plants were fieldset 22 Oct 2019; managed over the winter and harvested from mid-April to Mid-June based on 8 weekly harvests. Whole plant samples were collected at peak harvest to assess plant dry weights of the crowns and leaves. Field soil samples were collected as a baseline at cover crop seeding (from each rep), at planting from each plot, and again at peak harvest and 12 months later. Soils were analyzed for nutrient, pH, carbon, microbial activity, and soil health parameters. Parasitic nematode profiles were also secured on these same sampling dates (*data not shown*).

Data were analyzed according to the experimental design which was a randomized complete block design with four blocks (replications) and the 10 treatments. Each plot consisted of 3 beds 30 feet long planted to strawberries in twin rows on 12 in * 12 in spacing and offset in the twin rows. All experimental data were secured from the inner 20 plant zone of the inner bed to limit inter-plot interference. Yield data were analyzed using a two-way repeated-measures analysis.

RESULTS

Total yield was assessed weekly; cumulative yields were calculated in lbs/A and ranged from 4260 to 15829 lbs/A (Figure 1). PicClor60, Molasses + Mustard combined at half rates (Mol+Must ½), Molasses applied at full rates (Mol Full) and Mustard meal applied at ½ rate (Must ½) generated similar total yields (Figure 1). Mustard meal at the full rate (Must Full) and Molasses at the ½ rate (Mol ½) generated intermediate yields and did not offer a benefit compared to the untreated control covered in TIF with no amendments of fumigant (UTC STD). The compost/Cover crop (CC+Comp) and plots covered with clear plastic, amended with Mustard Meal Full rate (Must Full CLR) or not amended (UTC CLR) had the lowest yields.

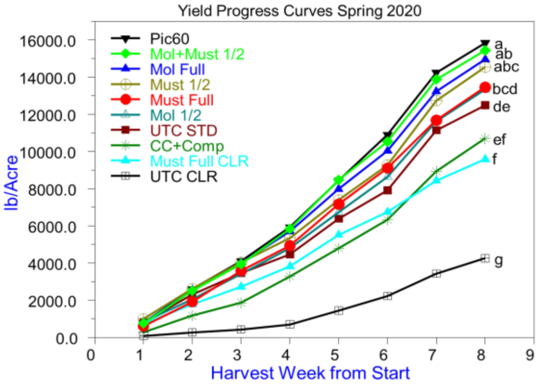

FIGURE 1: Cumulative yield (April to June) over eight weekly harvests as impacted by pre-plant soil treatments. Progress curves followed by the same letter are not significantly different from each other based on repeated measures analysis and the Fisher Protected LSD (P = 0.05). Acronyms are described in the text.

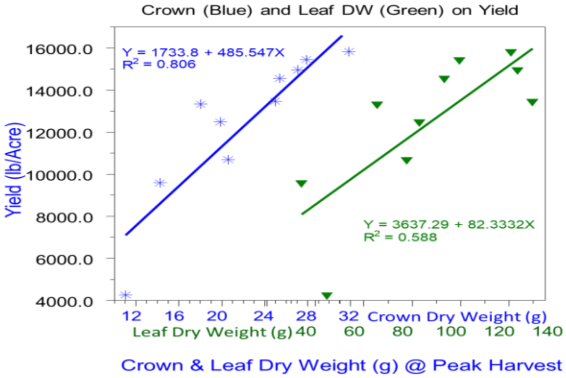

FIGURE 2: Dry weight of plant parts measured at peak harvest and as impacted by pre-plant soil treatments and their effect on total yield. Regression analysis shows the regression formula and regression coefficient for each parameter. Note X-axis has two scales representing each parameter.

Soil health parameters were highly impacted by treatment at planting, were all similar at peak harvest (Figure 3). The Soil Health index utilizes the 1-day CO_2-C divided by the organic C:N ratio plus a weighted organic carbon and organic N addition. The 1-day CO_2-C is determined as an indicator of microbial respiration utilizing an IR Gas Analyzer CO_2-C and is expressed as ppm/24 hrs after the soil has been dried then rewetted using protocols developed by Cornell Soil Health Testing protocols (https://soilhealth.cals.cornell.edu) and analyzed by Brookside laboratories, Inc, Ohio. In the case of this study, Soil Health Indices were correlated with the 1-day CO_2-C respiration assay [$Y = -5.79871 + 7.95136X$, EMS = 9.4005 $R^2 = 0.977$], data not shown. This suggests microbial activity at the time of sampling was the main driver impacting the Soil Health Index. The pH of the soils was also impacted by treatment. The pH values diverged significantly by planting time in 2019 (range 4.95 to 6.18), migrated closer together by peak harvest, and were all similar (range 6.15 to 6.3) after 12 months (Figure 4).

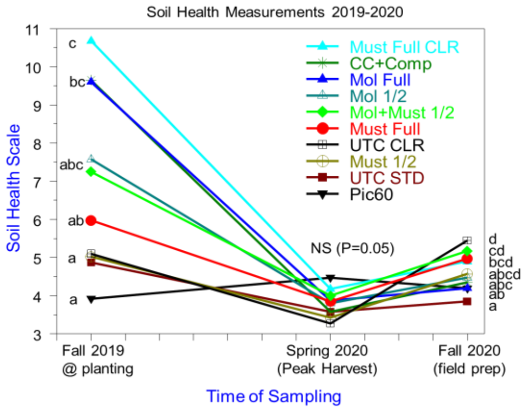

FIGURE 3: Soil Health Index values as calculated from soil samples taken at planting time (October 2019), peak harvest (June 2020), and just before field preparation 1 year later. Values within a sample date and followed by the same letter are not significantly different from the one-another based-on analysis of variance and Fisher's Protected LSD (P = 0.04) as impacted by pre-plant soil treatments.

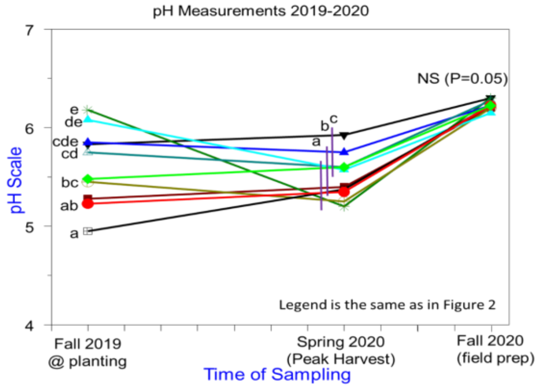

FIGURE 4: pH values as measured from soil samples taken at planting time (October 2019), peak harvest (June 2020), and just before field preparation 1 year later. Values within a sample date and followed by the same letter are not significantly different from the one-another based-on analysis of variance and Fisher's Protected LSD (P = 0.04) as impacted by pre-plant (fall 2019) soil treatments.

IMPACTS

Biologically based soil treatments were as effective as the standard fumigant in advancing plant growth and associated total yields. The flooding of beds covered with totally impermeable film (TIF) soon after carbon addition is designed to induce anaerobic conditions. This process of ASD is known to be suppressive to many soilborne pathogens and weed seeds (weed data analysis has not been completed yet). The most important problem our growers face is black root rot (BRR) caused by a complex of pathogens. Among them, *Pythium irregulare and Rhizoctonia fragariae* AG-A, AG-G predominated (Ferguson et al. 2003; Torres-Barragan et al. unpublished). The BRR complex does not kill plants but causes plant stunting and associated yield reductions of 20 to 40%. In this study, ASD treatments and the fumigant increased yield by 17% to 27%. Yield was fostered by superior plant growth as measured by crown and leaf growth, consistent with experience in NC and the Southeast USA.

The carbon-based treatments under TIF did not differ from one-another suggesting growers may have multiple options to induce ASD conditions. Many carbon sources have been used in strawberry research programs and by commercial growers. This study sought to document some of the physical, chemical, and biological parameters as impacted by pre-plant soil treatments. Treatments had a dramatic effect on the Soil Health Index and pH values soon after application (~3 weeks) as measured at planting time.

Additional work will be needed to reduce carbon costs – in many regions, ASD has been induced using various industry by-products. However, there is substantial evidence that ASD is a viable strategy to manage many soilborne diseases and weeds and to generate competitive yields for growers who are not able to fumigate or seek non-fumigant tactics in their farming systems. This project combined with other national initiatives should add to a body of knowledge that will help refine the ASD system for expanded commercial implementation.

LITERATURE CITED

1. Ferguson LM, Louws FJ, Abad ZG, Fernandez GE, Poling EB, Brannen PM. 2003. Impacts of alternatives on strawberry yield and root colonization by fungal pathogens. Proc Int Res Conf on Methyl Bromide Alternatives and Emissions Reduction. 56/1-56/8.
2. Grabowski MA. 2001. Biologically- and chemically-based alternatives to methyl bromide fumigation in strawberry production. NCSU MS thesis. pp 113.
3. Leandro LFS, Ferguson LM, Louws FJ, Fernandez GE. 2007a. Strawberry growth and productivity in fumigated compared to compost- amended production systems. HortScience 42: 227-231.
4. Leandro LFS, Guzman T, Ferguson LM, Fernandez GE, FJ Louws. 2007b. Population dynamics of *Trichoderma* in fumigated and compost-amended soil and on strawberry roots. Applied Soil Ecology 35:237-246.
5. Louws FJ. 2009. IPM for soilborne disease management for vegetable and strawberry crops in SE. In: Plant Pathology in the 21st Century: Contributions to the 9th International Congress. Gisi U, Chet I, Gullino, ML (Eds.) Springer, New York, 217-227.
6. Louws FJ, Grabowski MA, Fernandez GE, J & B Vollmer. 2000. Compost as an alternative to methyl bromide in plasticulture strawberry production. Proceedings of the International Research Conference on Methyl Bromide Altern. and Emissions Reduction. 33/1 – 33/2.
7. Rysin, O., A. McWhirt, G. Fernandez, F.J. Louws, and M.Schroeder-Moreno. 2015. Economic viability and environmental impact assessment of three different strawberry production systems in the Southeastern United States. HortTechnology 25: 585-594.
8. Schonbeck M and Morse R. 2004. Choosing the best cover crops for your organic no-till vegetable system. http://www.newfarm.org/features/0104/no-till/chart.shtml.
9. Schroeder-Moreno M. 2010. Selecting cover crops for diverse functions: an integrated soil management approach for organic strawberry production in North Carolina. Sustainable Agriculture Research and Education Project Final Report. Project Number: LS07-200 http://mysare.sare.org/mySARE/ProjectReport.aspx?do=viewRept&pn=LS07-200&y=2010&t=1
10. Shennan, C.; Muramoto, J.; Baird, G.; Zavatta, M.; Toyama, L; Mazzola, M. and Koike, S. T. 2016. Anaerobic soil disinfestation (ASD): A strategy for control of soil-borne diseases in

strawberry production. International Symposium on Innovation In Integrated And Organic Horticulture (Innohort). Acta Horticulturae 1137:113-119.

11. Shennan, C, Muramoto, **J.,** Koike, S., Bolda, M., and Daugovish, O. 2009. Optimizing Anaerobic Soil Disinfestation for Non-fumigated Strawberry Production in California. Proceedings of the Annual International Research Conference on Methyl Bromide Alternatives and Emissions Reductions: 101.1-101.3.
12. Shinmura A. 2000. Causal agent and control of root rot of Welsh onion. PSJ Soilborne Disease Workshop Report 20:133-143 (in Japanese with English Summary).
13. Sydorovych,O., C.D. Safley, L.M. Ferguson, E. B. Poling, G.E. Fernandez, P.M. Brannen, D.M. Monks and F.J. Louws. 2006. Economic evaluation of the methyl bromide alternatives for the production of strawberries in the Southeastern US. HortTechnology 16:118-128.
14. Torres-Barragan, A., P. Tran and F. J. Louws. 2013. The use of growth-promoting bacteria isolated from wild strawberry for the management of strawberry black root rot. Phytopathology 103:S134.
15. Tutor, R., B. Bruss, D. Wechsler, W. Buhler, A.Mila, B. Shew, S. Koenning, F. Wright, R. Welker and F.J. Louws. 2010. A multi-institutional public and private response to risk mitigation measures for soil fumigants**.** Proc. of the Int. Res. Conf. on Methyl Bromide Alternatives and Emissions Reduction. 45/1-45/2.
16. Welker, R.M., F. J. Louws, J. G. Driver, J.P. Smith, and C.A. Schiemann. 2008. On-farm research and extension activities to implement MB alternatives: an area-wide initiative update. Proc. of the Int. Res. Conf. on Methyl Bromide Alternatives and Emissions Reduction. 9/1-9/3. http://mbao.org/2008/Proceedings/009WelkerRMBAOAREAWIDEFJL.pdf