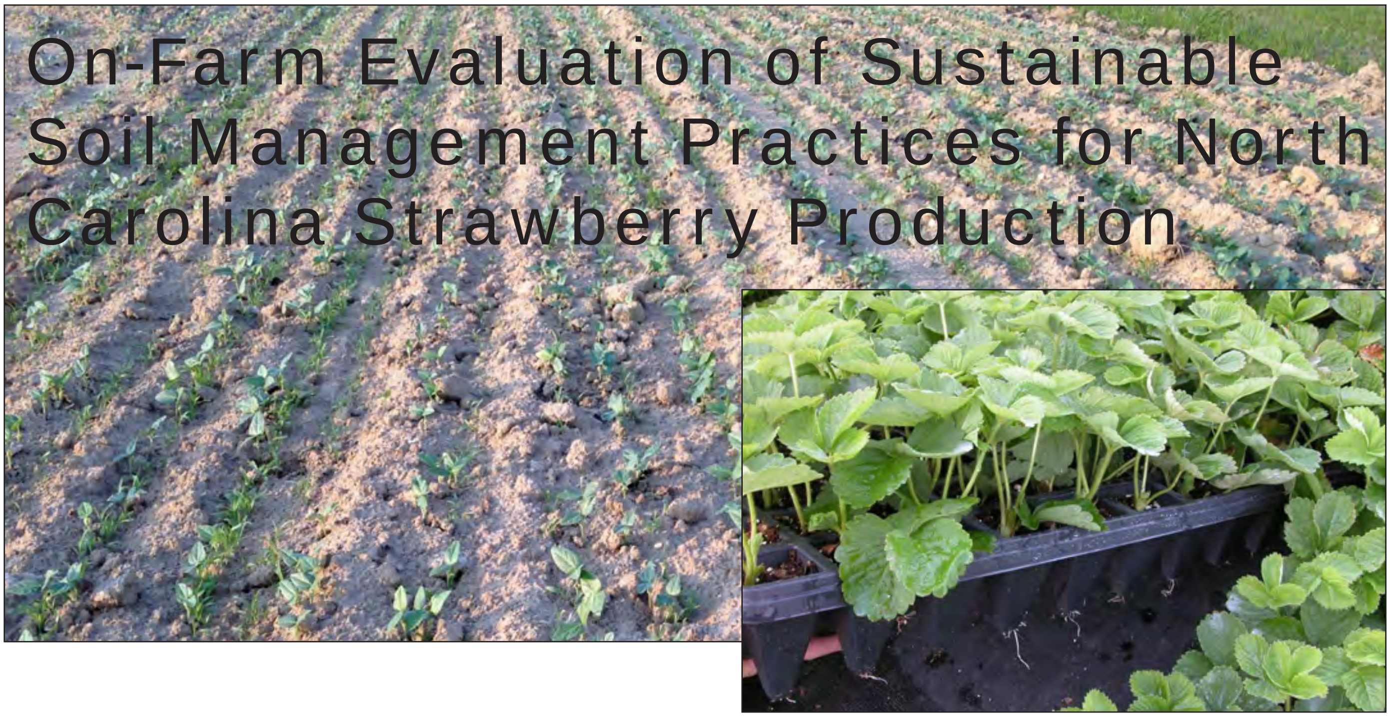
On-Farm Evaluation of Sustainable Soil Management Practices for North Carolina Strawberry Production



Our research project sought to evaluate whether soil management practices that are aimed at improving soil health (sustainable soil management practices) can have an impact on yields, fruit quality, and measures of soil health in both traditionally fumigated and non-fumigated strawberry production systems. The practices we evaluated were: compost applied at 7.5 tons per acre; a summer cover crop of 100 lbs of cowpea + 10 lbs. pearl millet; plug plant inoculation with vermicompost and native arbuscular mycorrhizal fungi (AMF); and various combinations of these practices including Compost + Cover Crops and Compost + Cover Crops + Plug Inoculation (ALL). These treatments were applied in both fumigated (Pic-Clor 60) and non-fumigated plasticulture systems.

Our main research questions were:

1. When compared between the two fumigation systems, what effect do these practices have on yield, fruit quality, and measures of soil health?

2. Can good soil microbes be reintroduced into fumigated systems via plug inoculation?

This study was conducted over the 2014 and 2015 seasons at the Center for Environmental Farming Systems (CEFS) in Goldsboro, NC. We also worked with five farmers to explore the use of inoculated plugs on their farms; one of these also initiated a wide range of sustainable soil management practices in association with the project. All research station plantings used the Chandler strawberry cultivar, while farms raised a variety of cultivars.

Project members were Drs. Michelle Schroeder-Moreno, Gina Fernandez, Yasmin Cardoza, and Hannah Burrack, and Amanda McWhirt. For more information, contact Amanda McWhirt, almcwhir@ncsu.edu.

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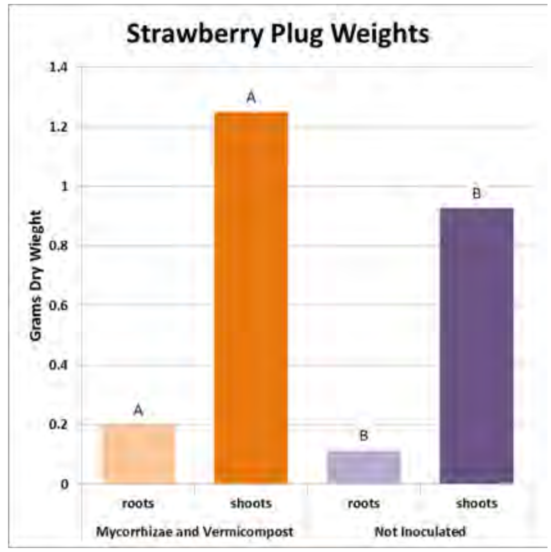
Research Station Results

Effects on Plant Growth

There were no strong effects of the soil management practices on plant growth except for with plug inoculation. In both years plug inoculation led to larger plugs at the time of planting, and in 2015, inoculated plugs had a larger root system in the non-fumigated plots as measured at 5 different points during the spring season. Fumigation increased crown weights in 2014, and overall plant size in 2015.



Yield Results

In both years we observed that certain management practices impacted yield differently depending on whether they were used in fumigated or non-fumigated production.

In some cases, management practices had different effects on yield when combined with other practices. There did not, however, seem to be an additive effect, where if two practices performed well apart, their effect was increased when the practices were combined.

In 2014,

- Fumigation did not increase yield.
- Plug inoculation increased yield in the non-fumigated system, compared to its control.
- Cover crop alone increased marketable yields in the fumigated system, compared to its control.
- Cover crop alone increased total yields in the fumigated system as compared to the non-fumigated system.

In 2015,

- Fumigation did increase yield.
- No soil management practice was different for total yields from its control within the same fumigation system.
- Cover crop alone increased total yields in the fumigated system as compared to the non-fumigated system.
- Cover crop + compost in the non-fumigated system was no different from the fumigated control.

Average Total Yields per Plant (lbs)

	2014	2015
Non-Fumigated	1.28 a	0.90 b
Fumigated	1.37 a	1.05 a

2014: Planted on Oct 4th , low temperature of 3.6° F on 1/30/14.

2015: Planted on Oct 14th , 9.7° F on 2/20/15, 25.4° F on 3/29/15 (many blossoms lost during this freeze). Southern stem blight caused by the soilborne pathogen Sclerotium rolfsii *was found in some plots in the late part of the season and was more concentrated in the non-fumigated plots.*

Conclusions

Soil management practices did not impact yields within each fumigation systems in a consistent manner over the two years they were studied. However, when averaged over the two years, plug inoculation yielded the highest in both fumigation systems and cover crops alone yielded the highest in the fumigated system.

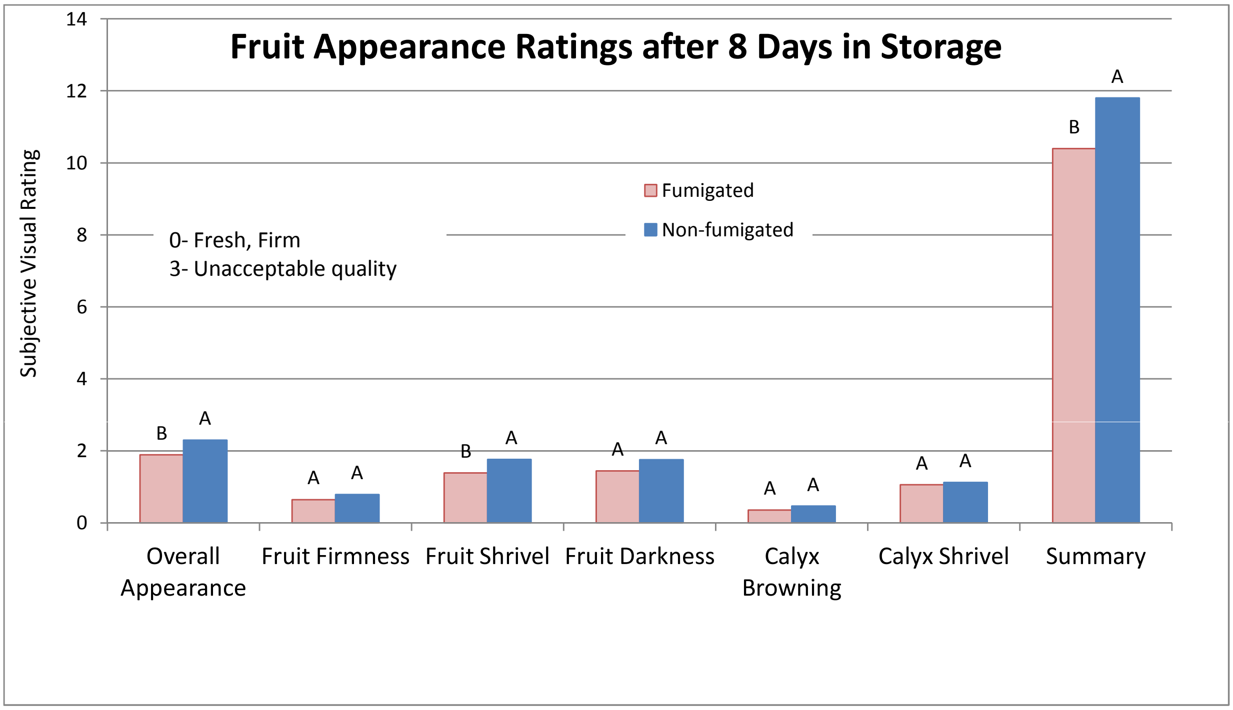
Average Per Plant Total Yield for the Two Seasons

Lbs per plant

	Fumigated	Non-Fumigated
Management Practice		
All	1.2 abc	1.1 abc
Compost + Cover Crop	1.1 abc	1.0 bc
Cover Crop	1.3 a	1.0 c
Compost	1.2 abc	1.1 abc
Plug Inoculation	1.3 ab	1.3 ab
Control	1.2 ab	1.1 abc

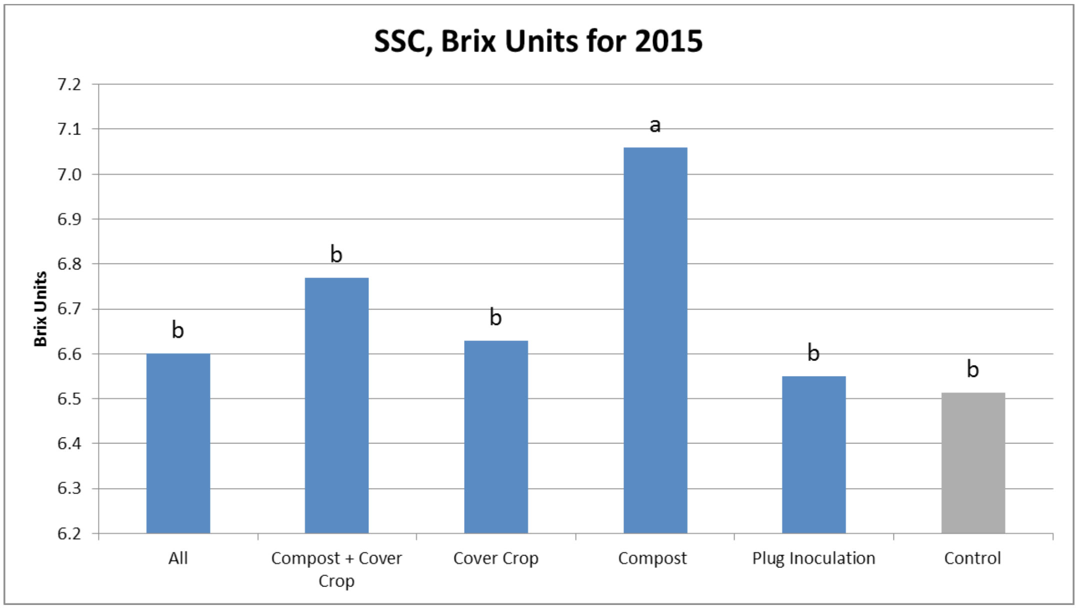
Fruit Quality Results

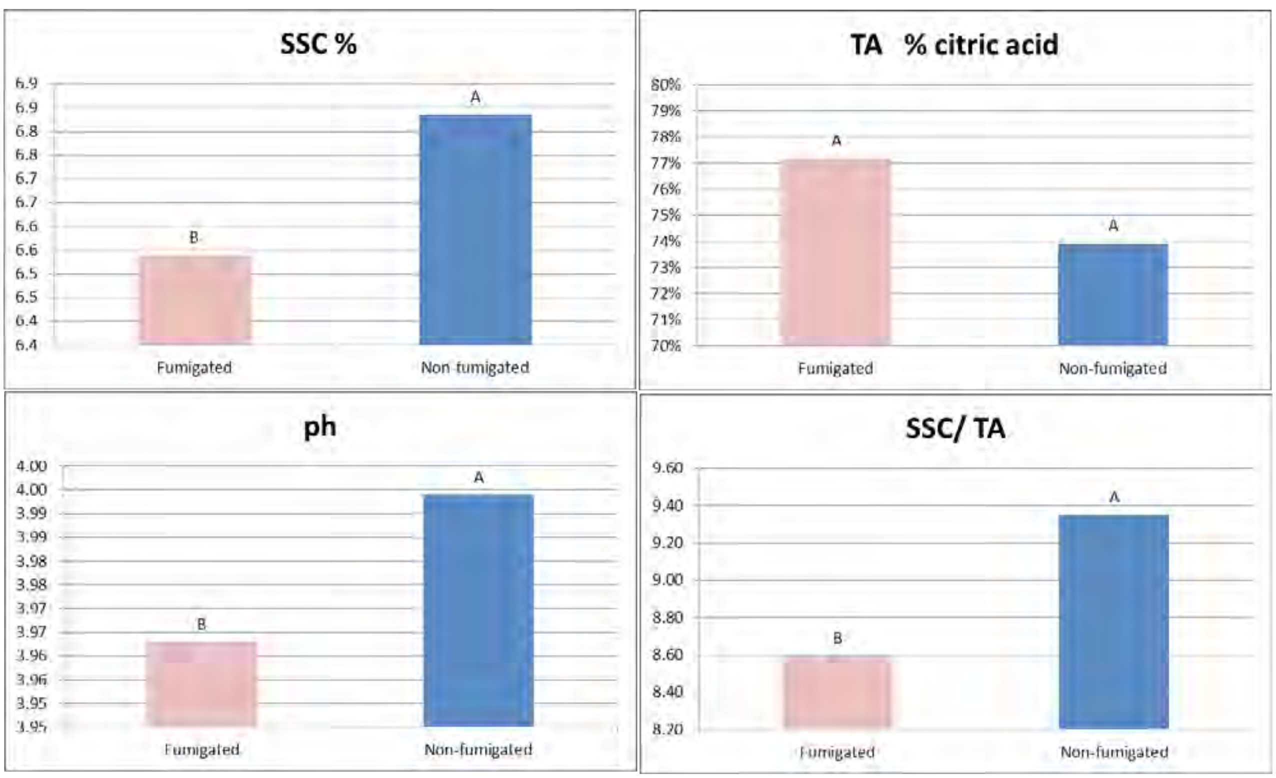
We only measured fruit flavor and shelf life in 2015, after our pickers at the research station noted that the non-fumigated berries "tasted sweeter" in 2014. In order to verify this, we collected berries on 3 different dates during the 2015 season and evaluated them for shelf life and flavor. *Lower* values in the chart below indicate *higher* quality. Fumigated berries had better quality after 8 days in refrigerated storage than unfumigated berries.



Measures of fruit flavor for Spring 2015

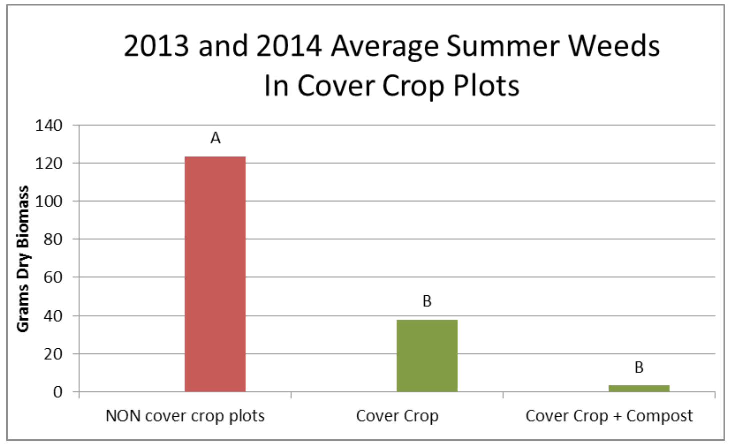
There were strong differences in flavor properties between fumigated and non-fumigated berries, as shown below. SSC = brix, a measure of sugar. TA % Citric Acid = a measure of the acid flavor. SSC/TA is the measure of the ratio of these two. Berries grown with compost alone had the highest brix levels.





Changes to Soil Health

Effects on summer weeds



Cover crops reduced weeds, and there was a slight additional reduction in weeds in those which also received compost, which may indicate more rapid cover crop establishment. Cover crop biomass was not different between plots that received compost prior to cover crop establishment and the non-compost plots.

Effects on soil stability, ability of the soil to resist erosion

After the second year, the non-fumigated plots had a higher measure of the soil being able to withstand erosion. Soil microbes contribute in part to this ability due to glue-like substances they excrete into the soil that bind soil particles together. We are still investigating this result.

Effects on nematodes

In nematode sampling in late May and early June of both 2014 and 2015, there was no effect of fumigation or soil management practices on nematode populations.

Effects on soil microbial communities

In sampling the size of the soil microbial community in early June of 2015, there was a significant effect of fumigation on reducing the soil microbial community. There was an effect of compost on increasing certain good microbes and reducing others in both the fumigated and non-fumigated system. We are still investigating these changes.

Nutrients Applied with Compost and Cover Crops

In both years compost and cover crops supplied sufficient pre-plant Nitrogen.

Pre-Plant Nutrients Supplied by Compost and Cover Crops

	Compost lbs / acre			Cover Crop lbs / acre			Total Nutrients Applied lbs / acre		
	N	P	K	N	P	K	N	P	K
2014	40.1	29.9	62.1	46.8	2.2	12.638	86.9	32.1	74.7
2015	31.9	51.2	34.0	45.3	2.4	12.2	67.3	53.6	46.3

These values are for estimated nutrients that will be available to the strawberry crop, not the total amount of nutrients applied. In general, it is estimated that 50% of organic N from compost will be available for plant uptake within the first year (this percentage is dependent on the C:N ratio), while 70 to 80% of P and 80 to 90% of K will be available.

Benefits of Each Management Practice

Plug Inoculation

On average, plants from inoculated plugs yielded the highest (1.3 lbs per plant) in both the fumigated and non-fumigated systems. This seems to be related to an increase in berry size, not number of berries. This practice did not reintroduce arbuscular mycorrhizal fungi (AMF) into fumigated systems in either our on-farm or research station plots.

Compost

Application of compost consistently increased measures of soil fertility in both years. Application of compost tended to increase soil pH slightly; annual soil testing would be advisable to avoid cumulative long-term effects. It also increased brix (measure of sugar) in the fruit quality. It can supply significant quantities of N, P and K and had some effect on increasing certain beneficial groups of soil microbial populations in both the fumigated and non-fumigated system.

Cover Crops

Cover crops increased yields most in the fumigated system. This may be due to increase nitrogen release in the fumigated system. They also reduced summer weeds and can supply a significant quantity of N.

Fumigation vs. Non-fumigation

Fumigated plots tended to yield slightly higher. Non-fumigated plots began flowering and yielding earlier in both years (approximately 5-7 days). They also had a flatter harvest curve than fumigated plots. Shelf life was greater for berries raised in the fumigated plots, while measures of flavor were increased in berries from the non-fumigated plots. When measured in June, there was no difference between fumigated and non-fumigated plots in nematode levels. Very low levels of sting nematode were present in our field. Measures of the number of soil microbes were lower in the fumigated system, even after harvest, including populations of beneficial organisms like AMF.

On-Farm Results (2015)

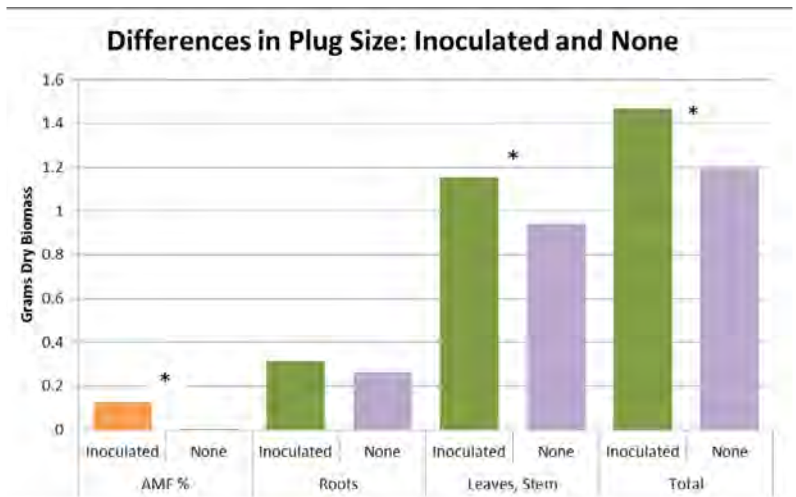
Inoculated Plugs were bigger for all sites (see chart to right).

Commercial inoculum did not establish AMF in the plugs as well as native inoculum did (see chart at top of page 7), however the commercial inoculum did result in larger roots.

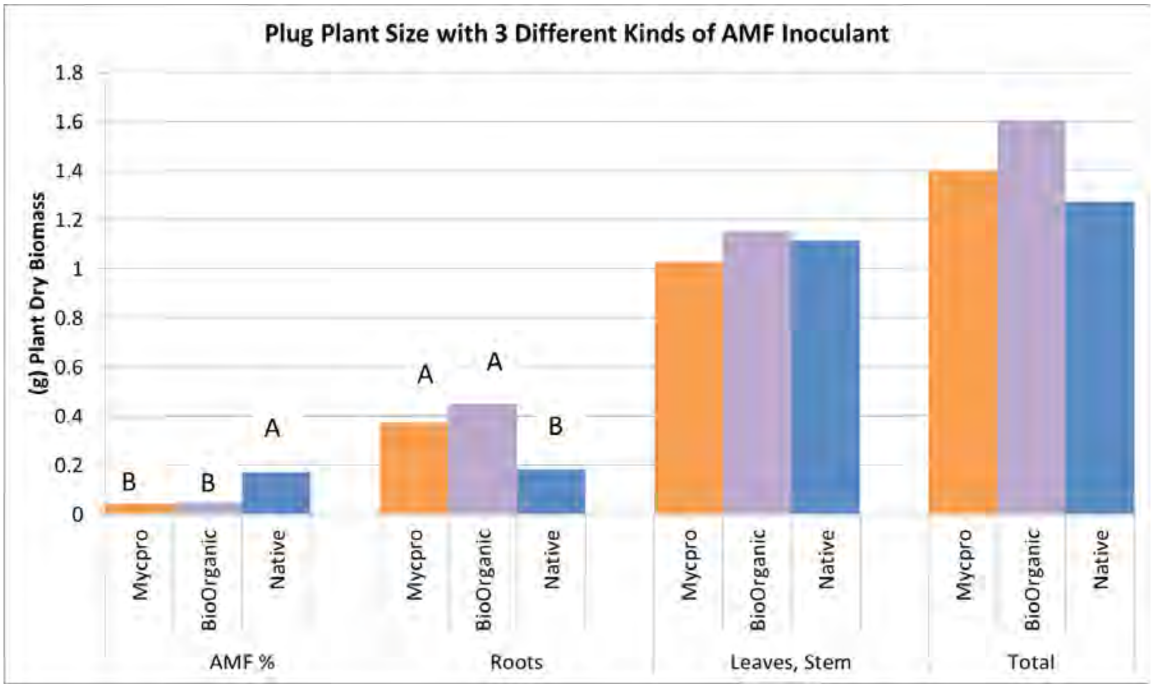
When comparing inoculated plugs and non-inoculated within the same fumigation system, there was no difference in yield.

Inoculated plugs were not able to establish AMF into fumigated systems via the plug inoculation, this matches our results in the research plots.

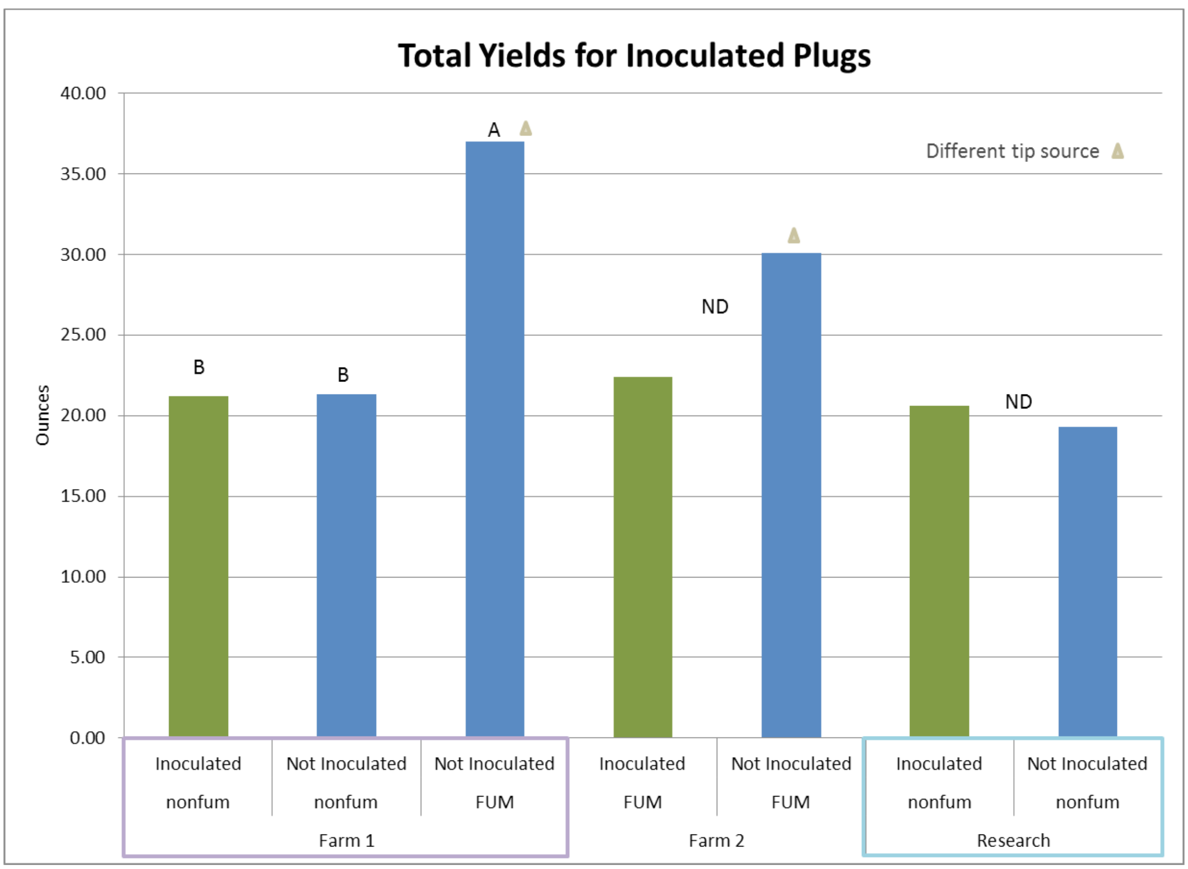
Early in the season flowers were counted on one date, and showed that compost + cover crop increased flower number at the piedmont farm. Later in the season, plants with all treatments (compost + cover crops + inoculated plugs) yielded the highest in one-day measurements taken just before Mothers Day.



Asterisks (*) indicates statistical differences within the same plant part category at p= 0.05

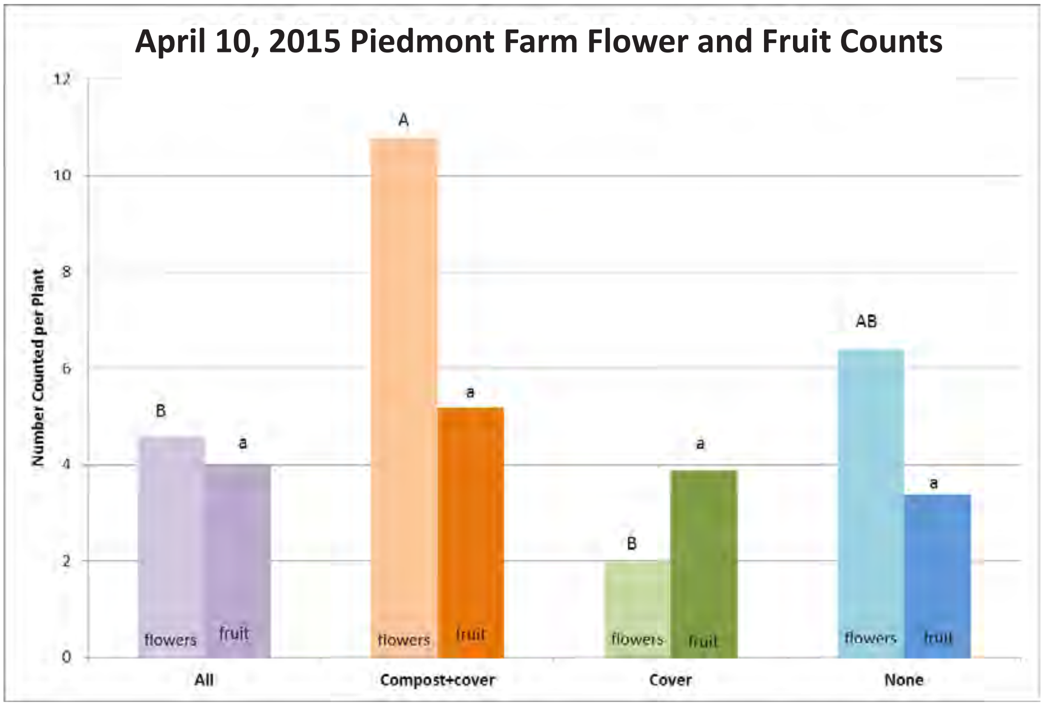


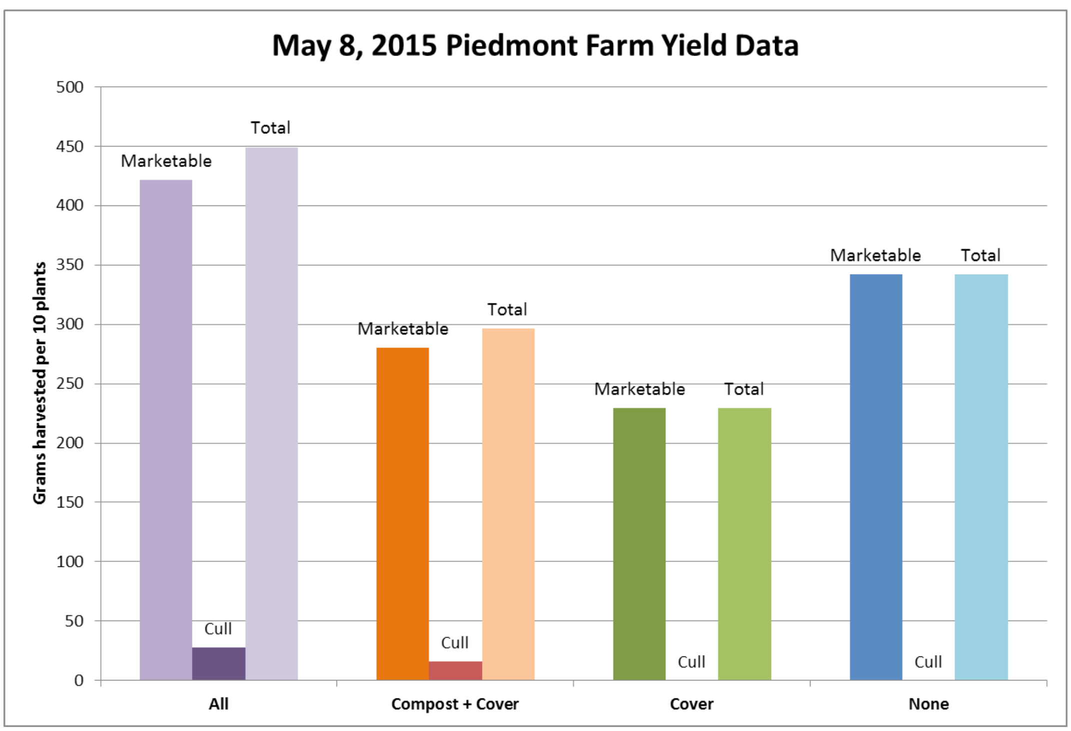
Different letters indicate statistical differences within the same plant part category at p= 0.05



Different letters indicate statistical differences within the same location at p= 0.05

Charts on this page are from the cooperating farm which incorporated a full range of soil improvement measures in association with this project. This farm did not fumigate for the 2015 crop year but had fumigated previous to that.





Economic Analysis

Costs for plug inoculants

Several different commercially available materials were used to inoculate plug media for on-farm trials. The mycorrhizal products were always used in combination with a vermicompost. Vermicompost replaced 20% of the growing medium by volume; inoculum products were added at the highest label-recommended rate.

Mycorrhizal Inoculants +	Description	Estimated Cost	Amount	Estimated Number of plugs treated *	Cost per plug	Cost per Acre ◊
Mycorrhizal Products	Super fine endo	$ 25.00	8 oz	2,000	$ 0.010	$142.50
Bio-organic Endomycorrhizal Inoculant	OMRI approved	$ 85.00	3 lb	12,000	$ 0.007	$106.25

Vermicompost	Description	Estimated Cost	Amount	Estimated Number of plugs treated **	Cost per plug	Cost per Acre ◊
Worm Power	OMRI approved	$ 38.00	15 lbs	2,000	$ 0.019	$285.00
Oregon Soil		$ 40.00	20 lbs	3,000	$ 0.013	$200.00

+Soil microbial inoculants are largely unregulated and the quality and efficacy of commercial products can vary widely. The commercial products used in this study were found to be satisfactory.

** Based on the highest label-recommended rates*

*** If 20% by volume of media replaced*

Combined Total Cost per Acre◊: $ 306.25 to $ 427.50

◊ For 15,000 plants per acre

Estimated costs per acre to apply compost and summer cover crops

Cover crop: $150 per acre (includes seed, machinery and labor)
Cowpea supplies on avg. 50 lbs of total N per acre

Compost: $234 per acre (at 8 tons/acre, includes material, delivery, machinery and labor)
Can supply between 40 and 70 lbs of total N, 30-50 lbs of P, and 30-70 lbs of K per acre

The nutrient content of these additions and the costs will vary based on locally available materials and farm labor costs. See enterprise budgets here for more information: http://strawberries.ces.ncsu.edu/2015/03/conventional-organic-and-compost-based-strawberry-production-budgets-updated-march-2015/

The cover crop is mown down while a CEFS apprentice and Dr. Michelle Schroeder-Moreno sample cowpea and pearl millet cover crop at the Center for Environmental Farming Systems (CEFS) in Goldsboro, NC.

Grower Interviews

Five North Carolina farmers (an organic grower, three conventional growers, and a plug producer) cooperated with this project in various ways. Below are their comments collected in Spring 2015, during the harvest season. Some responses have been edited or paraphrased.

In what ways did you work with inoculated plugs in this project?

RV: Amanda called me and asked if I'd participate – she'd provide the plants and we could pick the fruit. She delivered them, five or six trays [organic plugs]. I put them with the rest of our Camarosas and they performed well. I didn't see any differences in appearance or fruit set. All it took was a little bit of coordination and keeping track of where we put them. They came out and did bloom counts and checked on them.

SC: All I did was grow out the plugs for them, both conventional and organic. They looked good and healthy and promising. The researchers came and picked them up and took them to other farms. The ones that we still had here just got mixed in with the other plants, and I didn't keep up with them.

BC: We set out several hundred inoculated Camarosa plugs into fumigated land. They went in about five days after our others were transplanted. I think at one point they may have shown a little more vigor, and may have started yielding a day or two sooner. Our extension agent came out and took yield data over seven pickings.

Grower J.R. Odum with inoculated plug.

LB: All I did was provide the land, and left one row non-fumigated for the project. Our extension agent planted the plugs and was going to keep track of the inoculated and non-inoculated plants side-by-side. The inoculated plants look a bit smaller, and weeds grew around them on the non-fumigated row.

JO: We grow our plugs here and Amanda came out and helped us inoculate part of them. We set out the inoculated plugs on part of our field [as part of our bigger experiment with sustainable soil management practices]. There was very little visual difference, they seemed to root a bit better in the trays. I think I saw the difference in the spring; when they came out of dormancy they seemed to take off more quickly. The researchers came out and took fruit samples, but we didn't take yield data.

Would you use inoculated plugs in the future?

RV: The proof will be in the analysis – if it can be proven they that they make more fruit, anyone would do it.

BC: I'll be interested to see the data. I think we actually had better yield on the non-inoculated plugs, but that could be because the inoculated plugs were from a different source or went in a few days later. I would certainly consider using them if it's proven they increase yield, it's a tool like any other.

Do you have other thoughts about the project?

RV: We would have been glad to do more, like collect yield data, though it might be kind of a multi-year thing, where they didn't want to ask too much too soon. Any farmer willing to work with research knows there has to be yield data. Farms that see that are willing to collect data. The way you move it forward is to see if the practice is providing benefit in yield. I think it is likely hard to get large farms to participate in research; there's a better chance of getting people to consider it on a small farm.

BC: It's an interesting concept, and I am glad she's pursuing it.

JO: It was very easy to work with the researchers. Amanda was in touch with the direction we were going, always very clear about what was expected, and I never felt pressured to do something I didn't want to do. They were always there to answer questions.

Farm Profile: Exploring Multiple Sustainable Soil Management Practices

Note: Two other farms working with this project were already using compost and/or cover crops as part of their practices, but this grower first began experimenting with these practices as part of the project. This profile was written in Spring, 2015.

J.R. Odom and his wife, Emily, farm in Goldsboro, NC, with a focus on selling direct to the public. On the farm's 46 acres, he currently has 2.5 acres of strawberries (Chandler, Camarosa, and Camino Real varieties) in plasticulture production.

A third-generation farmer. J.R. is committed to rebuilding the soil on his farm. "It's old tobacco land, but my grandfather always rotated crops," says J.R. "When I started farming, the first few years I grew all cotton and then all soybeans, and ran it down. So I was searching for something like this project. I felt we needed to do something to increase the fertility of our soil."

J.R. decided to include his entire strawberry planting in the project. He had four combinations of the practices: compost; compost + cover crops; compost + cover crop + plugs inoculated with beneficial mycorrhizae and vermicompost; and a control. Though he had intended to fumigate, the weather wasn't cooperative, so for the first time, none of the strawberry land was fumigated. He raises his own plugs, so researcher Amanda McWhirt came out to the farm to help inoculate the plugs. "It was all very easy," says J.R., "they covered the cost of the cover crops and compost, and we never felt pressure to change what we do beyond what we were comfortable with."

"I had some problems with calibrating the seeder for the cover crop, so we got a *very* good stand in part of

Researcher Amanda McWhirt assists with preparing inoculated flats at the Odom farm.

the field and had to buy more seed. And we didn't have a flail mower, so we bush-hogged the cover crop twice, and had no problem getting it broken down before we incorporated it. Amanda did some testing, and we figured we got 60 units of N from the cover crops – that was our preplant fertilizer on those sections." J.R. applied whatever soil tests showed was needed on other plots, and during the growing season, he followed the same fertigation and management practices throughout.

Has he seen differences? There has been very little difference visually with the inoculated plugs, says J.R. But they seemed to root a bit better, to get established more quickly after they were transplanted, and to take off a bit more rapidly coming out of dormancy in the spring – though he recognizes his observations may be biased. He also thinks that the control plot had more disease pressure and smaller berries. He has not seen a difference in drainage or tilth, but thinks he may see more when the plastic is removed from this year's plant-

Applying compost before bedding the soil.

Young cowpea cover crop.

ing and the land is prepared for its next crop. Nor has he seen a difference among the varieties in how each responded to the different treatments.

But he's thinking long-term, and whether or not the research continues, he plans to continue the project on his own. "I don't think we'll see improvements in the yield side in the first five years," says J.R. "And I think if we take care of the soil and make it better, that will take away a lot of the problems we have."

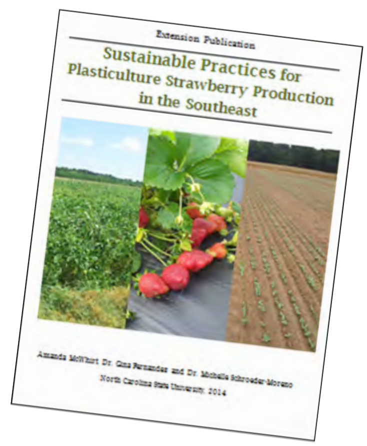
Mowing down the cover crop.

Trying these practices on your own farm

Sources of information

The Use of Beneficial Soil Inoculants for Strawberry Tip Production (On-line video: https://www.youtube.com/watch?v=-dET8r3bhdQ). This video demonstrates the technique of incorporating vermicompost and arbuscular mycorrhizal fungi (AMF) into strawberry tip establishment or plug production. In addition the general benefits of these soil inoculants on plant growth is described. This general technique can be applied to many types of plant establishment.

Sustainable Practices for Plasticulture Strawberry Production in the Southeast (online Extension publication, at http://content.ces.ncsu.edu/sustainable-practices-for-plasticulture-strawberry-production-in-the-southeast/). This publication outlines recommended cover crops, methods for establishment, and how to calculate nitrogen inputs from organic sources like compost and cover crops. It is a great resource for growers who are considering implementing these types of practices.



Sources of inoculants

Mycorrhizal inoculants are widely available online and often locally available in specialty garden shops. Soil microbial inoculants are largely unregulated and the quality and efficacy of commercial products can vary widely. The commercial products used in this study were found to be satisfactory.

Conducting on-farm research

If you experiment with inoculating plugs, consider conducting your own on-farm comparisons: Keep track of which plug trays you inoculate, set out a batch of the plants in locations where their growth and performance can be compared to nearby non-inoculated plants. Manage them the same way in terms of fertility, pest control, etc. For both the inoculated plants and non-inoculated "control" plants, note down observations such as plant size, growth, plant health, first flowering, first fruiting, and berry quality. For a "blind" experiment, arrange that the person making the observations doesn't know which group of plants is inoculated and which is not.