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CAL-collaborative organic research and extension network: on-farm research to improve strawberry/vegetable rotation systems in coastal California

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Abstract

CAL-CORE is a network of researchers, farmers, extension professionals, industry and non-profit organizations dedicated to furthering research into organic strawberry and vegetable production in coastal California. Formed 9 years ago, we have worked on a variety of fertility, pest and disease management issues facing organic growers. Currently, our main effort centers on vegetable/strawberry rotations and different options for fertility and disease management. In a replicated field trial we compare treatments across a range of sustainability criteria: crop yield, nitrogen cycling and losses, greenhouse gas emissions, disease incidence, biocontrol of insect pests, soil carbon pools, and economics. Main treatments are 2 versus 4 year rotations with different crop combinations believed to be either suppressive of a major soil borne disease (*Verticillium* wilt), or more profitable but more conducive to disease. Superimposed on the rotations are fertility treatments (legume/cereal cover crop only, legume/cereal cover crop + compost + additional fertility amendments, cereal cover crop + mustard seed meal, or untreated control) and in the two legume/cereal cover cropped treatments anaerobic soil disinfestation (ASD, a promising option for controlling a range of soil borne diseases) is used for disease management prior to planting strawberries. Six network farmers also chose a sub-set of these treatments to test on their farms and compare to their own management practices. The study is in year 4 and all treatments at all locations are now planted to strawberries. Preliminary data show *Verticillium* wilt to be the major cause of yield loss in strawberry, and that ASD provided partial control, but mustard seed meal did not. Soil inorganic N pools are very dynamic with rapid release of nitrate from crop residues observed. Soil carbon is already declining in the bare fallow (no winter cover crop) treatment and in the 2 year rotation as compared to the 4 year rotation. This project will provide farmers with tools to improve their production systems, meet water quality regulations, and quantify climate-related impacts of these intensive organic systems.

Keywords: nitrogen cycling, fertility management, soilborne disease, soil carbon, anaerobic soil disinfestation, mustard seed meal

INTRODUCTION

In the high input year round strawberry and vegetable cropping systems of coastal California, organic growers have to balance their desire to reduce environmental impacts with the multiple challenges of maintaining economically sustainable yields. These challenges include providing adequate plant nutrients while minimizing losses to protect

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water quality, maintaining low levels of disease, and building effective system-based pest management strategies. In comparison with conventionally managed systems, little research on organic systems has been available for growers to help meet these challenges and so in 2004 we formed a research-extension-grower network to develop and implement a collaborative organic research program (Muramoto et al., 2012). The California Collaborative Research and Extension network (CAL-CORE) which we report on here grew out of this initial program. The first 4-5 years of research, known as the Organic Research Network Project, was funded by the USDA-Organic Agriculture Research and Extension Initiative (USDA-OREI) program in 2004 (Grant number: 2004-51300-02232), with the goals of building an organic research and extension network to support organic vegetable and strawberry producers in the region and to develop integrated fertility and pest management strategies to minimize negative impacts of agriculture on surrounding natural ecosystems and improve the economic viability of organic farming. Multiple field experiments were carried out including cover crop/fertility trials (e.g., Muramoto et al., 2011), a strawberry rotation trial (Muramoto et al., 2014), studies of the role of trap crops and hedgerows in arthropod biological control (Swezey et al., 2007; Pisani-Gareau et al., 2013), and development of anaerobic soil disinfestation as a technique for controlling soil borne diseases in strawberry production (Shennan et al., 2014).

The current CAL-CORE program represents an extension and expansion of this earlier effort, bringing additional researchers, farmers, regions, and organizations into the network. Our goal is to provide a dynamic platform for network members to collaboratively research and evaluate integrated systems approaches to improve environmental sustainability and economic viability in a comprehensive manner. Using the information generated previously, a series of field experiments have been undertaken to examine the effect of crop rotations and specific management practices on productivity and economics as well as ecosystems services such as nutrient cycling; pest, disease, and weed suppression; soil carbon sequestration; and greenhouse gas (GHG) emissions. A combination of direct measurement, modeling and Life Cycle Analysis (LCA) are being used to describe the environmental imprint of the management systems being tested. The centerpiece of the project is a replicated rotation study being conducted at the University of California, Santa Cruz, Center for Agroecology and Sustainable Food Systems (CASFS) farm site which has been under organic management for 40 years. In addition a subset of the treatments in this study were chosen by six farmer collaborators to test on their fields. A number of additional satellite studies are also underway, but here we report on some of the preliminary findings from the main rotation study which is now in its 4th year and reflect on the functioning of the network as a mechanism for collaborative research and outreach. The goals of this study are to compare rotation length and crop composition on soil fertility and soil borne disease dynamics when used alone or in conjunction with soil amendments (mustard seed meal (MSM) or anaerobic soil disinfestation (ASD) (Shennan et al., 2014)).

METHODS

The CASFS field is an Elkhorn sandy loam (fine-loamy, mixed thermic Pachic Agriixeroll), and the experiment is a split-split plot design with four replicates. It compares two and four year vegetable/strawberry rotations (main plots) using combinations of crops (sub-plots) believed to be either suppressive (broccoli-based) of a major soil borne disease (*Verticillium* wilt), or more profitable but more conducive to disease (lettuce-based) (Table 1). Superimposed on the rotations are fertility treatments (sub-sub plots): legume/cereal cover crop only, legume/cereal cover crop + compost + additional fertility amendments, cereal cover crop + mustard seed meal, or untreated control. In the two legume/cereal cover cropped treatments anaerobic soil disinfestation (ASD) is used for disease management prior to planting strawberries. The study is in year 4 and all treatments were planted to strawberries in 2014.

Table 1. Crop rotation and management treatments. cc = cover crop, bf = bare fallow, mc = mustard seed meal, f = fertilizer, V-B = broccoli, V-L = lettuce, V-L/Ca = lettuce and cauliflower, asd+c = asd+compost, S = strawberry, S+ = strawberry + fertigation. Treatments 1a to 8a are 4 year rotations, and 1b to 8b are 2 year rotations.

Treatment	Year 1			Year 2			Year 3			Year 4		
	Fall 2011	Winter	Summer 2012	Fall 2012	Winter	Summer 2013	Fall 2013	Winter	Summer 2014	Fall 2014	Winter	Summer 2015
1a	cc	cc	V-B	cc	cc	V-L/Ca	cc	cc	V-B	asd	S+	S+
2a	cc	cc+c+f†	V-B	cc	cc+c+f	V-L/Ca	cc	cc+c+f	V-B	asd+c	S+	S+
3a	cc*	cc+mc†	V-B	cc	cc+mc	V-L/Ca	cc*	cc+mc	V-B	mc	S+	S+
4a	bf	bf	V-B	bf	bf	V-L/Ca	bf	bf	V-B		S	S
5a	cc	cc	V-L	cc	cc	V-B	cc	cc	V-L	asd	S+	S+
6a	cc	cc+c+f	V-L	cc	cc+c+f	V-B	cc	cc+c+f	V-L	asd+c	S+	S+
7a	cc*	cc+mc	V-L	cc	cc+mc	V-B	cc*	cc+mc	V-L	mc	S+	S+
8a	bf	bf	V-L	bf	bf	V-B	bf	bf	V-L		S	S
1b	cc	cc	V-B	asd	S+	S+	cc	cc	V-B	asd	S+	S+
2b	cc	cc+c+f	V-B	asd+c	S+	S+	cc	cc+c+f	V-B	asd+c	S+	S+
3b	cc	cc+mc	V-B	mc	S+	S+	cc*	cc+mc	V-B	mc	S+	S+
4b	bf	bf	V-B		S	S	bf	bf	V-B		S	S
5b	cc	cc	V-L	asd	S+	S+	cc	cc	V-L	asd	S+	S+
6b	cc	cc+c+f	V-L	asd+c	S+	S+	cc	cc+c+f	V-L	asd+c	S+	S+
7b	cc*	cc+mc	V-L	mc	S+	S+	cc*	cc+mc	V-L	mc	S+	S+
8b	bf	Bf	V-L		S	S	bf	bf	V-L		S	S

Winter cover crops in treatments 1a, 2a, 5a, 6a, 1b, 2b, 5b, and 6b were a mixture of bell bean (*Vicia faba* L.) 45%, purple vetch (*Vicia benghalensis* L.) 45%, and cereal rye (*Secale cereal*) 10% and were planted at a rate of 367 kg ha⁻¹ in November each fall and incorporated with a spader in April to May. In treatments 2a, 6a, 2b and 6b, compost (6.2 t ha⁻¹ for vegetables and 22 t ha⁻¹ for strawberries) and organic fertilizer (feather meal-based. 112 kg-TN ha⁻¹ only for vegetables) were added pre-plant for each crop. The cover crop was cereal rye for treatments 3a, 7a, 3b and 7b and mustard seed meal (Farm Fuel Inc., Watsonville, CA) was added at a rate of 2.1 t ha⁻¹ for vegetables and 3.4 t ha⁻¹ for strawberries >2 weeks prior to planting of each crop. Treatments 4a, 8a, 4b and 8b, are untreated controls and did not receive any amendments. Treatments 2a, 6a, 2b and 6b received supplemental fertilizer prior to broccoli or lettuce crops if the pre-side dress nitrate test showed levels below 25 mg kg⁻¹, and they received 15 kg-TN ha⁻¹ of organic fertilizer on lettuce in year 2.

Cash crop planting dates were June 27, 2012 for broccoli and lettuce in year 1; May 1 for lettuce and July 25, 2013 for cauliflower and broccoli in year 2; May 21, 2014 for broccoli and lettuce in year 3. Strawberries were planted in the 2 year rotation treatments on November 16, 2012 in year 2 and on November 18, 2014 in all treatments in year 4. Prior to strawberry planting in treatment 1b, 2b, 5b and 6b in year 2, ASD was carried out using rice bran (10 t ha⁻¹) and molasses (12 t ha⁻¹) as carbon sources. Rice bran was incorporated to a depth of 15 cm using a rolling cultivator to beds and beds reshaped, and molasses (diluted with water to 1:2) added through the drip line with 2 applications. The ASD treatment lasted 29 days and was terminated on November 9, 2012. In year 4 prior to strawberry planting ASD was carried out in treatment 1a, 2a, 5a, 6a, 1b, 2b, 5b and 6b using rice bran (13 t ha⁻¹) and molasses (9.6 t ha⁻¹) and the treatment lasted from October 14 to November 17, 2014. Water was applied through drip lines to create anaerobic conditions, 25 mm (+30 mm precipitation) in year 2 and 180 mm in year 4.

Broccoli, lettuce and cauliflowers harvests were taken from 3 m section of a middle bed and separated into marketable and unmarketable, and strawberries were harvested from 20 marked plants bi-weekly from April 2 to September 2, 2013 in year 2 and from

March 12, 2015 onwards in year 4. Plant disease was assessed as a wilt score between 1 and 8, with 1 for healthy plants and 8 for dead plants. Soils were sampled at pre-plant, harvest, and every 2 weeks for vegetables or monthly for strawberries during the growth period using a soil probe combining 6 to 10 cores as a composite sample per plot and analyzed for nitrate and ammonium colorimetrically using a Lachat flow injection analyzer. For soil C analysis 3 cores (5×15 cm) samples were taken from a depth of 0-15 and 15-30 cm of each plot and combined for 0-30 cm depth. Soils were then dried, ground to 0.5 mm, and analyzed using Vario CNS analyzer. For statistical analysis of soil C a nest-nest ANOVA was used to analyze differences between soil C values prior to the start of the experiment and soil C values obtained in August 2013. For analysis of harvest data a split-split plot ANOVA was used.

RESULTS AND DISCUSSION

Crop production

Cover crop biomass ranged between 6.5 and 11 t ha⁻¹ DW for the legume/cereal mix and 5.5 and 7.5 t ha⁻¹ DW for the cereal rye, similar to the biomass production observed in grower's fields in the region (data not shown). Similarly, broccoli and lettuce yields were in line with averages for this area. Broccoli yields were generally highest across all three years in the treatments receiving compost and supplemental organic fertilizer (CC+C+F) in addition to the winter cereal/legume cover crop mix (Figure 1), which fits with previous work showing benefits of additional fertility amendments beyond a winter cover crop for broccoli at this site (Muramoto et al., 2011). In contrast lettuce yields showed no treatment effects in any year (data not shown). Lower broccoli yields in the treatment with a rye winter cover crop plus mustard seed meal (CC+MC) may have been due to temporary N immobilization following rye incorporation, suggesting that insufficient N was mineralized from the mustard seed meal to compensate for immobilization. Strawberry yields in year 2 were severely impacted by *Verticillium* wilt caused by *Verticillium dahlia* (Figure 2). ASD failed to completely control this outbreak, but reduced disease incidence relative to other treatments. In other work ASD has proved effective at controlling *V. dahlia*, (Shennan et al., 2014) however poor drainage and lower than normal bed heights may have exacerbated the disease in this case. A new bed shaper was used in year 4 to create more favorable conditions for strawberry plants.

Figure 1. Broccoli yields in year 1 (A) and year 3 (B) for treatments 1a to 4a (4 year rotation) and 1b to 4b (2 year rotation). No significant difference between factors on the same line at P<0.05.

Figure 2. Correlation between wilt score and marketable strawberry fruit yield in year 2 across all treatments in the 2 year rotation.

Soil nitrogen dynamics, greenhouse gas emissions and soil carbon

Soil nitrate levels follow a similar pattern across all fertility treatments, but with higher peak levels found in the CC+C+F treatment (Figure 3). In all cases soil nitrate declined during the winter, peaked after cover crop incorporation in the spring, or in the case of the bare fallow following tillage and bed preparation, declined during crop growth, and subsequently peaked following incorporation of crop residue. Further data analysis of soil N and field measurements of greenhouse gas emissions is in progress and will be combined with use of the DNDC model (Li, 2000) to estimate nitrogen losses via leaching and denitrification for the different systems. This model will also predict changes in soil carbon over time which will be compared against field data. It is apparent that after 3 years total soil C declined more in the 2 versus 4 year rotation plots, and in the bare fallow plots compared to those receiving cover crops and other inputs (Figure 4). All treatments showed some decline, however, and while cover crops reduced this decline, there was no additional benefit observed from adding compost at the rates used in this trial to date. There is little information on the effects of organic management on soil C in these intensively tilled annual cropping systems in California. In one study soil total C increased by about 20% with organic management from the baseline after an 8-year period, and by 10-20% more than corresponding conventional systems (Clark et al., 1998). However, unlike here the rotations included high residue crops like corn as well as cover crop and composted manure inputs, and the study was conducted on land that had been conventionally managed for many decades. It will be interesting to see if soil C continues to decline in this long-term organically managed site, and whether differences between the 2 and 4 year rotations are maintained over time.

Figure 3. Soil nitrate levels 0-30 cm for treatments 1a (cc), 2a (cc+c+f), 3a (cc+mc) and 4a (bf).

Figure 4. Change in total soil C (0-30 cm depth) after 3 years A) comparing all 4 year versus 2 year rotation treatments, and B) comparing fertility treatments averaged across 2 and 4 year rotations. Different letters indicate that means are different at $p < 0.05$.

REFLECTIONS ON THE NETWORK MODEL

The experiment reported here emerged from discussion among network members with the goal of assessing management approaches that integrate crop rotation and soil treatments (ASD and mustard seed meal additions) to control critical soil borne diseases, improve nutrient cycling (reduce N losses) while supporting economic yields. Farmers also chose to test the 4-year broccoli-based rotation treatments (1a-4a) against their standard practices. This design allows us to see how the treatments perform across multiple locations and provides an opportunity to get feedback from farmers on their experience and perceptions of the treatments being tested. In addition to the data presented here, the same trials are being used to look at biological control of cabbage aphid and diamondback moth in broccoli as well as management impacts on greenhouse gas emissions. Ultimately these trials will provide a multi-faceted assessment of the environmental and economic performance of the rotations being tested.

We have regular network meetings to discuss management issues that emerge and to share the findings emerging from these experiments and other projects being conducted by network members. Over time a sense of community has developed, with exchanges of ideas happening both between researchers and farmers, but also among the farmers themselves. In a recent interview one farmer commented that the community-building process was one of the most valuable aspects of his participation in the project. The network has also served as an effective mechanism to better coordinate research efforts among researchers located in different institutions in coastal California and provide a more complete picture of how to improve these organic cropping systems.

CONCLUSION

The researcher-extension-grower network created 9 years ago continues to thrive and has generated valuable information on fertility and disease management and biocontrol options for organic farms in the region. Our current focus is on testing integrated systems building on information from the earlier studies. Preliminary results are demonstrating significant effects of rotation length and fertility/disease management strategies on crop productivity, disease incidence, soil carbon and soil nitrogen dynamics.

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