ORGANIC FARMING RESEARCH FOUNDATION

Project report submitted to the Organic Farming Research Foundation:

Project Title:

Maintaining Agroecosystem Health in an Organic Strawberry/Vegetable Rotation System

FINAL PROJECT REPORT

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EXECUTIVE SUMMARY*

Continued growth of organic strawberry and vegetable production in California faces two challenges: soil-borne disease management without use of synthetic chemical fumigants, and fertility management to optimize fertility input use while ensuring protection of vulnerable habitats.

The goal of this project is to demonstrate effects of diverse organic strawberry/vegetable rotations and integrated ecological practices on agroecosystem health.

In 2001, we initiated a replicated on-farm trial at Moss Landing, California with number of years between strawberry crops as the main plot treatment (5 levels) and strawberry cultivar as sub-plots (2 levels). Ecological practices such as biofumigation with broccoli residues and mustard incorporation, compost application, use of vegetables that do not host *Verticillium dahliae* (spinach and broccoli) as rotational crops, and choosing strawberry cultivars that are less sensitive to disease are used in an integrated manner. While the main treatment effects will be tested after the fifth year, soil health indicators (*Verticillium dahliae* propagule number, soil inorganic N, and other physicochemical indicators) and agroecosystem health indicators (yield, disease incidence, and nutrient budgets) will be monitored during all five years.

In the first three years, strawberries, vegetables and cover crops had moderate yields and no major disease problems. No significant differences were found between any treatments in yields of any crops during the period. The N monitoring in organic strawberries suggested: 1) the maximum N-loss during the rainy season reached 214 kg ha^{-1}, and 2) pre-plant plastic mulch application and adjusting basal/supplemental N rates can significantly reduce N-loss during the rainy season while maintaining fruit yield. Broccoli residue incorporations consistently reduced *Verticillium dahliae* propagule number in soils, whereas mustard incorporations did not. Further a major weed (*Capsella bursa-pastoris*) of the plot hosts *Verticillium dahliae*, suggesting weed management should be integrated with soil-borne disease management.

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* Later this project became a part of a larger project entitled “Improving fertility and pest management strategies for organic crop production and strengthening researcher/grower networks” funded by USDA-Integrated Organic Program (USDA-IOP) in 2004 (P.I.s Stephen R. Gliessman, Carol Shennan, Sean Swezey, Joji Muramoto, Steven T. Koike, Richard Smith, and Mark Bolda). See appendix for more information on the entire USDA-funded project.

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INTRODUCTION

With its Mediterranean climate of moist, mild winters and dry moderate summers, a broad range of berry and vegetable crops can be grown year round on the central coast of California. Monterey and Santa Cruz counties combined produced more than $400 million gross value of strawberries in 2001, and over $2 billion worth of vegetables (Monterey County Agricultural Commissioner, 2002; Santa Cruz County Agricultural Commissioner, 2002). As the interest in organic farming and the demand for organic produce has increased in California (Johnson, 2001; Swezey and Broom, 2000), organic farming on the central coast has also increased in recent years. There were 12,165 organic-certified acres in Monterey County in 2001, more than four times the organic acreage recorded in 1997. The total farm gate revenue from organic farming in this county was $108 million in 2001, representing a dramatic increase of over 800 percent in just six years.

Continued growth of organic strawberry and vegetable production in California, however, faces two challenges: soil-borne disease management without use of synthetic chemical fumigants, and fertility management to optimize fertility input use while ensuring protection of vulnerable habitats.

Verticillium wilt is a soil borne disease caused by *Verticillium dahliae* that can damage a wide range of important crops in California. Host crops include lettuce, tomatoes, potatoes, apples, cotton, cauliflower, artichokes, and strawberries (Bhat and Subbarao, 1999). Due to its resilient overwintering structure, this pathogen can survive many years in soil without host plants (Koike et al., 1994). In the pre-methyl bromide (MeBr) era, Verticillium wilt was a major limiting factor of strawberry production in California (Wilhelm and Paulus, 1980). Today it poses the greatest threat for organic strawberry production in the state. Verticillium was shown to increase after 3 years of continuous organic strawberry production (Gliessman et al., 1996), and organic growers need to rotate out of strawberries for several years (Gliessman et al., 1996; Gordon et al., 1994). For specialized strawberry growers wanting to convert to organic this requires a major change in system design and management, since MeBr had allowed near continuous strawberry production to be practiced. Given the high costs of strawberry production (in excess of $25,000/ac including harvest costs) and their high market value, organic strawberry growers need to develop cost effective rotations with other crops to diversify their market options and reduce fallow time as much as possible.

As “non-chemical” approaches to soil borne disease management in strawberries, the following practices have been tested: host resistance (Bull et al., 2001; Duniway et al., 2001; Shaw et al., 1997); small cell transplants (“plug plants”) (Sances, 2000); organic amendments such as compost (Sances, 2000), high nitrogen organic fertilizers (Duniway et al., 2001), broccoli residues (Sances and Ingham, 1997), and mustards and sudan grass residues (Gordon et al., 1994); microbial amendments including vesicular arbuscular mycorrhizae fungi (VAM) (Bull, 1998; Bull et al., 2001; Werner et al., 1990); and plant growth promoting rhizobacteria (PGPR) (Bull and Ajwa, 1999; Eayre, 2000); and crop rotations with broccoli, lettuce, or Brussels sprouts (Duniway et al., 2000; Shetty et al., 1999). However, no research exists that has integrated multiple approaches in a system-level study for shortening the fallow time of organic strawberry systems in California.

While considerable effort has focused on developing best management practices for conventional vegetable production in the region, there is a lack of equivalent information to help organic farmers manage fertility. Strawberries and vegetables have shallow root systems that are inefficient in absorbing nutrients. In addition, compost and cover crops, which are the most common organic nutrient sources among organic growers, are often inadequate to fulfill the late nitrogen demand of such crops (Muramoto, 2003; Smith and Miller, 1996). Consequently, many organic strawberry and vegetable growers have intensified their use of various kinds of commercial organic fertilizers that are relatively soluble in form. However, this practice has received substantial criticism since it is viewed as a form of "high-input organic agriculture" (Appropriate Technology Transfer for Rural Areas (ATTRA), 2003) which may not convey many of the environmental benefits commonly associated with organic production. Many studies exist on nitrate leaching from organic farms and their nutrient budgets in Europe (Eriksen et al., 1999; Hansen et al., 2000; Kristensen et al., 1994; Schlueter et al., 1997; Ulen, 1999; Wurbs et al., 2000), but few in California (Poudel et al., 2002). No studies have measured nitrogen losses in commercial organic farms in California.

To deal with the above issues, we initiated a research project that uses a systems approach with an evaluative concept "agroecosystem health" (Xu and Mage, 2001) to integrate the complex reality of organic farming.

The overall objective of this project is to demonstrate effects of diverse organic strawberry/vegetable rotations and integrated ecological practices on agroecosystem health. We hypothesized that:

1) The use of non-host rotation crops for Verticillium wilt plus bio-fumigation with broccoli, mustard or other crop residues and compost application will suppress disease development sufficiently to grow strawberries in rotation every 3 or 4 years without negatively affecting soil microbial diversity.
2) The use of field level nutrient budgets combined with nutrient content databases, and simulation models to predict periods of greatest vulnerability to nutrient losses, will enable farmers to significantly improve nutrient use efficiency by optimizing timing, quality and amounts of inputs used and crop rotations.

To test the above hypotheses, we initiated a five-year organic strawberry/vegetable rotation experiment in Moss Landing, California in 2001. Our OFRF research grant was awarded for the third year (2004-2005 season) of the rotation project. The overall project is in progress, and will be completed in the fall of 2006. Here we report results of the first three years of the rotation experiment.

After OFRF awarded this project, it became a part of a larger project entitled "Improving fertility and pest management strategies for organic crop production and strengthening researcher/grower networks" funded by the USDA-Integrated Organic Program (USDA-IOP) in 2004 (P.I.s Stephen R. Gliessman, Carol Shennan, Sean Swezey, Joji Muramoto, Steven T. Koike, Richard Smith, and Mark Bolda. $571,902 for four years). See appendix for more information on the entire USDA-funded project.

METHODS

1. Field Location and the Project History

The on-farm research site in this project, the Elkhorn Ranch, is located in Moss Landing, Monterey County, California. The ranch is adjacent to the Elkhorn Slough Estuarine Reserve, where non-point source pollution from agricultural practices has been documented as a major problem (ABA Consultants et al., 1989; Phillips, 1988; United States Soil Conservation Service, 1984). The field has a long history of conventional cultivation (strawberries, lettuce, etc.) prior to the transition. In 1998, with the hope that organic farming would limit pollution problems with synthetic chemicals, the owner of the land, Robert Stephens, provided a long-term lease on a 60-acre field to Dan Schmida, a well-known farmer in the region who has grown organic strawberries over the past 10 years. Divided into three 20-acre parcels, the land was placed into the three-year transition period required for organic certification, alternating winter cover crops with summer fallow. Researchers in the Program In Community and Agroecology (PICA) and the Center for Agroecology and Sustainable Food Systems (CASFS) at the University of California Santa Cruz (UCSC) were called upon by the grower and the landowner to develop a research component for monitoring the farm system once organic planting began. Further research partnerships have since been formed with UC Cooperative Extension and USDA-ARS researchers from the Salinas stations. Upon completion of the three-year organic transitional period, a replicated five-year rotation trial with five treatments was initiated in Oct. 2001.

The soil type of fields is Santa Ynez fine sandy loam (Fine, montmorillonitic thermic, Ultic Palexerolls), 2-9% slopes. The water infiltration is very slow due to the cemented layer at 45 to150cm deep. Organic matter content in the topsoil (0-15cm) is as low as 1% and the pH is 6.7 – 7.0. *Verticillium dahliae* population in the topsoil is 0-1 microsclerotia gram soil^{-1} in October, 2002.

2. Experimental Design

Given the high susceptibility of strawberries to Verticillium wilt, our strategy for shortening the rotation period of organic strawberries is to integrate the following ecological practices: biofumigation using broccoli residues (Koike and Subbarao, 2000; Shetty et al., 1999); cover crops including mustards (Gordon et al. 1994); compost application (Duniway et al., 2001; Lazarovits et al., 1999); selection of less sensitive strawberry cultivars to diseases (Bull et al., 2001; Shaw et al., 1996); and rotations with vegetables that do not host *Verticillium dahliae* (Bhat and Subbarao, 1999).

The experimental design is a split plot arrangement of treatments in a randomized complete block with different time periods of “rest” between strawberry plantings as the main plot (5 treatments), and strawberry cultivar (2 treatments) as sub-plots with four replications. The main treatments are:
Treatment A: Continuous strawberries with pre-plant biofumigation using broccoli residues
Treatment B: One-year break before replanting strawberries
Treatment C: Two-year break before replanting strawberries
Treatment D: Three-year break before replanting strawberries
Treatment E: No strawberries until fifth year.
(table 1 and fig. 1).

Table 1. The rotation treatments based on a combination of broccoli residue incorporation, diverse cover crops including mustards, organic soil amendments, selection of resistant strawberry cultivars, and rotations with vegetables that do not host *Verticillium dahliae*.

Treatment	Year 1	Year 2	Year 3	Year 4	Year 5
A (0 yr.*+ br.res.)	**st**---------	**st**---------	**st**---------	**st**---------	**st**---------
B (1 yr.*)	**st**---------	cc-vegs-	**st**---------	cc-vegs-	**st**---------
C (2 yrs.*)	cc-vegs-	**st**---------	cc-vegs--	cc-vegs-	**st**---------
D (3 yrs.*)	**st**---------	cc-vegs-	cc-vegs--	cc-vegs-	**st**---------
E (Control)	cc-vegs-	cc-vegs-	cc-vegs--	cc-vegs-	**st**---------

Number of years between strawberry crops.
br.res.: applying broccoli residues before planting strawberries.
cc-vegs: cover crops and vegetables (spinach and broccoli).
st: strawberries.

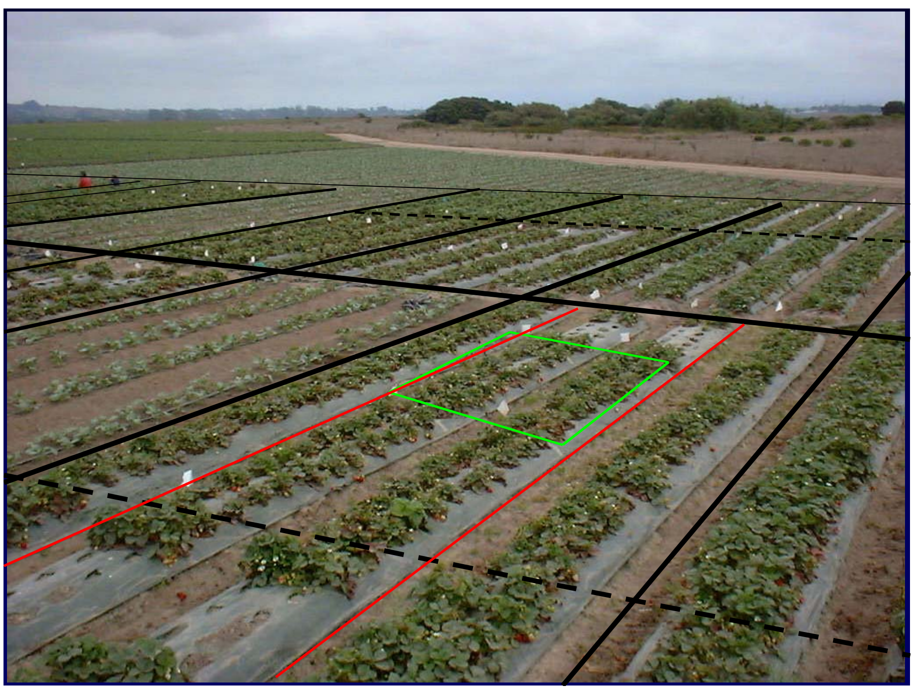


Fig. 1. Organic strawberry/vegetable rotation experiment at Elkhorn Ranch, Moss Landing, California. Each plot consists of four beds of which middle two-beds (between red lines) are used for sampling. A broken line indicates a border between sub-plots. The green area marks forty strawberry plants for fruit harvest data sampling.

The sub treatments for the first year were cv. Aromas and Diamante. From the second year, Diamante was replaced with cv. Seascape that performed better in other organic farms on the central coast of California (Bull et al., 2005).

Spinach (*Spinacia oleracea*) was chosen as a rotational crop since it does not host *Verticillium dahliae*, in addition to broccoli that is to be planted as a pre-crop to strawberries for biofumigation.

Each plot is 91.3 m^2 (4.91m wide x 18.6m long) consisting of 4 beds of strawberries (two plant rows per bed) or vegetables. Total area of ~1acre was loaned by the landowner for the experiment.

To test hypothesis 1, we will grow strawberries on all plots in the fifth year (year 2005-2006). By comparing the effect of the different rotation systems on strawberry fruit yields, disease incidence of the plants, *Verticillium dahliae* propagule population in the soils, and soil microbial communities measured by PLFA method, we will examine how much we can practically shorten the time before strawberries can be replanted on the same field to less than five years. Split plot Two-way ANOVA (for strawberry plots, with rotation patterns and cultivars (split plot) as variables) as well as repeated measures ANOVA will be applied for these data to test statistical differences among treatments.

To test hypothesis 2, we will parameterize and test simulation models such as NDICEA (Nitrogen Dynamics In Crop rotation of Ecological Agriculture), DNDC (DeNitrification and DeComposition), and EPIC (Erosion-Productivity Impact Calculator) using data collected from this experiment and others underway at other farm sites.

3. Cultural Practices

Unless otherwise specified, common cultural practices for organic strawberry production in central coast of California (Bolda at al., 2003) were used for growing strawberries in the experiment. Cultural practices including application rates of compost and organic fertilizers were adjusted for each year based on discussion between the grower and the project coordinator reflecting data from the previous year. A grape pomace/chicken manure-based compost was applied in early October of each year. The application rate of compost was 21.4 tons ha^{-1} (8.7 tons $acre^{-1}$) in year 1, 17.8 tons ha^{-1} (7.2 tons $acre^{-1}$) in year 2, and 34.7 tons ha^{-1} (14 tons $acre^{-1}$) in year 3. We also applied and rototilled broccoli residues into topsoil (0-15cm deep) to suppress *Verticillium dahliae* populations in soil (Koike and Subbarao, 2000). In the first year, 27.0 tons ha^{-1} (10.9 tons $acre^{-1}$, Moisture 86%) of fresh broccoli residues from an organic field in Gilroy, CA was applied to the all the plots after compost application. In year 2, before applying compost, a 27.1 tons ha^{-1} (11.0 tons $acre^{-1}$, Moisture 86%) of fresh broccoli residues from treatments C and E was directly incorporated to plots in which broccoli was grown and the same rate of residues from an adjacent organic broccoli field was applied to treatment A. In year 3, since we lost our broccoli by the damage of ground squirrels (see results section), fresh broccoli residues from an organic field (~0.2 acre) in Gilroy, CA (65.7 tons ha^{-1} (26.6 tons $acre^{-1}$, Moisture 87%)), were applied to treatment A and B (0.2 acre) after compost application. In the middle to late October, as beds were listed and shaped, a pelletized solid organic fertilizer was band applied in beds of all plots at the rate of 1167 kg ha^{-1} (1040 lbs $acre^{-1}$) in year 1, 593 kg ha^{-1} (529 lbs $acre^{-1}$) in year 2, and 706 kg ha^{-1} (629 lbs $acre^{-1}$) in year 3.

Strawberry transplants were planted in designated plots on Nov. 19, 2001 in year 1, Nov. 26, 2002 in year 2, and Nov. 14, 2003 in year 3. Plant population was in a range of 47,340 – 52,340 ha^{-1} (19,160 - 21,180 $acre^{-1}$). A black plastic-mulch was applied in January 2002 in year 1, whereas it was applied pre-planting in year 2 and 3 (fig. 5). A supplemental liquid organic fertilizer was applied to all plots throughout the growing season of strawberries and vegetables through the drip tape system (fertigation). See table 4 for total N application rates and fig. 5 for timings and frequency of fertigation.

According to the rotation design (table 1), cover crops and vegetables were planted in designated plots each year. For cover crops, a mixed cover crop of oats (*Avena sativa*. 9 lbs $acre^{-1}$), bell beans (*Vicia faba*, 33 lbs $acre^{-1}$), winter peas (*Pisum* sp., 23 lbs $acre^{-1}$), common vetch (*Vicia purpurea,* 28 lbs $acre^{-1}$) and mustard (*Brassica campestris* in year 1 and *Brassica juncea* in year 2, 5 lbs $acre^{-1}$) was planted in year 1 and 2, where only mustard (*Brassica juncea,* 35 lbs $acre^{-1}$) was planted in year 3. After mustard, spinach and broccoli were planted in each year. See table 2 for further information on cultural practices.

4. Agroecosystem Health Indicators
Yield Survey: Fresh strawberry fruit yield was measured for each cultivar once or twice per week from 40 designated harvest plants during the harvest period (see fig. 1 and table 2). Marketable and cull fruit yields were weighed separately by an experienced harvester. Vegetable yields were measured by randomly taking harvestable plants from 0.5 to 1 m-long sections with four replicates in the beds of a plot.
Nitrogen Dynamics Monitoring:
Throughout the growth period (Nov.-Sept.), samplings were done 3 to 4 times for plants and once a month for soils from 0-60 cm deep in year 1 and 2, and 0-90 cm deep in year 3. Biomass and T-N content in each part of the strawberry plant, including total fruit biomass and its N content, were determined. Cumulative daily N uptakes were calculated from regression curves of N content and biomass of plants and fruits (Hunt, 1982). Nitrate and ammonium was extracted from soil with 2M KCl and determined by the flow injection analysis method (Lachat Instruments, 1993a, 1993b). Soil bulk density in all plots was determined using the soil core method at the end of season each year. Nitrate plus ammonium content was expressed volumetrically as inorganic N (= NO_3-N + NH_4-N kg ha^{-1}).

We estimated N-Loss from the root zone during the rainy season (between 0 and 20 weeks after planting, which is approximately from mid November to early April) using the following formula:

$$\text{N-Loss}_{20wks}\ (\text{kg ha}^{-1}) = (\text{Soil inorg. N}_0 - \text{Soil inorg. N}_{20wks}) - (\text{Plant uptake N}_{20wks} - \text{Plant input N}_0)$$

where Soil inorg. N_0 is Inorganic N (kg ha^{-1}) in 0-30 cm deep soil on the planting day; Soil inorg. N_{20wks} is Inorganic N (kg ha^{-1}) in 0-30 cm deep soil at 20 weeks after planting; Plant uptake N_{20wks} is Plant uptake N (kg ha^{-1}) at 20 weeks after planting; and Plant input N_0 is N input (kg ha^{-1}) from transplants. [To obtain plant nutrient input (nutrient kg/ha), we measured biomass and nutrient contents of transplants (strawberries) and seeds (vegetables) and then multiplied these values by planting density (# or kg per ha).] We defined a 0-30cm soil layer in the bed area as the strawberry root zone, based on literature (University of California Integrated Pest Management Program, 1994) and a preliminary strawberry root profile survey (fig. 3). N-Loss is considered to consist mainly of leached-N and denitrified-N with minor contributions from biological immobilized-N.

In the present report, to discuss the effect of different farming practices on N-$Loss_{20wks}$, one treatment that had similar levels of fruit yield and N uptake by strawberries (~120 kg ha^{-1}) was selected from each year and their N-$Loss_{20wks}$ were compared to each other (treatment A from year 1 and 3, and treatment C from year 2). Additionally soil samples from the furrow area between the raised beds were taken to examine nitrate distribution and dynamics throughout the field in year 1.

Table 2. Major cultural practices in the rotation experiment.

Strawberries			**Cover Crops and Vegetables**		
DATE	D.A.P.*	PRACTICE	DATE	D.A.P.*	PRACTICE
Year 1			Year 1		
10/2/01	-48	compost application	10/2/01	-48	compost application
10/13/01	-37	broccoli application	10/13/01	-37	broccoli application
10/22/01	-28	listing beds and applying organic fertlilizers	10/22/01	-28	listing beds and applying organic fertlilizers
11/19/01	0	strawberry planting	11/19/01	0	cover crop planting
1/8/02	50	plastic mulch application	3/1/02	102	cover crop incorporation
5/2/02	164	strawberry fruit harvest began	6/19/02	212	spinach planting
10/1/02	316	strawberry fruit harvest ended	7/25/02	248	spinach harvest
10/5/02	320	strawberry incorporation	8/2/02	256	broccoli transplanting
Year 2			Year 2		
10/5/02	-52	broccoli application	10/5/02	-52	broccoli application
10/6/02	-51	compost application	10/6/02	-51	compost application
11/25/02	-1	listing beds, applying organic fertilizer and plastic mulch	11/25/02	-1	listing beds
			12/7/02	11	cover crop planting
11/26/02	0	strawberry planting	4/8/03	133	cover crop incorporation
5/1/03	156	strawberry fruit harvest began	5/21/03	176	spinach planting
9/27/03	305	strawberry fruit harvest ended	7/1/03	217	spinach harvest
10/1/03	309	strawberry incorporation	8/2/03	249	broccoli transplanting
			10/1/03	309	weeding
Year 3			Year 3		
10/8/03	-37	compost application	10/8/03	-37	compost application
10/9/03	-36	broccoli application	10/10/03	-35	listing beds and applying organic fertlilizers
10/10/03	-35	listing beds and applying organic fertlilizers	11/5/03	-9	cover crop planting
11/13/03	-1	plastic mulch application	4/5/04	143	cover crop incorporation
11/14/03	0	strawberry planting	4/29/04	167	spinach planting
4/10/04	148	strawberry fruit harvest began	6/17/04	216	weeding
9/30/04	321	strawberry fruit harvest ended	7/7/04	236	broccoli transplanting
10/5/04	326	strawberry incorporation	10/5/04	326	broccoli roto-tilled

* Days after strawberry planting in each year.

5. Soil Health Indicator

Verticillium dahliae *Test:* Propagule numbers of *Verticillium dahliae,* the main fungal pathogen of strawberry, was monitored in soils in each plot three times during each strawberry crop and periodically during non-host vegetable crops. *Verticillium dahliae* was quantified using standard soil plating methods (Butterfield and Devay, 1977; Koike et al., 1993).

Further analyses of agroecosystem health indicators (e.g. economic analysis of different rotations) and soil health indicators (e.g. PLFA analysis for soil microbial communities, potentially mineralizable nitrogen, soil chemical analysis other than nitrogen), will be conducted with other funds in the future.

RESULTS

1. Crop Growth and Yields

Strawberries grew well without any major pest and disease problems and had relatively high yields for an organic system. Average marketable fruit yield of cv. Aromas was 36-44 tons ha^{-1} during the first three years (table 3). Although treatment A (continuous strawberries with broccoli applications) produced numerically lower fruit yield than in treatment C in the second year (fig. 2), no significant differences were found in the fruit yields between any rotation treatments in any year. Between subplots, fruit yield of cv. Diamante was significantly lower than cv. Aromas (averaged 31 tons ha^{-1}) in year 1, whereas yield of cv. Seascape was comparable with cv. Aromas in years 2 and 3 (data not shown).

Fresh biomass of mustard cover crop increased from year 1 to years 2 and 3 (table 3). Although a mix of cover crops was planted in years 1 and 2, mustard dominated over other cover crops in both years. Mustard biomass was low in year 1 due mainly to the shorter growing season. Spinach yield was fair in years 1 and 2 but the low germination rate resulted in no harvest of spinach in year 3 (table 3). Broccoli biomass was ~30 tons ha^{-1} in years 1 and 3, whereas virtually all broccoli plants were damaged by ground squirrels resulting in no broccoli harvest in year 2 (table 3). Consequently, organic broccoli residues were brought from another field and were applied in plots that were going to have strawberries in year 3.

2. Nitrogen Dynamics Monitoring

In year 1, pre-plant soil inorganic N analysis revealed 150 kg-N ha^{-1} of residual inorganic N (fig. 4 and 5-left). By adding 222 kg-N ha^{-1} of total basal N, inorganic N content at the time of planting rose to 260 kg-N ha^{-1}. After receiving 280 mm of precipitation, the grower applied plastic mulch in January 2002. In the meantime, it was estimated that 214 kg ha^{-1} of inorganic N was lost from the root zone within 20 weeks from planting (fig. 4 and 5-left). Cumulative daily N uptake of strawberry plants showed that ~80% of the total N uptake took place in the latter half of the growth period (fig. 4 and 5-left). Total N uptake by strawberry was ~120 kg-N ha^{-1}.

Based on the results of the first year, the grower modified his N fertility management for year 2. He adopted: 1) pre-plant plastic mulch application to reduce N-loss during the rainy season, and 2) adjusted the rates of basal/supplemental organic fertilizer applications to better meet the N demand of strawberries. He decreased the rate of pre-plant pelletized organic fertilizers to one-half of the previous year and increased the rate of liquid fertilizers through fertigation in the late growth stage (fig. 5-middle). As a result, the amount of N-loss during the rainy season (Nov. 2002-April 2003) was reduced to 13 kg-N ha^{-1} without sacrificing fruit yield and N uptake of strawberries (fig. 5-middle).

Table 3. Average crop yields of the Elkhorn rotation experiment (fresh weight tons ha^{-1})

Crop	Year 1	Year 2	Year 3
Strawberries* (Aromas)	**42 (A, B, D)****	**36 (A, C)**	**44 (A, B)**
Mustard	**18 (C, E)**	**45 (B, D, E)**	**57 (C, D, E)**
Spinach	**13 (C, E)**	**7.4 (B, D, E)**	**not harvested**
Broccoli***	**30 (C, E)**	**not harvested**	**29 (C, D, E)**

* Marketable fruit yield
** There is no significant difference between any treatments at the 5% level of probability, according to Tukey's honestly significant difference test.
*** Total fresh biomass. Damage by ground squirrels resulted in no broccoli harvest in year 2.
Key to treatments:
A: Continuous strawberries with pre-plant biofumigation using broccoli residues
B: One-year break before replanting strawberries
C: Two-year break before replanting strawberries
D: Three-year break before replanting strawberries
E: No strawberries until fifth year.

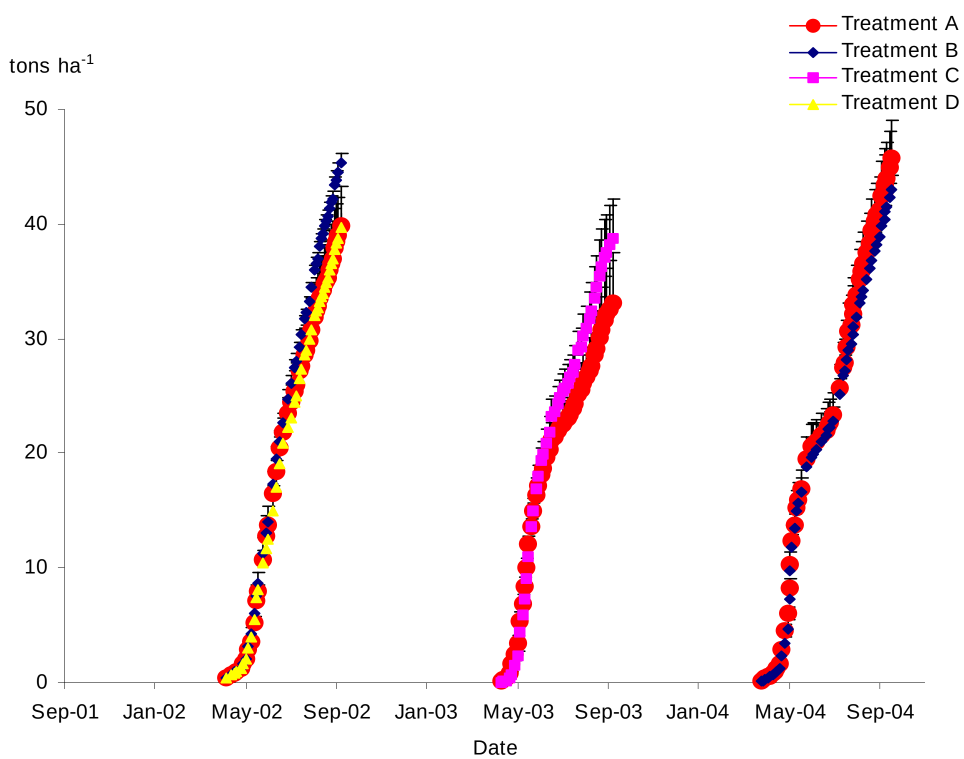


Fig. 2 Cumulative marketable fruit yield of Aromas strawberries (each point is the mean of 4 replicates, and bars show standard error of the mean).

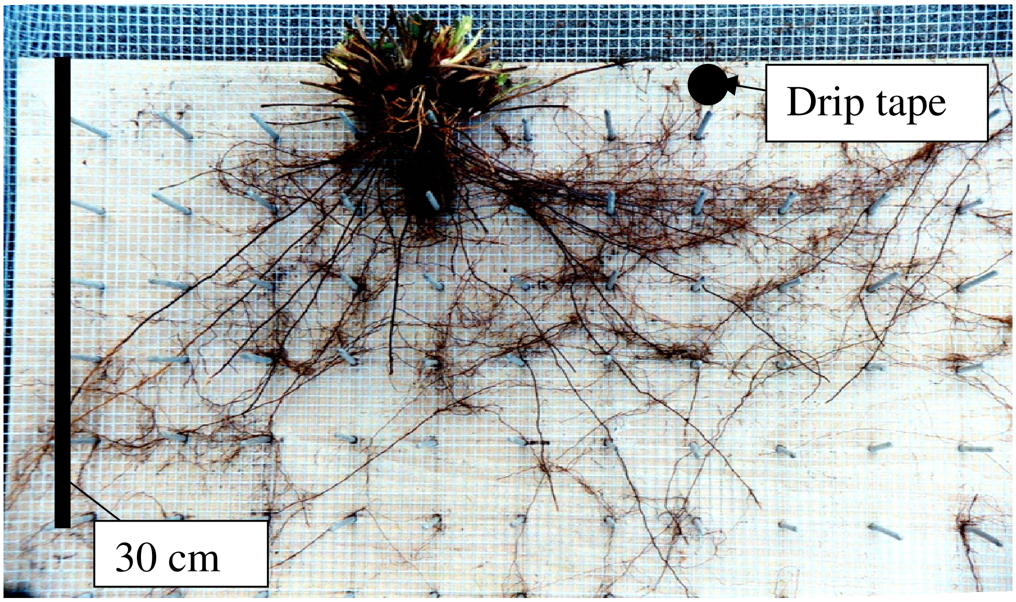


Fig. 3 An Example of Vertical Root Distribution Pattern of Organic Strawberries Sampled by Pin-Board Method (Cultivar: Aromas, Soil type: Santa Ynez fine sandy loam (Fine, montmorillonitic thermic, Ultic Palexerolls), Location: Moss Landing, California). Picture by J. Muramoto)

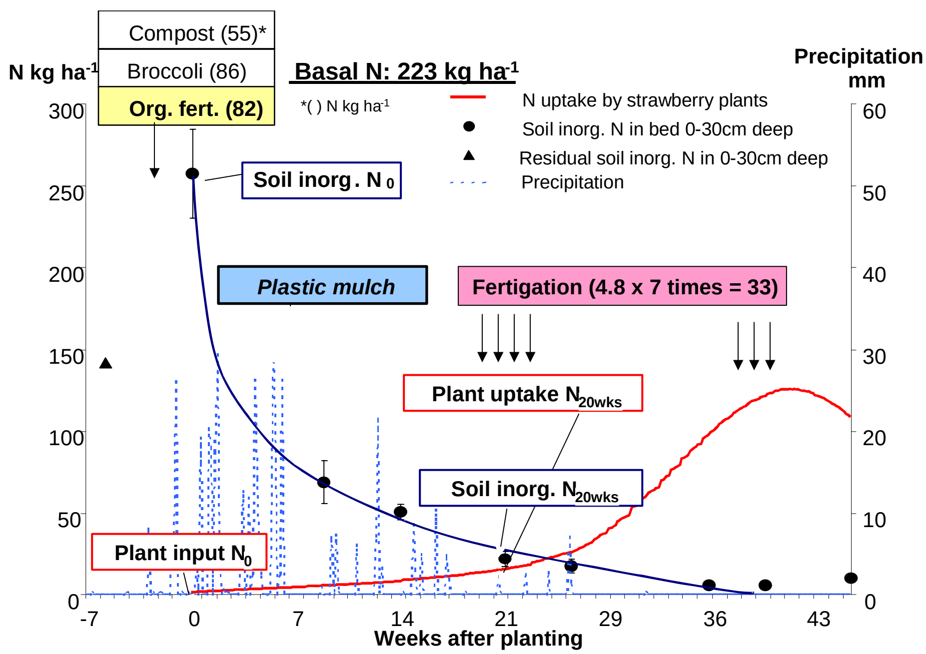


Fig. 4 N dynamics and N loss during the rainy season from an organic strawberry field in Moss Landing, California (cv. Aromas. Treatment A. Year 1). Estimated N-Loss during the rainy season was: $N\text{-}Loss_{20wks} = 214$ kg ha^{-1}.

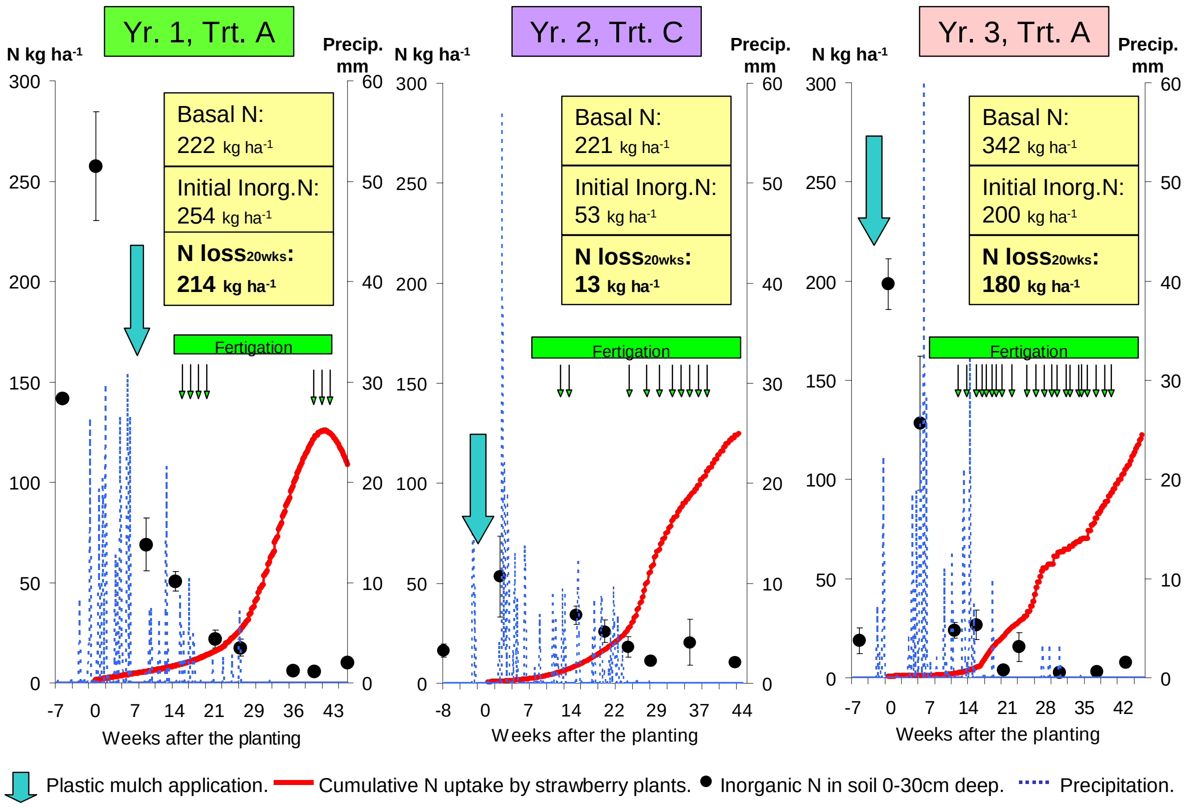
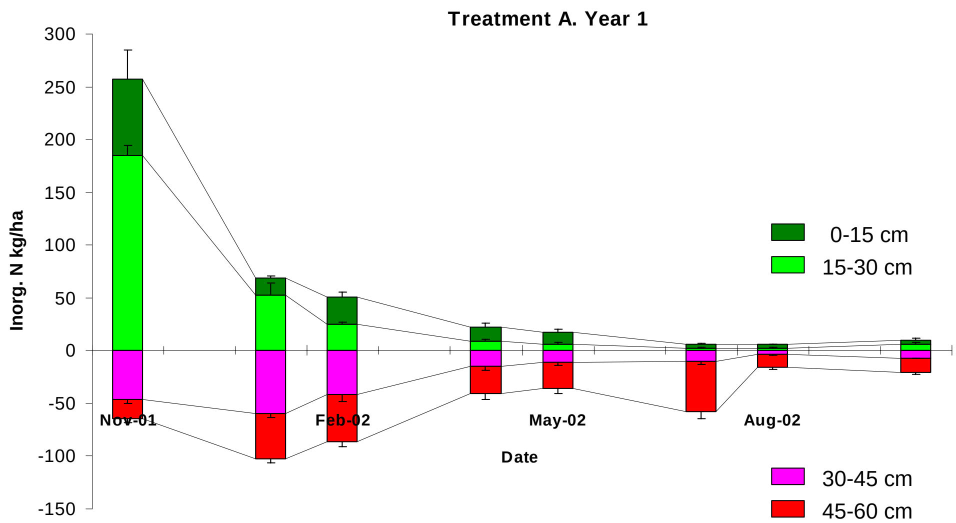


Fig. 5 N dynamics in strawberry plots during the first three years. For comparison, a strawberry plot that had ~120 kg ha^{-1} of cumulative N uptake was chosen from each year. Although total basal N rate of year 2 was similar to year 1, solid organic fertilizer application rate in year 2 was reduced to less than a half of year 1. See table 4 for N application rates and sources for each year.

Table 4. N application rate and sources for organic strawberries*

Source	Year 1 (N kg ha^{-1})	Year 2 (N kg ha^{-1})	Year 3 (N kg ha^{-1})	Year 4 (N kg ha^{-1})
Compost	55	66	115	11
Broccoli	86	118	153	73
Organic fertilizer**	82	37	75	52
Total basal	223	221	342	136
Supplemental organic fertilizer***	33	75	22	?
Grand total N	256	296	364	?

* N application rates of compost and broccoli residues were adjusted to bed area by multiplying by 0.58 (bed/whole field ratio).
** commercial solid organic fertilizer.
*** a liquid organic fertilizer that is applied through fertigation.



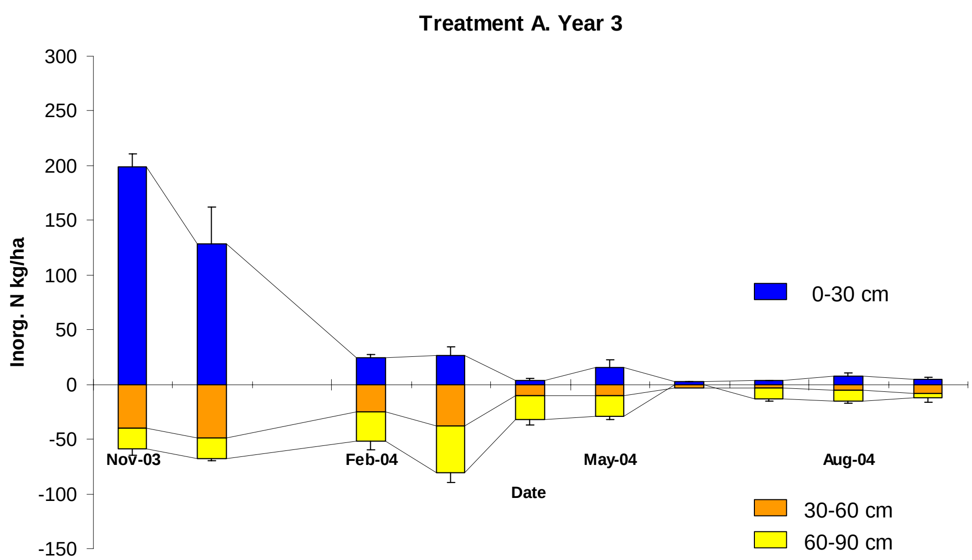


Fig. 6 Changes in soil nitrate content in and below the root zone of 0-30 cm deep. Top: treatment A in year 1. Bottom: treatment A in year 3. Soil inorganic N content below 30cm deep was expressed as negative values. Note that below root zone was 30-45cm and 45-60cm (2 layers) in year 1, and 30-60cm and 60-90cm (2 layers) in year 3.

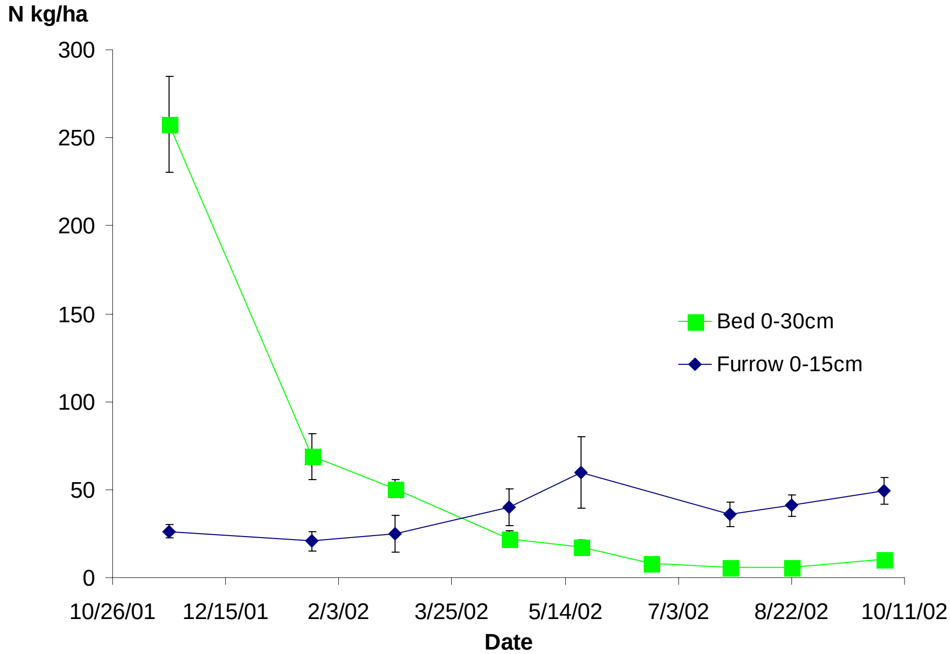


Fig. 7 Increase of soil inorganic N in furrow soil (0-15 cm deep) during the summer (year 1. treatment A).

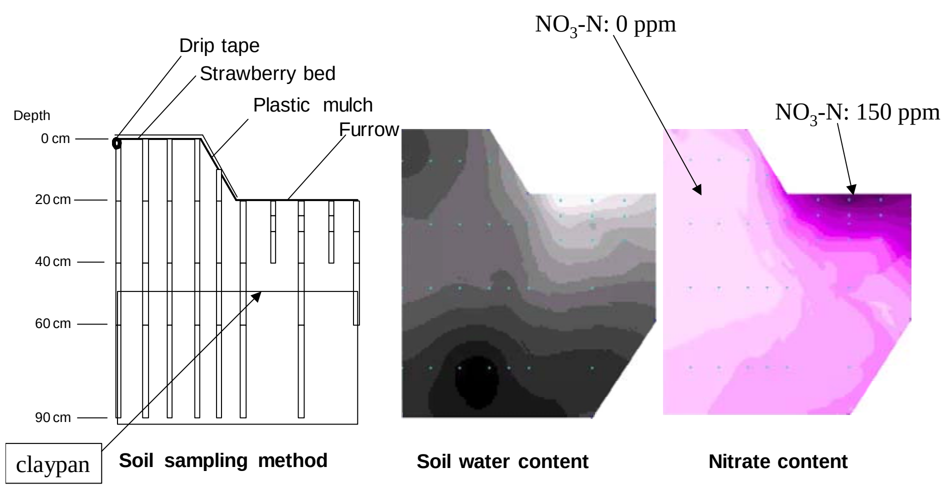


Fig. 8 Nitrate and water content distributions across a strawberry bed and furrow profile. For both soil water and nitrate, the darker the color, the higher the contents. The images were made using the Kriging method. Soils were sampled on 9/5/02 (year1, treatment A).

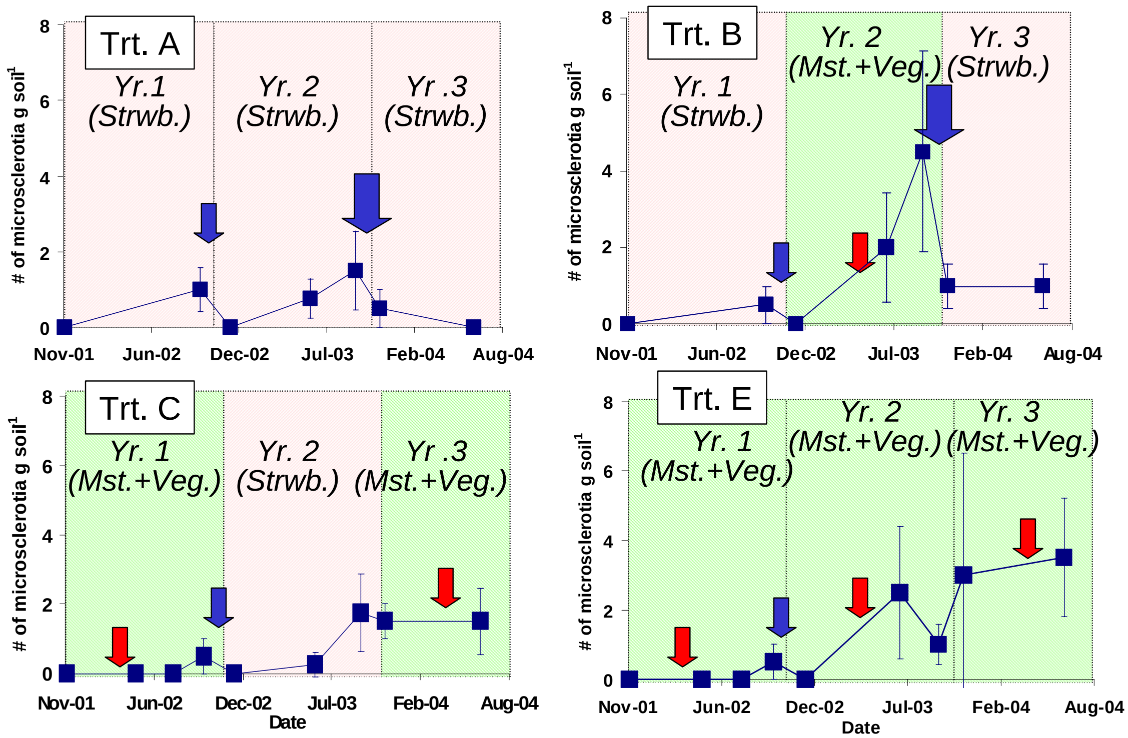
Fig. 9 A strawberry plot right after a storm (Dec. 2004). Water in furrows contained ~10 mg kg^{-1} of nitrate-N, suggesting surface run-off can be a major path for losing nitrate to the environment.

In the third year, we tried pre-plant plastic mulch under higher application rates of compost and broccoli residues. The rate of both compost and broccoli were approximately twice that of year 2. As a result, the initial inorganic N level soared to 200 kg ha^{-1} (fig. 5-right). Although N loss during the first 7 weeks from the planting seemed to be slowed down, the amount of N-loss during the 20 weeks from the planting reached 180 kg ha^{-1}, a similar level with the year 1 (fig. 5-right).

To demonstrate the fate of lost N, the amount of leached nitrate was examined by taking deeper layer soil samples (30-60 cm deep in year 1 and 2, and 30-90 cm deep in year 3) once a month in the bed area. Results from year 1 and 3 at treatment A showed ~30 kg ha^{-1} of inorganic N (mainly nitrate) had been leached down below the root zone before the summer of each year (fig. 6). Apparently these amounts did not account for the N loss during the rainy seasons mentioned earlier. Additionally, ~20 kg ha^{-1} of inorganic N was detected at 45-60 cm deep in July of year 1 (fig. 6-top), indicating leaching from the supplemental N application through fertigation.

To demonstrate N dynamics, we monitored soil inorganic N in furrow soils as well as bed soils in year 1. From the spring to the summer, inorganic N content in the top 15 cm of furrow soil increased, whereas inorganic N content in bed topsoil decreased (fig. 7). To further examine soil water and nitrate distribution across the soil profile, we conducted intensive soil samplings, as shown in fig. 8-left. The results demonstrated a clear relationship between soil and nitrate dynamics across the soil profile (fig. 8-middle for soil moisture, and fig. 8-right for nitrate). These figures created using the Kriging method

(Oliver, 1990) indicate: 1) soil water movement from deeper claypan area toward the furrow surface from which soil moisture evaporated (fig. 8-middle), and 2) subsequent movement of nitrate from the bed area to the furrow surface at which nitrate accumulated (fig. 8-right).



Strwb. strawberries. *Mst.* mustard. *Veg.* vegetables.

Fig. 10 Changes in number of *Verticillium dahliae* microsclerotia in soils in the different treatments. The mean ± SEM. Broccoli residues or mustard incorporation.

Pink and green background indicates strawberries and mustard+vegetables, respectively. A larger amount of broccoli residues was applied at the end of year 2 in treatment A and B (indicated with larger arrows. See text for actual rates).

A similar trend of decreasing inorganic N in the topsoil of bed areas was also observed during the summer of year 3 (fig. 6-bottom).

3. Verticillium dahliae *Test*

The Verticillium test brought about generally low counts (less than 5 microsclerotia gram soil^{-1}) in the first three years (fig. 10). Interestingly numbers of *Verticillium dahliae* microsclerotia in soils decreased consistently after incorporating broccoli residues regardless of treatments, whereas no such reduction was observed after mustard incorporation (fig. 10). In treatments B and E, *Verticillium dahliae* microsclerotia in soils increased during the summer of year 2 when broccoli was lost due to ground squirrel damage.

DISCUSSION

The first indicator we measured on agroecosystem health is crop yield. During the first three years, the fruit yield of organic strawberries has been excellent for an organic production system: total fruit yield of the first year of the experiment was 83% of the average total yield of both conventionally and organically produced fresh and processing strawberries of Monterey County in the same year (Monterey County Agricultural Commissioner, 2003). Although we saw a slight fall of the fruit yield in the continuous strawberry plot (treatment A) in year 2, we have not seen any significant difference in fruit yield and disease level between any treatments as of the end of year 3. This probably relates to: 1) the low background level of *Verticillium dahliae* population of the field (<1 microsclerotia gram soil^{-1}), and 2) effect of broccoli residue incorporation in suppressing *Verticillium dahliae* populations in the soil. We are expecting to see more differences between main treatments in fruit yield and disease level by the end of year 5.

On the other hand, yield of spinach and broccoli tended to be low to fair. Our grower specializes in berries and has limited experience growing vegetables. Although we have tried to find an organic grower who is willing to manage the vegetables in the rotation experiment, we have been unsuccessful. Collaboration between specialized organic strawberry growers and specialized organic vegetable growers is a key challenge of sustainable organic production in the area. We will do our best for one more year in growing vegetables in year 4, the last year for vegetable production in the experiment.

We estimated N loss during the rainy seasons as another indicator for agroecosystem health. Results from year 1 showed that organic strawberry production could have a considerable N-loss and a significant impact on the environment during the rainy season (fig. 4). It also suggests the importance of examining residual inorganic N levels by soil testing in organic systems. Some conventional practices such as this and irrigation management using soil water sensors should be used to enhance N-use efficiency in organic systems.

Results from year 2, in contrast, demonstrated that relatively simple adjustments in N management could make a big difference in reducing N-loss while maintaining the fruit yield from year 1. Adjustments the grower adopted in year 2 were: a pre-plant plastic mulch application, and adjusting rates and timings of N applications to better match with the plant N demand. It should be noted, however, that the residual N level at the time of planting in the second year was much lower than the first year, and precipitation during 0 and 20 weeks after planting in the second year (318 mm) was 15% less than the first year.

Use of a black plastic mulch is a common practice in California organic strawberry production (Gliessman et al., 1996), but the timing of mulch application varies among growers. Placing a plastic mulch before planting can increase water run-off into the furrows, leading to a potential increase in soil erosion in high slope fields (Martin and Bull, 2002). On the other hand, some organic strawberry growers choose pre-plant application because of reduced weed growth in later season. Unlike conventional strawberry systems where use of control-release N fertilizers is widespread, no organic control-release N fertilizers are currently available that can synchronize the soil N release with the strawberry N demand. Therefore, a pre-plant plastic mulch application might help reserve inorganic N mineralized in soil in beds during the early rainy season when the system is most susceptible to N leaching. As is discussed later, however, this practice had a limited value in preventing the N loss under a high initial inorganic N level (year 3).

To better synchronize N supply and N demand (Campbell et al., 1995; Woomer and Swift, 1994), we need to know the N uptake pattern of strawberries. Interestingly this kind of fundamental data has not been published for most strawberry cultivars in California even under conventional systems and more so for organic systems. The N uptake pattern of strawberry plants (red curves in figs. 4 and 5) suggests that the peak N demand exists in the mid to later growth stages, whereas less N is utilized in the early stage. N fertility studies for organic long-season vegetable production indicate cover crops or compost alone might be inadequate to fulfill the late N demand of these crops (Gaskell et al., 2000; Gaskell and Klauer, 2001) and the same is likely to be true in organic strawberry production.

In year 2, to meet the N demand of strawberries, the grower decreased the basal N rate of the organic fertilizer and increased the rate of liquid organic fertilizer for the late stage. Under the current organic strawberry systems, fertigation and foliar N application are the only practical options as supplemental N application measures. It should be noted, however, that organic fertigation may have a high risk of N leaching under excess irrigation conditions (Pritts and Handley, 1998), as we detected an increased inorganic N level in a deeper soil layer in one summer (fig. 6, top, in July 2002). Effectiveness of foliar N application in organic strawberry systems has not been well studied.

We then examined the effect of pre-plant plastic mulch under a higher application rate of compost and broccoli residues in year 3. It resulted in increased levels of inorganic N at planting and increased N loss during the rainy season, suggesting a limited ability of pre-plant plastic mulch application and the greater importance of a low inorganic N level at the planting for minimizing N loss during the rainy season.

As far as the fate of lost N is concerned, it appears that the amount of nitrate leaching does not account for the total N loss during the rainy season from the field (fig. 6). A preliminary observation and N monitoring of run-off water indicates surface run-off is likely to be a major path of N loss during the rainy season (fig. 9). Further, monitoring inorganic N both in bed and furrow soils during the summer revealed a horizontal nitrate movement from bed to furrow where few roots exist (fig. 7 and 8). Since the accumulated nitrate in furrows will be eventually leached down by the winter storms, it can be seen as another type of N leaching.

For the current season (year 4), we reduced total basal N application rate to 136 kg ha^{-1}, the lowest rate in the experiment (table 4). As of the summer in 2005, the fruit yield of strawberries in treatment A appears to be comparable with the year 3 (data not shown). Further studies with different N rates and timings are required to determine the early N demand and appropriate rate and type of pre-plant N application, including broccoli residue application, in organic strawberry systems.

As a soil health indicator, we monitored the *Verticillium dahliae* population in soil. During the first three years, broccoli residue applications constantly reduced numbers of *Verticillium dahliae* microsclerotia in soil, even under continuous cropping of strawberries in treatment A (fig. 10). This agrees with Shetty et al. (1999), who found broccoli residue application reduced *Verticillium dahliae* population in soil under low to moderate disease pressure. Although the mechanism of this suppression has not been completely elucidated, studies suggest involvement of microbial processes in addition to chemical toxicity of isothiocyanates (ITCs) in brassicas (Shetty et al., 2000). On the contrary, mustard applications in the present study did not decrease numbers of *Verticillium dahliae* microsclerotia in soil (fig. 10). Another study also found that mustard incorporation did not reduce *Verticillium dahliae* microsclerotia in soil, but it reduced wilting symptom on potatoes (A. McGuire, personal communication, November 2, 2004), suggesting a different mechanism of disease suppression such as microbial competition among root colonizers (Davis et al., 1996).

In the summer of year 2 in treatment B and E, number of *Verticillium dahliae* microsclerotia in soil increased. This coincides with the time when we lost broccoli plants by the damage of ground squirrels, which left plots in weedy condition. Later we learned that the major weed of the field, Shepherd's purse (*Capsella bursa-pastoris*) also hosts *Verticillium dahliae*. Therefore, weed management should be integrated with the soil-borne disease management.

CONCLUSIONS

- During the first three years, yields of organic strawberries were excellent but of organic vegetables and mustard cover crops were low to moderate. No major disease and pest problems were observed.
- N management in organic strawberries is challenging due to the high N sensitivity and long growth period of strawberries, the application of basal fertilizers immediately prior to the rainy season (in winter planting systems) and the lack of organic control-released N fertilizers.
- Biofumigation with broccoli residues reduced soil *Verticillium dahliae* population.
- The combination of compost and broccoli residue application increased the amount of initial soil inorganic N at planting and subsequent N loss during the rainy season. Basal fertilizer rate needs to be adjusted accordingly.
- It is important to reduce populations of weeds that host key diseases.
- The grower is eager to adopt findings of the project to improve his management. The project will be used as a demonstration project for local organic growers.

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Appendix: Summary of a larger project entitled “Improving fertility and pest management strategies for organic crop production and strengthening researcher/grower networks” funded by USDA-Integrated Organic Program (USDA-IOP #2004-51300-02232).

ACCESSION NO: 0201343 **SUBFILE:** CRIS
PROJ NO: CALW-2004-05136 **AGENCY:** CSREES CALW
PROJ TYPE: OTHER GRANTS **PROJ STATUS:** NEW
CONTRACT / GRANT / AGREEMENT NO: 2004-51300-02232 **PROPOSAL NO:** 2004-05136
START: 15 SEP 2004 **TERM:** 14 SEP 2008 **GRANT YR:** 2004
GRANT AMT: $571,902

INVESTIGATOR: Gliessman, S. R.; Shennan, C.; Swezey, S. L.; Muramoto, J.; Koike, S. T.; Smith, R. F.; Bolda, M. P.

PERFORMING INSTITUTION:
University of California, Santa Cruz
Santa Cruz, CALIFORNIA 95064

IMPROVING FERTILITY AND PEST MANAGEMENT STRATEGIES FOR ORGANIC CROP PRODUCTION AND STRENGTHENING RESEARCHER/GROWER NETWORKS

NON-TECHNICAL SUMMARY: The California organic agriculture industry is growing in size and consumer acceptance. In 2003, approximately 1,800 registered organic farmers produced $340 million in sales on over 180,000 acres. Unfortunately, this rapid expansion in organic farming is taking place with a very limited scientific research base. Organic vegetable and strawberry growers in California consistently voice concerns about the lack of knowledge that can be used to manage soil, insect pests, pathogens, and fertility in an integrative manner. The long-term goals of this project are two fold: first, to strengthen an existing organic research and extension network to support organic vegetable and strawberry producers in the region; and second, to develop and evaluate integrated fertility and pest management strategies in order to improve farm management and sustainability, minimizing negative impacts of agriculture on surrounding sensitive natural ecosystems, and improve the economic viability of organic farming. A team of organic growers, multidisciplinary researchers from multi-institutions, extension specialists, and three regional NGOs will work closely on this research, education and extension project, and evaluate improvements in knowledge and networks to support organic production.

OBJECTIVES: The goals of this project are: 1) To strengthen an existing organic research and extension network to support organic vegetable and strawberry producers in the region, and 2) To develop and evaluate integrated fertility and pest management strategies. The underlying hypothesis for goal 1 is that the capacity and effectiveness of regional research, education and extension networks for organic agriculture will be strengthened by the participatory collaborations proposed. For goal 2, we will test the following hypotheses: A. Fertility management 1) The use of field level nutrient budgets combined with nutrient content database and simulation models to predict periods of greatest vulnerability to nutrient losses will enable farmers to significantly improve nutrient use efficiency by optimizing timing, quality and amounts of inputs used and crop rotations. 2) Tissue tests based on total N levels will be better predictors of N sufficiency and deficiency for organically produced crops than those based on tissue nitrate levels previously developed for chemically fertilized crops. B. Disease management 1) The use of non-host rotation crops for Verticillium wilt plus bio-fumigation with broccoli and compost application will suppress disease development sufficiently to grow strawberries in rotation every 3 or 4 years without negatively affecting soil microbial diversity. 2) Incorporating mustard cover crops can be an effective means of controlling Verticillium wilt, but the degree of control will depend on the amount of biomass incorporated and the type of mustard. 3) Anaerobic decomposition of crop residues can be an effective means of controlling Verticillium wilt, but the degree of control will depend on the ability to sustain anaerobic conditions, accumulated degree days of anaerobic decomposition, and the amount of biomass incorporated. C. Insect pest management 1) By avoiding excess N fertilization, organic growers can reduce abundance of two-spotted spider mites and other foliar pests. 2) By planting and managing a system of alfalfa trap crops, organic strawberries can be economically protected from lygus bug damage. 3) Organic annual crop fields with hedgerows will support a higher number of arthropod natural enemies and fewer pests than similar fields with unmanaged margins due to enhanced biological control of insect pests in fields with hedgerows. D. Weed management 1) Incorporating mustard cover crops can be an effective means of reducing the seed bank of some weeds, but the degree of control will depend on the amount of biomass incorporated and the type of mustard. 2) Anaerobic decomposition of crop residues can be an effective means of reducing the seed bank of some weeds, but the degree of control will depend on the ability to sustain anaerobic conditions, accumulated degree days of anaerobic decomposition, and the amount of biomass incorporated, rather than the type of biomass used. E. Economic impacts 1) Improved fertility and disease management will result in economic savings to growers through reduced input costs.

APPROACH: For goal 1, we will form a network advisory board that includes researchers, farmers, extension specialists, representatives from an existing statewide organic growers association (CCOF), and two-regional NGOs to review progress and examine data as it emerges. This board will also develop outreach and extension programs, to include field days, workshops, short courses, a project web site, and a variety of publications aimed at farmers, resource management agencies, environmental organizations and the academic community. Improvements in the information available for organic producers and in research/extension capacity will be assessed by tracking the number and types of growers and industry representatives attending outreach activities, collecting feedback on the quality and usefulness of the findings to different attendees, and pre-assessment and post-assessment surveys on knowledge and practices used by organic growers before and after the project. For goal 2, by conducting multiple replicated trials on local organic farms, we will examine the effects of diverse vegetable/cover crop/strawberry rotations, fertility management and different disease and pest management options on crop yields, soil quality, weed population dynamics, arthropod pest pressure, and suppression of *Verticillium dahliae*, a key pathogen of organic vegetables and strawberries. To optimize fertility management, we will: a) develop a nutrient budget tool backed by a comprehensive nutrient content database of organic amendments, cover crops, and crop residues; b) evaluate three N simulation models, EPIC (Erosion-Productivity Impact Calculator), DNDC (DeNitrification and DeComposition), and NDICEA (Nitrogen Dynamics in Crop Rotations in Ecological Agriculture), for their use in fertility management planning in organic production, and c) develop nitrogen sufficiency tissue tests for organic broccoli and strawberries. For suppression of Verticillium wilt, we will evaluate anaerobic decomposition of cover crop residues under silage tarps after residue incorporation and biofumigation with Brassica spp. Changes in soil *Verticillium dahliae* populations and soil microbial diversity analyzed by PLFA method will be assessed in a replicated on-farm trial with diverse rotations and integrated ecological practices. Biological control of insect pests using in-field insectaries, trap crops, and hedgerows will be evaluated and demonstrated on local farms. Responses of spider mite (on strawberries) and aphid (on broccoli) population to different N application rates will be examined. The effects of rotation design and fertility and disease management on weed population dynamics will also be monitored. Finally, the economic feasibility for each of the management alternatives under investigation will be determined and models for a representative small organic farm as well as a larger operation will be developed. A team of organic growers, multidisciplinary researchers from multi-institutions, extension specialists, and three regional NGOs will work closely on this research, education and extension project, and evaluate improvements in knowledge and networks to support organic production.

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