SUSTAINABLE AGRICULTURE FARMING SYSTEMS PROJECT
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Long-term comparison of yield and nitrogen use in organic, winter legume cover crop and conventional farming systems

By Kathleen M. Reed, William R. Horwath, Steve Kaffka, R. Ford Denison, Dennis Bryant, and Z. Kabir

We have recently analyzed 11-years of data comparing nitrogen use in the organic, winter legume cover crop (WLCC), and conventional farming systems at a field research site for sustainable agriculture at UC Davis, the Center for Integrated Farming Systems (CIFS). This article outlines results from a study at the CIFS site comparing three tomato/corn cropping systems for yield and N uptake from 1994 to 2004, and suggests possible reasons for yield differences among farming systems. CIFS represents the merger of the Sustainable Agriculture Farming Systems (SAFS) project, which began in 1988, and the Long Term Research on Agriculture Systems (LTRAS) project, which began in 1991. The former SAFS site was designed to introduce crop diversity and winter cover crops into rotations, with a specific emphasis on the conversion from conventional to low-input and organic systems. The goals of LTRAS have been to evaluate the effects of differing amounts of fertilizer, organic matter and irrigation on the long-term capacity to sustain or improve crop yields and related environmental properties. Cropping systems in this study are designed to reflect this research purpose rather than as models for commercial farmers.

(photo by Lyra Halprin)

Eleven years of data comparing nitrogen at UC Davis' sustainable ag research site is now available. Researchers (l-r) Wes Wallender, Sam Prentice, Aaron Ristow and Will Horwath are pictured at the site.

Yield and N Uptake

Corn

Corn yields across all systems ranged from 4,823 to 14,966 lbs/acre (standardized to 15.5% moisture). Conventional yields were highest in 1994 and lowest in 1995 and 1999, when conventional planting dates were delayed and corresponded with the organic and WLCC systems (Fig. 1). Organic corn yield was lowest in 2002 (4,823 lbs/acre). However WLCC corn yields were lowest in 2004 (5325 lbs/acre), while in the same year conventional yields of 14,966 lbs/acre were the highest ever observed in the trial. One reason for low yields that year in the WLCC system may be that the only N input to corn and the prior tomato crop was from the

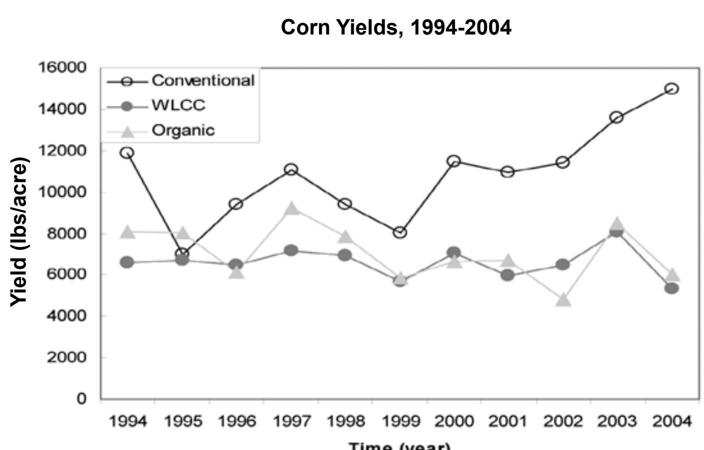

Figure 1

–continued page 2

SAFS update

Welcome to the *Sustainable Agriculture Farming Systems (SAFS) Project, Winter/Spring 2006, Vol. 6/No.2* newsletter, which presents research results from the UC Davis Center for Integrated Farming Systems (CIFS). CIFS is the result of the merger of the campus' SAFS project and Long Term Research on Agriculture Systems (LTRAS) project. The articles here continue our efforts to provide useful information on economically and ecologically sustainable research and management practices for California growers. We are pleased to work with the statewide UC Sustainable Agriculture Research and Education Program (SAREP) on outreach. **Note:** Please join us for our annual field day tentatively scheduled for late June 2006. Stay tuned.

—Will Horwath, project leader

previous winter's cover crops. Previously, the tomato phase of this cropping system had been fertilized.

Plant N uptake was correlated with corn yields. Conventional yield and N uptake varied from year to year from 1993 to 2004, while organic and WLCC yields and N uptake decreased over the last six years remaining low or declined. In this experiment, cropping systems are compared, so conventional corn tends to be planted several weeks to a month earlier than the other systems, which must accumulate cover-crop biomass in the spring. In the organic and WLCC systems, planting must be delayed until after the incorporation of fresh organic matter. Earlier planting tends to result in higher yields. This may not be the only cause of yield differences. In another study at the CIFS site starting in 2005, fertilizing the WLCC system with the later planting dates has increased yields (data not shown) comparable to the conventional system, showing that N availability or timing also is a critical issue affecting maximum yield potential.

Tomato

Tomato yields ranged from 21,178 to 70,538 lbs/acre during the study (Fig. 2). Average organic and WLCC tomato yields were, for the most part, comparable to the conventional yields. However, organic yields varied less over the years than conventional and WLCC yields. Tomato N uptake generally mimicked yields over the course of this study.

N balance, N storage in soil, and N loss

The N balance from 1994 to 2004 revealed that the organic system had the greatest cumulative N input and N balance, while the conventional system had the largest N output in harvested crops. Although the organic system had the greatest cumulative N input, it also had the lowest N output of all the systems. Soil N storage was highest in the organic farming system, which was the only system with an increase in soil N. A buildup of soil organic matter is required to increase the potential for N mineralization. Despite that increase in soil N and C, corn yields were consistently lower in the WLCC and organic systems than in the conventional one and have remained low for the last several years.

Comparison among farming systems of total soil N storage at 0-30 cm depth between 1993 and 2004 showed the greatest quantity of N storage in the organic system. While the organic system accumulated 611 lbs N/acre, soil N storage decreased by more than 290 lbs N/acre in both the WLCC and conventional systems (Table 1). The amount of unaccounted N (presumed lost to the atmosphere or groundwater) was greatest in the organic system (1,589 lbs N/acre), however, N input was also highest in this system. There were also large amounts of unaccounted N in the conventional and WLCC systems, 1,033 and 809 lbs N/acre respectively over the duration of the study. The organic system lost 72 percent of its 11-year crop N balance, while storing 28 percent of that N in the soil. However, both the WLCC and conventional systems lost 100 percent of their 11-year crop N balance and showed a depletion of soil N. Though the organic system showed a more positive N balance compared to the other systems, it had an overall greater loss of the cumulative amount of total N applied during the study. Even though lower amounts of C and N were added to the organic system after 1997, amounts may still have been in excess.

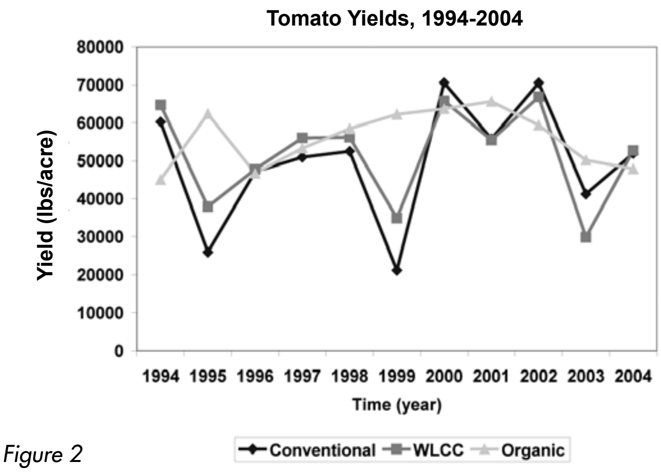

Figure 2

Table 1. Cumulative N balance, soil storage (at 0-30 cm soil depth), and loss for the organic, WLCC, and conventional cropping systems at CIFS, 1993-2004.

Farming System	N balance (lbs N/acre)[a]	Soil N storage (lbs N/acre)[b]	N loss (lbs N/acre)[c]
Organic	2200[a]	611[a]	1589[a]
WLCC	516[c]	-293[b]	809[b]
Conventional	691[b]	-342[b]	1033[b]

[a] N balance = total N input – crop removal
[b] Soil N storage = soil N in 2004 – soil N in 1993 (based on 2005 and estimated 1993 bulk density measurements)
[c] N loss = N balance – soil N storage

The mean balance of soil C over the 11-year study was 8,268 lbs C/acre in the organic system, 345 lbs C/acre in the WLCC system, and -1,144 lbs C/acre in the conventional system (data not shown). The organic system may have reached maximum capacity for N and C storage by 1997, and may have been unable to store additional N and C in subsequent years. The results indicate that despite large amounts of C and N applied as manure and cover crops, these soils have a limited capacity to accumulate organic matter. California's warm climate, combined with tillage and irrigation during the warm growing season are probably the primary reasons for this limitation. However, the initial accumulation of 8.3 tons of C in the organic system is significant and shows the potential to store C in these intensively managed systems that include cover crops and manure.

At the former SAFS site prior to 2003, there was a four-year crop rotation of tomato, safflower, corn, oats/vetch, and beans in the organic, intermediate (WLCC), and one conventional system, while the other conventional system had a two-year, two-crop rotation of tomato and wheat. The organic and WLCC systems at that site had much lower losses over a 10-year period, 80 and 33 lbs N/acre respectively, compared with the two-year and four-year conventional systems, which lost 365 and 403 lbs N/acre respectively. Long-term yields for both corn and tomato were comparable among all three farming systems at the former SAFS site, but corn planting in the conventional systems was delayed to correspond to optimum dates for the organic and WLCC systems.

Over the 11-year study at CIFS, the conventional and WLCC systems lost soil organic matter, while there was an increase in soil organic matter in the organic system. The accumulation of N and C in the organic system may improve soil quality over the long-term, while loss of soil N and C in the conventional system may decrease long-term soil quality in that system. Soil quality measured in this way apparently was not correlated with yield over this 11 year period, however. Low crop diversity may have resulted in negligible C and N gains in the conventional system despite this system attaining the greatest overall crop yields. A lower C and N gain in the WLCC systems was most likely attributed to lower corn yields and correspondingly lower stubble dry matter amounts left in the field after grain harvest, combined with cover crops planted only every other year only before corn. In the former SAFS project, N input amounts for some systems were considerably less than in the LTRAS experiment, which may have contributed to the lower amounts of unaccounted N. Furthermore, cropping systems used in the former SAFS project were more diverse than those used in the LTRAS project. These diverse cropping systems may have also contributed to lower amounts of unaccounted N and to more positive long-term soil C and N balances at the former SAFS site. In comparing the SAFS and CIFS studies, the results suggest that future cropping systems should include diverse crop rotations and winter cover crops.

Can winter cover cropping improve water quality of tail-water discharge?

By Aaron Ristow, Sam Prentice, Wes Wallender, and William Horwath

New regulations are holding California growers accountable for detected pollutants draining off their land. In response, there has been growing interest among farmers, researchers, governmental agencies, and environmental conservation groups in investigating the viability of alternative crop production practices that function to conserve soil and water resources. One option SAFS researchers are exploring is the use of winter cover crops to minimize discharge concentrations and/or load of targeted materials that affect water quality parameters. Preliminary analysis has demonstrated a dramatic decline in amount of surface discharge from growers' fields while also improving the quality of discharge managed with winter cover crops (*SAFS Newsletter Fall 2005, Vol.6, No.1*).

These results for winter discharge are not surprising. Winter cover cropping provides protection from water erosion by improving aggregate stability and increasing soil water retention and infiltration. However, research has shown that cover cropping in the winter may conflict with water conservation in the summer. While cover crops may increase rainfall infiltration, their increased evaporative demand has been shown to deplete soil moisture from deeper layers of the soil as they mature, limiting soil water availability for the ensuing crop. In addition, enhanced infiltration from cover cropping during the winter months may extend into the growing season. Thus, in order to meet the water needs of summer crops, more surface water deliveries may be required.

To address these concerns, SAFS researchers have established a network of automated water samplers in grower fields in the surrounding Central Valley. The network of automated samplers provide year-round monitoring of surface runoff that generates data with considerable resolution to more precisely compare the effectiveness of cover crops in minimizing runoff quantity and improving overall runoff quality. Runoff volume and materials that affect water quality parameters are being determined, including suspended sediment, turbidity, phosphate, inorganic nitrogen, total dissolved nitrogen and phosphorous, dissolved organic carbon, and herbicides.

Soil water retention and infiltration

The net effect of increased water use vs. increased infiltration depends on several factors, such as cover crop dry matter production rate, degree of soil cover and soil slope, soil infiltration rate, and rainfall intensity. Preliminary analysis of our data suggests significant enhanced infiltration of rainwater during the winter months due to the winter cover cropping. Interestingly, for the summer months, approximately 50 percent of the irrigation water applications to the winter fallow (bare) field were not discharged and are assumed to have infiltrated. Surprisingly, during the same period, only 19 percent of surface water deliveries are assumed to have infiltrated from the winter cover cropped field. Perhaps cover crop root channels were developed during the winter, or changes to it and to other soil physical characteristics as a result of cover crop residues enhanced infiltration deeper into soil. Enhanced biotic activity, ranging from earthworms and microbial turnover, may increase aggregate stability and soil structure to promote infiltration in cover cropped fields. The result suggests that cover cropped fields may offset evapotranspiration through increased winter infiltration or by infiltrating water past the rooting zone in this part of California. Research in the San Joaquin Valley has suggested the opposite, that cover crop evapotranspiration may negatively affect water balance. The decreased infiltration in the cover cropped field during irrigation implies declining water use efficiency if established irrigation schedules are used in fields managed for winter runoff with winter cover crops. More research is needed to determine whether irrigation schedules or frequency of water application can be reduced to increase water use efficiency in cover cropped fields.

Concentration

Runoff from the cover cropped field had lower seasonal average concentrations of nitrate, ammonium, and total dissolved nitrogen. Concentration of phosphate and dissolved organic carbon were not statistically different. It is important to recognize that seasonal average concentrations of materials that affect water quality parameters were all below 5 mg/L (Fig. 1). This is well within drinking water quality standards for the city of Davis.

Nitrogen (N) assimilation in the cover crop throughout the winter could account for the reduced concentrations of N in the cover crop tail water. For example, it is known that a winter cover crop can effectively immobilize large quantities of nitrate, delaying the nitrogen availability until newly planted crop roots become active in the spring. In addition, the increased biomass of the residue may immobilize N during the summer when decomposition of the cover crop residues is at its highest.

Load

We have remarked on how winter cover crops during the winter storm season can significantly reduce loads of all materials that affect water quality parameters during winter months (*SAFS Newsletter Fall 2005, Vol.6, No.1*). Further analysis is needed on total seasonal loads in irrigation tail water between the fallow and cover cropped systems across crop rotations and soils to conclusively state the benefits of cover crops.

In conclusion, it was surprising to discover that the winter cover cropped field infiltrated only 19 percent of irrigation water deliveries in contrast to the 50 percent infiltrated deliveries from the winter fallow field. This suggests that the grower could apply less water to the cover cropped field. We stress this may be region specific with these results reflecting higher rainfall areas. Further investigation is required before recommendations can be made. In addition, N concentrations were lower in the winter cover cropped tail water compared to the winter fallow field, suggesting residual water quality enhancement from the use of winter cover crops.

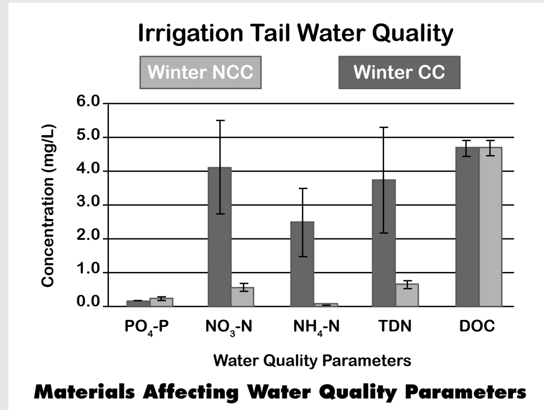

Figure 1. Comparison between average concentrations of materials that affect water quality parameters from irrigation tail water discharge leaving a winter non-cover cropped field (fallow, bare) and winter cover cropped field. Standard error is shown

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More information on UC Davis sustainable agriculture farming systems projects is available online at **http://safs.ucdavis.edu**, including expanded newsletter articles, SAFS/LTRAS updates, and other resources.

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