SUSTAINABLE AGRICULTURE FARMING SYSTEMS PROJECT
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Managing the soil food web in legume-vegetable rotations

by Howard Ferris, Louise E. Jackson, Hideomi Minoshima, Jeffrey P. Mitchell, Sara Sanchez Moreno, Kate M. Scow, Steven R. Temple

These SAFS project researchers study the changes in soil biology that occur as a result of farming practices. Achieving a functioning soil community following a history of conventional agricultural practices may require a prolonged transition. Here researchers describe the importance of soil food webs in alternative farming systems and explore some approaches to enhancing their activity.

Introduction – Structure, Functions and Importance of Soil Food Webs

The soil food web is that community of organisms that utilize one another, either by predation or consumption of dead bodies, as sources of carbon and energy. The activities of soil organisms result in ecological functions essential to crop production and soil fertility (see box). By consuming, digesting, assimilating, and metabolizing the bodies of their food sources, organisms convert complex organic molecules into forms suitable for their own structural and metabolic needs. Materials indigestible to the consumer are eliminated in simpler forms that are more accessible to other organisms. Some of the molecules that are digested may be in excess of the consumer's needs and are excreted in mineral forms that are readily available to plants and to other soil organisms. Molecules taken up by bacteria and passed on to their consumers are considered to be in the "bacterial decomposition channel" (Fig. 1). Many of the organisms in this channel are metabolically very active and molecules pass through the bacterial channel rapidly. Materials decomposed and digested by fungi are often more complex and their flow through the "fungal decomposition channel (Fig. 2)" may be slower.

The ecological functions of soil food webs include:

- Decomposition of organic matter
- Cycling of minerals and nutrients
- Reservoirs of minerals and nutrients
- Redistribution of minerals and nutrients
- Sequestration of carbon
- Degradation of pollutants, pesticides
- Modification of soil structure
- Biological regulation of pest species

Carbon and energy obtained by consumers at the entry level of the food web are utilized for growth, reproduction and respiration. Carbon dioxide lost from the soil due to respiration of organisms represents a net loss in resources to the consumers of those organisms, that is, the next trophic (feeding) level. The loss of carbon at each trophic level limits the abundance of predators (Fig. 3) that can be supported by any group of prey. Predators, which may regulate or even suppress pest species, are usually larger organisms. Their environment is easily destroyed by physical disturbance of the soil; they are slow to recover from toxic or environmental perturbations, their life cycles are longer and their reproductive potential lower than opportunistic organisms at the entry level of the food web.

Tillage mixes organic matter into the soil so that products of its decomposition are available to plant roots. However, the disturbance disrupts the higher trophic levels of the food web. Managing the

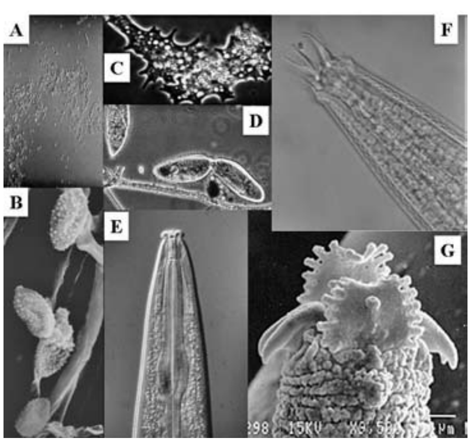

Fig. 1. Organisms of the bacterial decomposition channel. A) Bacteria at the limit of resolution of a light microscope; B) Bacteria visualized with a scanning electron microscope; C) and D) Amoeboid and ciliated protozoa; E) Opportunistic bacterial-feeding nematodes; and F) and G) Bacterial-feeding nematodes with specialized feeding structures.

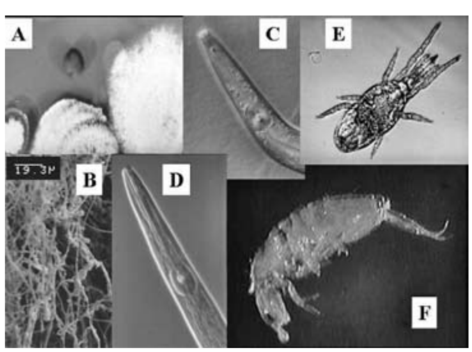

Fig. 2. Organisms of the fungal decomposition channel. A) Fungi under a light microscope; B) Fungi visualized with a scanning electron microscope; C) and D) Fungal-feeding nematodes; E) and F) Fungal feeding mite and collembolan.

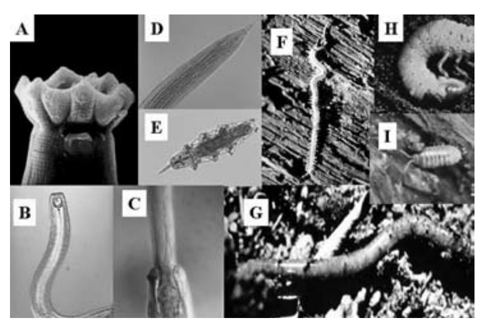

Fig. 3. Organisms sensitive to environmental disturbance and toxic concentrations of pesticides and fertilizers. Some are predators of organisms at lower trophic levels, e.g. A, B, C and D. Omnivore and predator nematodes; E) Tardigrades; others are large bodied and require soil aggregates and channels through the soil e.g. F, H and I. Larger arthropods and G) Earthworms.

delivery of resources into the food web without disturbing its structure in the process, and at the same time optimizing crop growth, may be the greatest challenge of conservation tillage systems.

A Food Web Management Experiment: Rationale and Approach

We hypothesized that continuous inputs of plant-derived carbon and nitrogen, combined with conservation tillage (CT), should promote soil communities that decompose residue and result in a more complex multi-layered food web than in systems with periodic fallow and standard tillage (ST). The potential for lower yields in crops grown with CT than ST must be evaluated against the benefits of storing carbon in the soil and the functions of a complex food web. At the Long-Term Research for Agricultural Systems (LTRAS) facility at UC Davis, we compared four cropping systems:

- Conservation tillage and continuous crop rotation (CTCC);
- Conservation tillage and fallow rotation (CTF);
- Standard tillage and continuous crop rotation (STCC);
- Standard tillage and fallow rotation (STF).

The continuous crop (CC) rotation had greater plant biomass, more crop cycles, more continuous plant cover, and more crop diversity than the fallow rotation (F) which included a fall and summer fallow (Table 1).

Although this was a very successful experiment, we experienced some farming problems with the CTCC systems; the sudan/sorghum cover crop had an inhibitory effect on stand establishment of the garbanzos where there was a thick residue on the soil. Herbicides used immediately after planting may have impacted garbanzo growth since a herbicide-free control plot had higher biomass. Garbanzos in the CT plots were difficult to harvest because the high density of weeds interfered with cutting the dried stalks. Cowpeas were originally intended as a cash crop, but since planting was delayed due to late harvest of garbanzos, the cowpeas became a cover crop. Water infiltration during the summer irrigation of cowpeas was uneven in the CT treatments due to accumulation of crop residues.

Table 1. Continuous crop and fallow rotations under conservation and standard tillage.

	Summer 03	Fall 03	Wint./Spr.03/04	Summer 04
Continuous Crop	Tomato	Sudan/Sorghum	Garbanzo	Cowpea
Fallow Rotation	Tomato	Fallow	Garbanzo	Fallow

Soil Carbon, Nitrogen, Soil Food Webs: Though total soil C did not increase after one year of CTCC cropping, increases in total microbial biomass, fungi, and total nematodes were evident in the surface layer, compared to ST, or CTF. Total soil C (g/m^2 at 0-30 cm) was similar in CTCC, CTF and STCC treatments, and higher than in STF (Fig. 4).

Nitrate did not differ significantly among treatments but was much higher in June 2004 than on other sampling dates, and higher at 0-5 cm than deeper in the soil, possibly due to the dry summer conditions that minimized leaching.

The soil microbial biomass (MBC), a good indicator of soil C availability, was significantly higher at 0-5 cm than below 5 cm. MBC was greatest in the CT plots in which microbes accumulated in the surface layer presumably due to easy access to residue on the soil surface (Fig. 5).

Nematodes accumulated in the soil surface layer in all treatments, especially in CT plots (Fig. 6). The Enrichment Index (EI), which indicates the biomass of opportunistic fungal- and bacterial-feeding nematodes that respond rapidly to increases in food resources, was higher in ST plots, especially STCC plots. The Channel Index (CI), an indicator of the decomposition pathway by bacteria or fungi, was higher in CT than ST plots, and much lower in STCC than either CT plot, indicating greater activity in fungal decomposition pathways in CT plots. The EI and CI levels suggest that lack of disturbance by tillage leads to favorable habitats for fungi and that disturbance by tillage, with readily available food due to continuous cropping, leads to more bacteria.

In summary, we explored options for replacing the typical tomato/wheat fallow rotation of the Sacramento Valley of California with alternative crops, lower inputs of non-renewable resources, and increased C sequestration. Conservation tillage with continuous crop rotations of tomato and legumes resulted in lower yields and similar C storage at 0-30

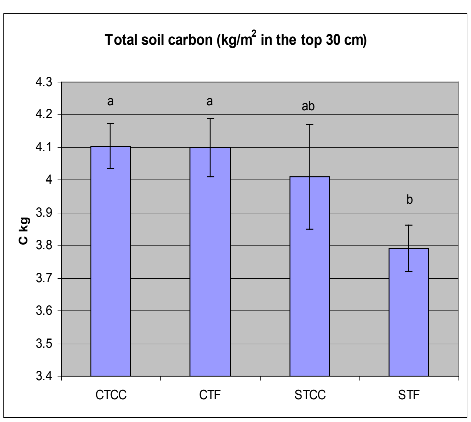

Fig. 4. Total soil C (kg/m2 in the top 30 cm) by treatment. Continuous crop (CC) and fallow (F) rotations under conservation (CT) and standard (ST) tillage.

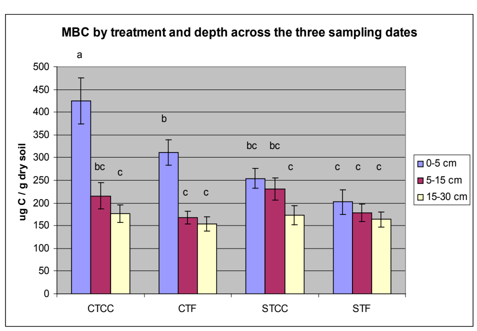

Fig. 5. Total soil microbial biomass C (MBC) by treatment and depth across three sampling dates (Dec. 03, June 04, Dec. 04). Continuous crop (CC) and fallow (F) rotations under conservation (CT) and standard (ST) tillage.

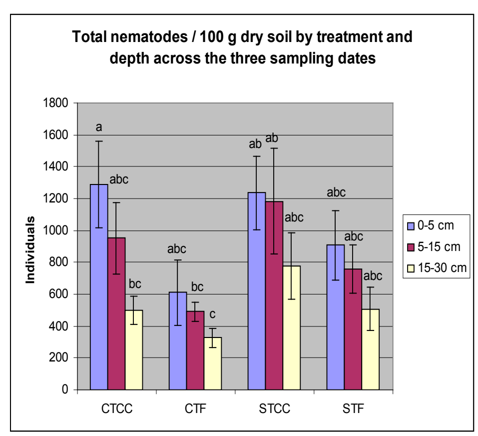

Fig. 6. Total nematodes by treatment and depth across the three sampling dates (Dec. 03, June 04, Dec. 04). Continuous crop (CC) and fallow (F) rotations under conservation (CT) and standard (ST) tillage.

cm compared to standard tillage with continuous cropping, or conservation tillage with periodic fallow. Conservation tillage with continuous C input at the soil surface led to a habitat favorable for microbial biomass, fungi, and nematodes. However, conservation tillage will require innovative management solutions to reduce problems such as high weed biomass and uneven water availability during furrow irrigation.

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Sustainable ag research highlights differences among water conservation management practices

by Aaron Ristow, Sam Prentice, and William Horwath

The Issue

California adds over 550,000 people annually to its population, which is expected to reach 48 million by 2030. Experts project that by 2020, demand for water will exceed supply by 2.4 million acre-feet in good rainfall years and double that in drought years. Predicted trends in population growth and global climate change are raising water quality concerns for Sacramento-San Joaquin Delta inflows. Over the last 15 years, the focus of the federal Clean Water Act has turned toward Non-Point Source Polluters (NPSP) and Total Maximum Daily Load (TMDL) monitoring. All businesses that discharge into waterways are required to have a permit. However, for two decades agriculture was exempt. That changed in the Central Valley in 2004. New regulations are now holding California growers accountable for pollutants draining off their land – either from irrigation or winter runoff. Policymakers and water users have begun considering several alternatives to address future supply and demand. Options include expansion of nontraditional sources of supply, reallocation through water marketing, and using water conservation practices such as winter cover crops (CC) and conservation tillage (CT).

The Project

The objectives of the UC sustainable farming systems study are to 1) quantify discharge from research plots and farms using CC and CT compared to conventional practices, 2) quantify NPSP concentrations and loads in runoff, and 3) inform farmers, policymakers, and the general public about the usefulness of CC and CT in addressing water issues.

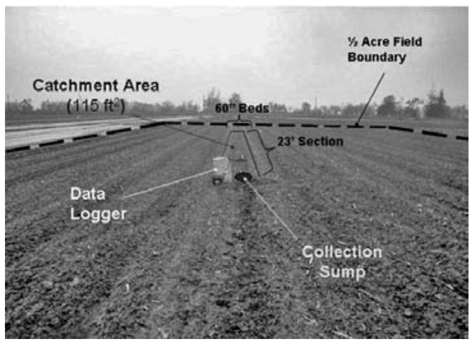

Figure 1. *Project set-up at SAFS research fields in Yolo County.*

During the last two years, we have addressed these objectives by establishing a network of automated water samplers at the long-term UC Davis sustainable agriculture research plots and in grower fields in the Sacramento Valley. Automated samplers provide year-round monitoring of surface runoff to assess the performance of CC and CT at minimizing runoff quantity and improving runoff quality. Runoff volume and water quality parameters identified include suspended sediment, turbidity, inorganic phosphate and nitrogen, total dissolved nitrogen and phosphorous, dissolved organic carbon, and herbicides.

Our research includes conventional, low-input, and organic systems under either standard tillage (ST) or CT. The organic and low-input systems utilize winter legume cover crops (CC) as the primary nitrogen input. The CT systems incorporate practices that maintain at least 30 percent of the crop residue on the soil surface or reduces tillage passes by at least 40 percent.[1] The standard tillage systems mirror management practices typical of the surrounding area.

Measurements

At the SAFS plots, one furrow from each plot was isolated to channel runoff into a 1m by 12 in. diameter catchment (Fig. 1). At the end of each rain event, a sample was taken for analysis and the catchment emptied. In the growers' fields, data-logger-equipped autosamplers were used to collect samples and record flow measurements taken during all runoff events.

Results

Our research team has analyzed runoff quantity and quality data from five storm events during the 2003-2004 rain season and continuously from irrigation tailwater during the 2004 growing season. Preliminary analysis of growers' field data illustrate the effectiveness of CC at substantially minimizing discharge and NPSP loads. However, with the possible exception of sediment discharges, seasonal NPSP loading from winter fallow fields is not dramatic, suggesting that other field scale strategies (e.g., reconfiguring drainage patterns) may also be effective at meeting agricultural water quality goals.

Peak flow winter (2004-05) runoff velocities were 100% lower for CC field runoff events. That same year total discharge from grower fields was 18 times lower from the CC field. In Winter 2004-2005 there was an average of 28 times the reduction of discharge from the grower CC fields compared to the fallow fields. It appeared that the cover crop was effective at reducing storm runoff soon after germination. However, on our research plots, CC showed higher discharge volumes NPSP loads compared to winter fallow treatments. This discrepancy between research plots and grower fields could be a result of differences in soil type or method of measurement. The results show additional research is required to understand the interplay between field size and configuration, soil type, and runoff monitoring strategies when developing predictive models for water quality concerns.

In Winter 2004–2005, discharge from the low-input CT treatment was significantly higher than other treatments except for the organic standard tillage. This was somewhat consistent with that of the growers' CT vs. Winter Fallow comparisons. In both the research plots and the growers' field, CT management produced greater NPSP loads in runoff water compared to non-CT management, primarily due to higher cumulative discharge. In general, concentrations of various problem materials were similar for all treatments.

The increase in runoff from CT is unexpected. Results from the Midwest, where CT promotes infiltration, suggest the opposite. One possible explanation is that California soils generally have higher clay content, and are therefore more likely to create a soil crust that inhibits infiltration. It would be expected that after many years of CT, infiltration may be enhanced, as soil near the surface accumulates organic matter. However, all CT treatments were in the first or second year of management, and therefore were still building organic matter on the surface.

Summary

Farming practices that preserve or enhance soil cover entering the rainy season appear to be effective at reducing cumulative runoff and, hence, NPSP loads. In general, research plots and grower fields demonstrate challenges to agricultural runoff monitoring. Adherence to strict CT practices can immediately reduce fuel costs, but the potential benefits to water quality may take years to realize. In the short term, growers may have other water conservation options, including reconfiguring fields to reduce runoff velocity and thus erosion. Our research has shown that CC and CT can behave differently in California compared to other areas. On a farm scale, CC significantly reduces winter runoff but also may affect subsoil water recharge and soil moisture content at the time of planting. The potential for winter CC to alter the water budget of subsequent crops under furrow irrigation systems poses important questions, considering future water supply concerns. Additional research is needed to develop conceptual models that correlate water inputs and load reductions with alternative agricultural management practices in California. Such information would be beneficial to water quality stakeholders hoping to address future quality and supply issues.

[1] Standards as set by UC Cooperative Extension

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