The sustainable agriculture farming system project in California's Sacramento Valley

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The Sustainable Agriculture Farming Systems project (SAFS) was established in 1988 to study the transition from conventional to low-input and organic crop production practices. The project includes four-year crop rotations under conventional (conv-4), low-input, and organic management and a conventionally managed, two-year rotation (conv-2). Positive effects on soil quality resulting from low-input and organic management include increased soil organic matter, a reduction in soil-borne diseases, increased pools of P and K, higher microbial biomass and activity, an increase in mobile humic acids and increased water infiltration rates and soil water-holding capacity. Pesticide use in the low-input cropping system is about 25% of that used in the conventional systems. The most profitable farming system continues to be the conv-2 system due to the greater frequency of tomato in that rotation. Among the four-year rotations, the organic system, in which the produce commands premium prices, is the most profitable, although least profitable if premium prices are not applied. Information generated from SAFS research has been disseminated via videotape, workshops, annual field days, field tours, educational materials, peer-reviewed articles and an Internet homepage. Future challenges for the SAFS project include development of reduced-tillage and cover crop management strategies to optimize N availability following cash crops, weed management in organic and low-input systems, improvement of water-use efficiency in alternative systems and sequestration of C in the soil.

The Sustainable Agriculture Farming System project (SAFS) is an interdisciplinary, participatory and collaborative research effort. Its management team includes eight research and extension faculty (the Principal Investigators) from six departments within the college of Agricultural and Environmental Sciences at the University of California Davis, two Farm Advisors and three conventional and organic farmers. Dr Poudel is the former Research Manager for the SAFS project, while all the other co-authors served as Principal Investigators.

Dr Poudel is a soil scientist with strong research interests in soil fertility, environmental quality and sustainable agriculture. Dr Ferris is a nematologist, and has research interests in nematode community structure, the role of microbivorous nematodes in soil fertility, and the use of nematode faunal analyses as indicators of the soil environment. Dr Klonsky is an agricultural economist who has done extensive research into the economic feasibility of alternative and organic farming practices. Dr Horwath is a soil biogeochemist with current research interests in C and N cycling in managed and natural ecosystems and the influence of soil organic matter dynamics on soil C sequestration. Dr Scow is a soil microbial ecologist, and her current research interests include the biodegradation of organic pollutants by soil and groundwater micro-organisms, characterizing microbial communities in complex environments, and understanding the environmental and

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management factors governing the composition of microbial communities in soils. Dr van Bruggen, formerly with the Department of Plant Pathology at the University of California Davis, is a plant pathologist with strong interests in microbial ecology and sustainable agriculture. She guides research on soil health, disease suppression and nutrient cycling in organic farming systems in the Netherlands and developing countries. Dr Lanini is a weed ecologist with current research interests in low-input weed management in field and vegetable crops. Dr Mitchell is a soil scientist with research programmes on soil and water management, soil quality assessment, conservation tillage and participatory research methodologies in intensive vegetable production systems in California. Dr Temple is an agronomist, and his research programme focuses on the genetic improvement and agronomy of cowpeas, common and lima beans, and chickpeas.

Food and fibre production in the USA since the 1940s has been heavily dependent on off-farm resources including fertilizers, pesticides and energy. These dependencies are of questionable sustainability and, in some cases, have resulted in environmental degradation and human health risks. Potential contamination of food and the environment attributed to conventional crop production has made agricultural producers and processors keenly interested in alternative farming strategies. Low-input farming strategies that require fewer external resources and that are environmentally benign are critically needed to address societal and political concerns about the sustainability of agriculture systems.

Many of the available alternative farming practices have only been tested regionally on small-scale systems. There is little reliable information available to farmers who are considering the transition from conventional to low-input or organic farming. Few long-term or systems (whole-farm) research and education projects have been undertaken to quantify and analyse the complex ecological and economic consequences of the transition from conventional farming systems.

In 1988, a group of farmers from Yolo County, California, and researchers from the University of California (UC) Davis designed and initiated a large interdisciplinary research and outreach endeavour, the 'Sustainable Agriculture Farming Systems project (SAFS)'. The objectives of the project were the long-term comparison among farming systems of: (1) the abundance, diversity and management of weed, pathogen, arthropod and nematode populations; (2) soil biological, physical and chemical properties and water relationships; (3) crop growth, yield and quality; and (4) economic viability of the farming systems. Integral to the project is the evaluation of known and novel farming practices that show potential to reduce dependence on non-renewable resources. The final objective is to distribute information generated by the project and to facilitate communication regarding the adoption of alternative farming practices.

Philosophy behind the project

In common with many alternative agriculture projects, the philosophy underlying the SAFS project is to develop and provide technology that optimizes the quality of life for present generations without compromising that of future generations. The four cornerstones of SAFS are: (1) the use of 'best farmer practices' for each farming system; (2) grower participation at all levels of design, management and interpretation; (3) interdisciplinary collaboration; and (4) communication and outreach.

The use of 'best farmer practices' for each farming system is a keystone principle underlying the interaction and collaborations of farmer cooperators and researchers. Its acceptance is fundamental to the group dynamics. The participation of growers in management decisions is crucial for the success and credibility of the project. The growers attend and fully participate in monthly meetings to coordinate production management and farming practices. Research plans are made by subgroups of Principal Investigators (PIs) representing disciplinary areas, eg soil biology and fertility, water relationships, pest management, or economics and energy analysis. The plans are presented and are modified, if necessary, by the full group of project members, and ratified by consensus. There is a strong emphasis on collaborative research among the PIs in investigating interrelationships among several farming system components in each system. Often subsets of common samples are used for a number of analyses by different collaborators. Our basic philosophy is that a holistic systems approach will promote understanding of the complex ecological and economic consequences of the transition from conventional to low-input or organic farming systems. We anticipate that the use of information generated from the project enhances the probability of successful transition and of achieving long-term viability.

Besides local research participation, there has been invaluable international collaboration. Many visiting scientists have conducted research at the SAFS site and contributed their expertise and energy to the project. The process of investigating the transition from conventional practices through an interdisciplinary team approach has been an educational experience for all participants. We expect that our experiences will be helpful to others undertaking similar projects. The project is making significant contributions to the conceptual understanding and appreciation of the principles of sustainable agriculture. It provides a knowledge base for researchers, agriculturists, politicians and the public, and its impacts are expected to extend well beyond the Sacramento Valley of California.

Unique features

Several aspects of the SAFS project make it unique among similar projects elsewhere: the combination of a Mediterranean climate with a relatively long (four-year, five crop) rotation with three complete rotation cycles over a total of 12 years; management of each system using best farmer practices; and the degree to which farmers and farm advisers have become involved in the planning, execution and interpretation of all disciplinary facets of the project. A comparison of the SAFS project with other projects having common objectives in the USA and elsewhere has been reported by Kaffka.[1]

The study attempts to combine the best features of both on-farm and experiment station research; it is established under controlled conditions on a research farm, yet employs commercial farming practices that must be economically justifiable and that are regularly evaluated by farmer cooperators. Three farmers (two organic and one conventional) and two University of California Farm Advisers are participating. Many disciplines have been represented during the course of the project: agronomy, agricultural economics, water science, entomology, agricultural engineering, soil science, environmental toxicology, nematology, plant pathology, soil microbiology, crop nutrition and weed science. Box 1 describes the farming systems.

Box 1. Experimental design and farming systems

The four farming systems in SAFS are four-year rotations under conventional (conv-4), low-input and organic management and a conventionally managed, two-year rotation (conv-2). The conv-2 system is similar to the common practice for conventional growers in the region.[2] All three 4-year rotations include processing tomato (*Lycopersicon esculentum* Mill.), safflower (*Carthamus tinctorius* L.), bean (*Phaseolus vulgaris* L.) and corn (*Zea mays* L.). In the conv-4 treatment, beans are double cropped with winter wheat (*Triticum aestivum* L.), while in the low-input and organic treatments, beans follow a cover-crop mixture of oats (*Avena sativa* L.), vetch (*Vicia* spp.) and pea (*Pisum* sp.). Cover crops are grown during the winter preceding all other cash crops in the low-input and organic systems. The conv-2 system is a tomato–wheat rotation. There are four replications of each treatment and all possible crop rotation entry points are represented within each farming system replicate, resulting in a total of 56 plots. The plots measure 68 m by 18 m (0.12 ha) each and are arranged in a randomized block, split-plot design.

In addition to the 8.1 hectares occupied by crops in the main experiment, a 3.2-hectare companion area contains larger (0.5 hectare) blocks planted to the same five crops and managed similarly to the low-input system. Alternative cover crop options, as well as improved practices for weed management, tillage and crop nutrition, are evaluated at the companion site by project researchers with a broad array of disciplinary interests.

Research progress and findings

Data collection

The SAFS project has generated several valuable datasets, including data on soil fertility, plant growth, nutrient accumulation, water relationships, product quality, crop yields, pests and diseases, and environmental risks. Data are collected on stand establishment, crop growth rates, biomass and the yield and quality of crops. Crop yields are determined by both hand and machine harvest. Soil mineral N levels are monitored by frequent sampling at various depths in different crops and farming systems. Plant nutrient status is determined by leaf petiole or other tissue analysis. Soil water content is measured by neutron probe to monitor water usage by plants and the supply, uniformity of distribution, and depth of penetration of irrigation water. Deep soil cores are taken at several times during the year for determination of nitrate and ammonium and to assess the potential for leaching of nitrate into the groundwater. An assessment of changes in selected soil characteristics is made after each four-year rotation cycle. Samples are archived for future evaluation.

Microbial measurements include microbial biomass C and N, potentially mineralizable N, and community composition (as measured by phospholipid fatty acid analysis). The impact of plant-parasitic nematode populations on the growth and yield of crops is assessed by measuring population densities under each crop and farming system at key times of the year. Community structures of non-parasitic nematodes are also monitored to assess their impact on nutrient cycling and soil fertility. Above- and below-ground populations of economically and ecologically significant arthropods are monitored, and their damage and impact on crop yield and quality is quantified. Plant pathogen populations and the onset, progress and severity of plant disease are monitored. The diversity and abundance of weed populations are quantified by recording species compositions, diversity and biomass at regular intervals.

A daily log is maintained to record all field activities and farming operations, the rates of materials applied and the equipment used for each operation. Price data for materials and equipment are obtained from local suppliers. Data are analysed using Budget Planner microcomputer software.[3] Information is carefully evaluated for quality before accession into core datasets. Core data are available to all participants in the project.

Soil chemistry, biology and physics

A commonly held, but largely untested belief is that it is difficult to increase organic matter content in California agricultural soils due to the warm arid climate. There is considerable evidence, however, that after eight years of farming, the carbon dynamics and soil organic matter (SOM) now differ between the organic and conventional systems of the SAFS project (Table 1). After eight years of differential management, levels of soil organic matter in the organic and the low-input farming systems were 20 and 10% greater, respectively, than in the conv-2 system. The changes in organic matter content are consistent with rates of organic inputs into each system.

Humic acids were measured to assess the more stable pools of soil C. Within humic substances, the mobile humic acid (MHA) fraction is among the most dynamic components of SOM, and is directly involved in short-term nutrient cycling. Assessments of nutrient dynamics based on MHA analysis are considered to be more precise than those based on bulk soil analysis. Differences among farming systems in the mass of the MHA fraction were highly significant for the organic, low-input and conventional soils in 1998 (Table 1). MHA accumulation was greatest in the organic system. It was intermediate in the low-input and conv-4, and least in the conv-2 system. These results, combined with data on total soil organic matter, reveal the potential for sequestering C and N in this Mediterranean environment.

Despite its greater SOM and MHA pools, the organic system is highly variable in N availability on an annual basis.[4] Nitrogen availability is a function of current and historical N inputs, as well as activity and structure of the soil food web.[5] Nitrogen is released slowly from organic pools in the organic and low-input systems. Available mineral N in the soil solution differs during the growing season in the organic and conventional plots:[6] the organic plots have lower mineral N levels from mid-season to late-season while, due to sidedressing (the application of synthetic fertilizers alongside the developing crop rhizosphere), the conventional plots have greater mid-season to late-season mineral N levels. The organic and low-input systems have larger pools of stored nutrients than the conventional systems. Box 2 describes changes in soil properties in the SAFS project.

The farming systems influence the composition of soil microbial communities.[7] Phospholipid fatty acid analysis (PLFA) provides an assessment of the total microbial biomass, as well as information about community composition. Microbial community structure was assessed throughout the 1997 growing season, following tillage and fertilization, at different spatial locations within the field, and within different farming systems. Microbial biomass was usually higher (up to 2x) in the organic and low-input systems than in the conventional systems; microbial activity, when measured, showed the same pattern.[8] The PLFA fingerprints for microbial communities in the organic and conventionally managed plots, though significantly different on most dates, indicated substantial microbial diversity in both systems.[9] Microbial communities in low-input plots were intermediate in composition between the conventional and organic communities.

Fungi were greater in relative abundance in organic than in conventional soils, yet made up a very small portion of the detritivore community in any farming system. On a single date in the latter part of the growing season in 1997, the communities associated with some crops could be distinguished from the others (eg wheat, beans from others), while others were similar to one other (eg tomatoes, safflower and corn). Communities in the conv-2 plots were distinctly different from those in the three four-year rotation plots. Soil respiration and organic matter decomposition rates after addition of cover crops were measured in soil samples collected four times from conv-4 and organic plots and incubated in the laboratory. There was no consistent difference between the organic and four-year conventional communities. This suggests that, despite differences in microbial biomass, the conventional communities are not substantially different from the organic communities with respect to their potential for cover crop decomposition.

Table 1. Average carbon inputs,[1] soil organic matter (SOM)[2] and humic acids (MHA)[3] in the organic, low-input and conventional farming systems at SAFS.

	Total C inputs (Mg ha^{-1})	SOM (%)	SOM (Mg ha^{-1})	MHA (Mg ha^{-1})
Organic	97.8	1.83	34.9	14.5
Low-input	90.8	1.69	32.2	13.4
Conv-4	51.2	1.54	29.3	12.7
Conv-2	40.2	1.53	29.1	11.7

[1]Carbon inputs over 8 years (1989–96).
[2]Soil organic matter at 0–15 cm soil depth averaged across all crops (1996).
[3]Mobile humic fraction at 0–15 cm soil depth averaged for all crops (1998).

Symptoms of corky root disease in tomato are significantly more severe in plots with a two-year rotation than in plots with a four-year rotation. Microsclerotia of the causal organism, *Pyrenochaeta lycopersici*, are similar to those of *Verticillium dahliae*. Consequently, we infer that the breakdown of *P. lycopersici* microsclerotia will take more than two, but less than four years, thus accounting for the increase in disease severity in the two-year rotation.[10] Soft root tips caused by *Pythium* or *Phytophthora* sp. and red root rot caused by *Fusarium* sp. are also generally more severe in the two-year rotation than in the four-year rotations. Apparently the short, intense rotation reverts to host crops too frequently to allow for natural regulation of root diseases. The system is not sustainable in that regard and pesticide intervention will probably be necessary. In the other systems, levels of plant-parasitic nematodes and fungal root pathogens are regulated by the rotation period (four years).

Statistically significant differences in root-knot nematode (*Meloidogyne* spp.) population levels in tomato plots were found only in 1994. In that year, higher densities were found in the conventional compared with the alternative tomato systems, suggesting that the soil management practices used in the low-input and organic systems may have suppressed this pest. However, the degree of galling due to root-knot nematodes in these soils has always been very low and there was no significant difference between treatments.

Weed species and abundance changed during the transition from conventional to low-input or organic farming systems. Weeds are most abundant and most problematic in the organic farming system, and least abundant in the conventional systems in which chemical intervention is used. Weed seed densities have almost doubled in low-input and organic plots (10,000/m^2) compared with conventionally managed systems. Weed seed density is similar for the two conventionally managed systems, but the species composition varies. In conv-2 plots, winter weeds have increased, particularly annual bluegrass (*Poa annua*) and chickweed (*Stellaria media*). In the conv-4 plots, summer weeds predominate, with redroot pigweed (*Amaranthus retroflexus*) and lambsquarters

Box 2. Changes in soil properties in the organic, low-input and conventional farming systems at SAFS

- Increased SOM and potentially mineralizable N pools in the organic and low-input systems; and increased soluble P and exchangeable K in the organic system.
- Increased water infiltration rates in the organic and low-input systems.
- Greater exchangeable Ca:Mg ratios (0–30 cm soil depth) in the organic and low-input systems; and development of restrictive layers in conventional systems.
- Greater abundance and species richness of ground beetles in the organic system.
- Soil food web maturity and enrichment in the organic and low-input systems. Greater abundance of bactivorous nematode and more microbial biomass in the organic and low-input systems.
- More weeds in the organic and low-input systems, and more diseases in the conventional 2-year rotation.
- Greater microbial biomass and activity in the organic and low-input systems than in the conventional systems.
- Greater N loss from conventional systems.

(*Chenopodium album* L.) having the greatest seed increases. The seed banks of redroot pigweed, barnyardgrass (*Echinochloa crus-galli*) and chickweed have increased three- to tenfold in the low-input and organic plots compared with the conventional ones. By 1999, nightshade (*Solanum* sp.) and field bindweed (*Convolvulus arvensis*), resistant to the common herbicides, had become prevalent in the conventional system. Frequent cultivation in the organic and low-input systems prevented these weeds from becoming established, but did not deter the rapidly growing barnyardgrass. The general trends are for the weed community to shift from annual to predominantly perennial species under conventional management, and from broad-leaved weeds to grasses under low-input and organic management. These changes reflect the management in different systems, including escapes from herbicides in the conventional systems and from cultivation in the organic system.

Some clear differences in soil physical conditions among farming systems are emerging. The soil in the low-input and organic systems has better tilth and is easier to work than that of the conventional systems. The proportion of water-stable aggregates, which varies seasonally, is generally greater in the organic and low-input than in the conventional soils. Aggregate stability is a reflection of the abundance and activity of the soil microbial community. Related to the improved soil structure, water infiltration rates are greater in the low-input and organic systems,[11] as is the volume of water that will percolate into the soil profile (Figure 1). The differences in water percolation rates among the farming systems are amplified by a restrictive layer that develops at 20–30 cm depth in the conventional systems. Besides reducing water and root penetration, the restrictive layer in the conventional system requires additional management and energy investment in the form of ripping the soil before planting.

Salt levels in the organic system have increased over the course of the experiment, presumably associated with the use of composted animal manures. However, there were no detectable differences in the electrical conductivity of the soil solution among systems in 1996. The continued increase in soil salt concentration is neither ecologically nor agronomically sustainable and will require future management intervention. Interesting differences are emerging in extractable cation ratios, with the Ca:Mg ratio in the upper 15 cm of the soil profile at 0.73 in the conventional soils, 0.79 in the low-input, and 0.83 in the organic soils. The low Ca:Mg ratios of the conventional soil may be contributing to the development of restrictive layers.

Crop yields

Comparable crop yields are obtained from the organic, low-input and conventional farming systems (Table 2). Early in the experiment, however, tomato and corn yields in the organic system were generally lower than those of the low-input and conventional systems, mainly due to N limitation. But, as soil N fertility in the organic system improved, crop yields became similar among the organic, low-input and conventional systems.

Product quality

Soluble solid concentration of tomato fruit is an important quality parameter evaluated by processing industries in determining crop prices. The impacts of farming systems on tomato product quality were assessed in 1998. Fruit soluble solids for the organic (4.45 brix) and low-input (4.72 brix) tomatoes were below the average fruit soluble solids for the state (5.31 brix),[12] while tomatoes from the conventional system had higher soluble solids (5.85 brix) than the average value for the state. The soluble solid concentration of the tomato crop in each system was inversely proportional to the amount of irrigation water applied to that farming system. The higher infiltration rate and corresponding amount of water that percolated through the soil profile in the organic and low-input systems appear to have a negative impact on fruit quality in the alternative systems. Additional research is under way to test this hypothesis.

Pesticide use

Cumulative pesticide usage over the course of the project has been greatest in the conv-2 system, followed by the conv-4 system, the low-input system, and finally the organic system (Table 3). Total usage is related to the philosophy and protocols of the farming systems, and the crop rotation. The major uses of pesticides are in the management of weeds in the conventional and low-input systems.

A large proportion of cumulative pesticide use in the organic, low-input and conventional tomatoes was from the application of sulphur (Thiolux) to control russet mites in 1989, 1990 and 1991. A cumulative

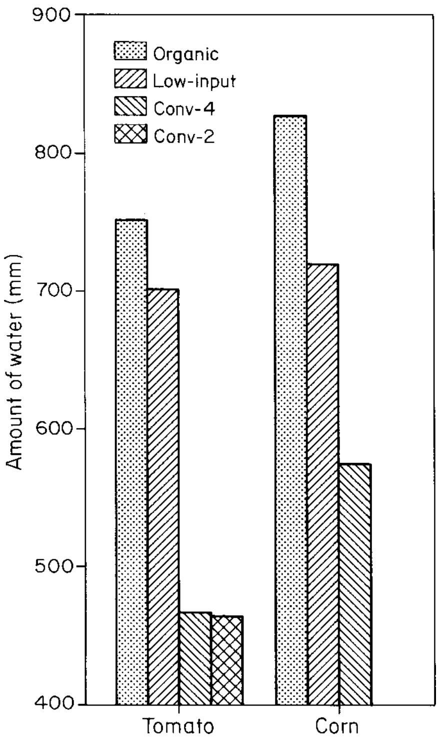

Figure 1. Average amount of water applied in tomato and corn production in a cropping season (1995–98).

amount of 20 kg/ha^{-1} (active ingredient) of sulphur was applied to each of these farming systems during the three-year period. Potassium salts (Safer soap), neem oil (Trilogy 90EC) and *Bacillus thuringiensis* (Dipel) are applied to organic tomatoes, while glyphosate (Round-up Ultra), trifluralin (Treflan) and napropamide (Devrinol) are commonly applied to the low-input and conventional tomatoes. Glyphosate, metolachlor (Dual) and 2,4-D (Weedar) are major pesticides used in corn, whereas glyphosate and trifluralin are frequently applied to safflower. Trifluralin, sethoxydim (Poast) and dicofol (Kelthane) are the major pesticides used in beans. In wheat, diclofop (Hoelon), bromoxynil plus MCPA (Bronate) and MCPA (Rhomene) are the common pesticides applied.

Economic viability

Although they vary annually as a reflection of supply and demand, premium prices are available for the organically produced commodities grown in the SAFS project. The net return for the organic system is calculated in two ways, one using conventional prices and the other with premium organic prices. Prices and costs are obtained from local growers and input suppliers annually. Analysis of the whole farm performance of each system, measured as average cumulative net income per hectare (Figure 2), reveals that the economic viability of the organic system has depended on premium prices. While the organic system with premium prices has performed better than the conv-4 or low-input systems, large increases in organic production within the region would probably result in a depression of the premium prices. Assessed under a conventional price structure, the organic system has not been profitable. The cumulative net return for the conv-2 system has always been higher than that for any other system due to the greater frequency of high-value tomato crops in this rotation. However, the economic and environmental viability of that system is threatened by the greater prevalence of pests and diseases and by the greater reliance on pesticides.

The SAFS project has demonstrated the potential to reduce synthetic fertilizer and chemical inputs and to maintain yields in irrigated agricultural systems in northern California. The costs and challenges differ dramatically between crops and farming systems. Fertility management in the alternative systems has been more expensive than for the conventional systems because of the cost of producing, irrigating and incorporating cover crops. In addition, the use of composted manure, kelp and fish emulsion on tomatoes, and composted manure on corn, in the organic system have been sizeable expenses. The move to transplanted tomatoes in 1992 added about $741 per hectare in costs to the alternative systems, but has allowed a delay in planting so that the cover crop can grow for a longer period of time before incorporation. That has increased nitrogen and biomass production, reduced weed pressure through competition, and consequently has reduced hand-hoeing costs.

Outreach

Results from the SAFS have been disseminated through diverse media, including technical publications, popular press publications, national and international conference presentations, videotape, audio-tutorial slide sets, annual field days, workshops, field tours, individual or group visits and web pages. In addition to 52 peer-reviewed research articles and seven popular press publications, results from the SAFS project have been presented at more than 80 national and international conferences. Over its 11-year duration, the SAFS project has hosted more than 1,600 visitors at its 11 annual field days, six workshops, tours and individual group visits. The SAFS web pages are periodically updated and are used to present information related to general project description, research findings, education and outreach, and announcements. The SAFS plots serve as a living laboratory for field trips and formal university classes, and are a source of samples for a number of classes taught on the campus. International guests representing more than 30 countries have visited the SAFS research site.

Table 2. Average crop yields (Mg ha^{-1}) at the SAFS project, 1989–99.

Crop	Organic	Low-input	Conv-4	Conv-2
Tomato	67.2	74.5	77.2	73.1
Safflower	2.4	2.3	2.7	–[1]
Corn	10.5	11.9	11.2	–
Wheat	–	–	5.6	5.6
Beans	1.9	1.9	1.7	–

[1]Not applicable.

Future challenges

The following challenges remain:

- Weed management. While other pest species are generally regulated by the rotations and associated cultural practices, the combination of high soil nutrient

Table 3. Cumulative pesticide use (kg ha[-1] active ingredient) at the SAFS project, 1989–99.

Crop	Organic	Low-input	Conv-4	Conv-2
Tomato	25.2	24.7	49.5	49.4
Corn	0	7.2	28.6	–[1]
Safflower	0	0.9	12.2	–
Bean	0	1.4	8.9	–
Wheat	–	–	18.3	19.1
Oats/vetch	0	0	–	–
Total[2]	25.2	34.2	117.5	137.0

[1]Not applicable.
[2]Pesticide use multiplied by 2 in the Conv-2 system to account for two-year rotation (area in tomato and wheat is twice that of the other farming systems).

levels, irrigation and frequent tillage provides environments for specific communities of weed competitors in each farming system.

- Fertility management for organic and low-input systems. The basic design of the rotations, repeatedly using *Vicia* spp. as a cover crop, is of concern since foliar diseases have increased, in particular leaf blight caused by *Ovularia* sp. Consequently, cover crop biomass and associated N input at SAFS plots have decreased markedly compared with early years, while weed severity has increased. The optimization of cover crop decomposition through the timing of incorporation and the management of microbial and nematode communities continues to be a challenge.
- Reduction in the frequency and intensity of tillage operations. The intensive tillage currently practised in the area, among other consequences, (i) is a major source of fugitive dust, (ii) stimulates exponential increases in soil respiration and the consequent loss of sequestered carbon to the atmosphere as CO_2, (iii) degrades soil structure, (iv) increases soil compaction, and (v) disrupts soil biological activity. However, scepticism in relation to the adoption of reduced tillage exists primarily due to practical difficulties such as fertilizer/herbicide application, furrow irrigation and effective weed control in cover-crop-based systems. In addition, the economic viability of reduced tillage, especially in irrigated field row-crop production systems in the Western USA, is unknown.
- Increased water-use efficiency. Increasing demands for non-agricultural uses of very scarce water resources, and drought-induced limitations of good quality water, are recent public concerns in the Sacramento Valley. An important future challenge for the SAFS project is to improve the water-use efficiency of the alternative systems, while conserving water from winter rainfall.

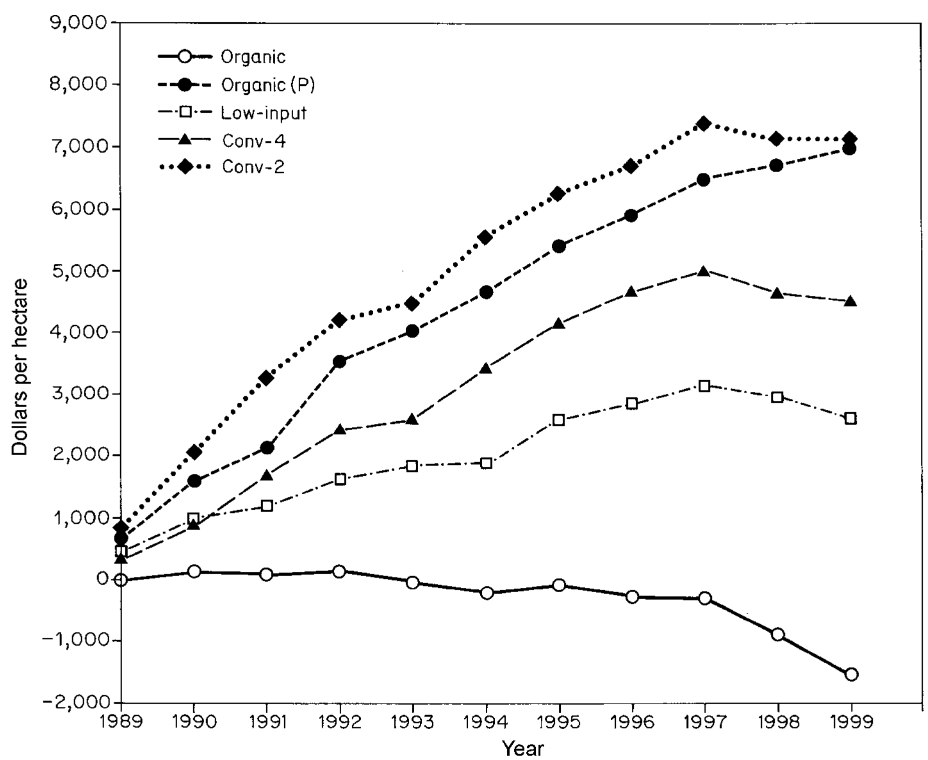

Figure 2. Whole farm cumulative net return (1989–99) at SAFS project.
Note: Organic (P) represents organic system with premium prices.

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