# interdisciplinary, experiment station-based participatory comparison of alternative crop management systems for California's Sacramento Valley

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Abstract. *In 1989, a group of researchers, farmers and farm advisers initiated an interdisciplinary study of the transition from conventional to low-input and organic management of a 4-year, five-crop rotation. Crop yields initially varied among systems, but now appear to be approaching each other after a transition period that included the development of practices and equipment most appropriate for each systems. Farming practices and crop production costs are carefully documented to compare the various systems' economic performance and biological risks. Supplying adequate N and managing weeds were challenges for the low-input and organic systems during the first rotation cycle, and experiments are being conducted on an 8-acre companion block to find solutions to these and other problems. Leading conventional and organic growers provide a much-needed farmer perspective on cropping practices and economic interpretations, because we try to provide "best farmer" management of each system. Research groups within the project are focusing on soil microbiology, economics, pest management, agronomy and cover crop management.*

Key words: farming systems, crop rotation, participatory research, organic farming, sustainable agriculture, soil ecology

## Introduction

Public concern about pesticide residues in food, environmental quality, groundwater contamination, dependence on finite supplies of fossil fuels, and soil and water conservation have led many growers and researchers to consider alternative means of agricultural production. New research in this area is generally labeled "sustainable agriculture." Practices commonly associated with sustainable management include reduced use of chemicals and fossil fuels, maximum use of on-farm inputs, crop nutrient recycling, and increased use of diversified crop rotations that enhance soil cover and fertility.

MacRae et al. (1990) outlined three approaches for moving agricultural systems toward sustainability: increased efficiency of input use, substitution of inputs, and redesigned systems. Increased efficiency might involve banding herbicides or sidedressing corn with N, for example. Substitution methods include replacing inorganic fertilizer by cover crops or manure, or replacing pesticides by biological control. Redesigning a system, which is much more complex, involves restructuring the farming operation so that it mimics natural ecosystems by cycling nutrients, mixing species (polycropping), conserving organic matter, and providing habitat for natural enemies.

Much early work among university researchers focused on substitution rather than systems redesign and did not take into account the many integrative factors that comprise a sustainable system. Therefore, much of this research was unable to show that sustainable agriculture was an acceptable approach (Janke et al., 1991). As the concepts and practices of sustainable agriculture have become more widespread, research in the U.S. has shifted toward experiments that include systems redesign. These experiments include farming systems research at experiment stations (House et al., 1984; Granatstein et al., 1987; Liebhardt et al., 1989; Luna et al., 1991; Peters et al., 1992), where it is possible to control the management and timing of operations. Much systems research also is being conducted on working farms, where comparisons may be confounded by soil, climatic, and management differences, but where real world constraints are integral components of the project (Lockeretz et al., 1981; Reganold et al., 1987; Reganold, 1988; Dobbs et al., 1991; Shennan et al., 1991).

Although farming systems experiments increasingly address system redesign, the

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question of how farming systems are best studied has received less attention. Since sustainable farming systems are complex and specific to the location, understanding the principles and processes that characterize such systems is most readily achieved by a multidisciplinary project.

In 1988, a group of farmers and University of California researchers met at U.C. Davis to plan the Sustainable Agriculture Farming Systems Project, a large, interdisciplinary project whose primary objective was to compare conventional, low-input, and organic farming systems using a management style we call "best farmer practices." 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. The project also is unusual in that four farmers (two organic and two conventional) and two Yolo County farm advisers participate in all decisions. Ten disciplines currently are represented: agronomy, agricultural economics, entomology, water science, nematology, plant pathology, soil microbiology, soil fertility, crop nutrition and weed science. Besides contributing disciplinary experience, each participant expects to learn from agricultural practitioners and find new, interdisciplinary applications for their science.

The study has three objectives:

1. To compare four farming systems that differ in their reliance on nonrenewable resources. This comparison will run for 12 years, encompassing three 4-year rotation cycles, and will document the following: growth, yield and quality of crops as influenced by management practices and rotations; abundance and diversity of weed, pathogen, arthropod and nematode populations and their effects on crop growth, yield and quality; changes in the biological, physical, and chemical properties of the soil and its water relations, and the effects of these changes on soil quality and crop productivity; and the cost of inputs, value of products, economic risk, and energy budgets.
2. To evaluate existing and novel low-input and organic farming systems, with emphasis on innovations that correct deficiencies, enhance profitability or reduce risk.
3. To distribute, demonstrate and facilitate adoption of information generated by this project.

This paper describes the design and function of the project and summarizes yield results from the first 4-year rotation cycle. More detailed descriptions of methods and data from studies of soils, pest management, and economics are reported elsewhere (respectively in Scow et al., in press; Lanini et al., in press; and Klonsky, in press).

## Experimental Design

The 20-A main experiment compares conventional, low-input, and organic management of a 4-year, five-crop rotation consisting of processing tomatoes (*Lycopersicon esculentum*), safflower (*Carthamus tinctorius)*, field corn (*Zea mays*), and either a small grain, a winter legume, or both, double cropped with dry beans

**Table 1. Crops grown for each rotation entry point in four farming systems.**

| System | Rotation | 1989 | 1990 | 1991 | 1992 |
|---|---|---|---|---|---|
| CONV 4[1] | 1 | tomato | safflower | corn | wheat/bean |
| CONV 4 | 2 | wheat | tomato | safflower | corn |
| CONV 4 | 3 | corn | wheat/bean | tomato | safflower |
| CONV 4 | 4 | safflower | corn | wheat/bean | tomato |
| CONV 2 | 1 | tomato | wheat | tomato | wheat |
| CONV 2 | 2 | wheat | tomato | wheat | tomato |
| LOW | 1 | tomato | vetch/safflower | vetch/corn | oat-vetch/bean |
| LOW | 2 | lupin | vetch/tomato | vetch/safflower | vetch/corn |
| LOW | 3 | corn | lupin[2]/bean | vetch/tomato | safflower[2]/bean |
| LOW | 4 | safflower | vetch/corn | oat-vetch/bean | vetch/tomato |
| ORG | 1 | tomato | vetch/safflower | vetch/corn | oat-vetch/bean |
| ORG | 2 | lupin[2]/barley | vetch[3]/tomato | vetch/safflower | vetch/corn |
| ORG | 3 | corn | lupin[2]/bean | vetch/tomato | safflower[2]/bean |
| ORG | 4 | safflower | vetch/corn | oat-vetch/bean | vetch/tomato |

[1] Conventional 4-year and Conventional 2-year.
[2] Because of a combination of poor crop stand and slow development (compared with weed competitors), the crop and weed biomass were disked as a green manure.
[3] Vetch cover crop was disked and replanted late, which resulted in a poor production of biomass.

(*Phaseolus vulgaris*) (Table 1). This rotation includes most of the annual row crops available to a grower in transition to low-input and organic practices; these crops are being grown by the project's certified organic cooperators. Because there are no adequate methods for managing weeds and providing adequate N fertility in organic and low-input wheat (*Triticum aestivum*) production, a mixture of oats (*Avena sativa*) and lana vetch (*Vicia dasycarpa*) was substituted for wheat in those two systems following corn and before double-cropped dry beans. A fourth management system is the conventional 2-year rotation of wheat and tomato used by growers and farm managers who wish to maximize short-term profits. Besides the five cash crops, the low-input and organic systems use N-fixing legume cover crops during the winter and spring preceding tomatoes, safflower and corn.

The experiment was designed to run for three cycles of the crop rotation, after which future directions will be determined. Crop production was begun late in 1988 on 0.3-A plots replicated four times for each crop and entry point of the rotation, for a total of 56 plots. Conventional (CONV-2 and CONV-4) management reflects the practices currently used by most row crop farmers in the Sacramento/Woodland area; organic (ORG) management is defined by California Certified Organic Farmer regulations; and low-input (LOW) management seeks to reduce dependence on inorganic fertilizers, pesticides, supplemental water, and fossil fuel (tillage). Because conventional "best farmer" practices often include IPM scouting and soil moisture monitoring, low-input management criteria have been the most difficult to define and apply consistently.

## Systems Management

Each system is managed using "best farmer" practices recommended by the farmers and farm advisers who are members of the project, rather than by a prescribed set of guidelines. Best farmer management of each system requires appropriate equipment and timely management decisions that are responsive to weather and the biotic challenges of farming. We emphasize the effects of crops and weeds on subsequent crops, competing demands on management and equipment, economics of the whole farm, and long-term changes in the system, especially in soils.

Project leadership is shared by investigators who have no formal sustainable agriculture assignments but contribute time and resources to the multidisciplinary project to strengthen their individual teaching, research, and extension activities. Most important farm planning decisions are made by consensus, with special weight given to the recommendations of grower participants. The dynamics of our interdisciplinary and participatory process are vital to project success; the growers do not always have the same opinion, but as a group their perspective often differs from that of the researchers. Growers contribute actively to designing, executing, and interpreting all disciplinary aspects of the project.

## Sampling and Pest Monitoring

We have taken extensive soil and plant samples throughout the project to make appropriate recommendations for crop nutrition and to document possible changes in soil physical and chemical properties, microbial activity, nematode and pathogen populations, and levels of toxic chemicals. Soil samples for nutrient analyses (20 to 30 random cores per plot) are taken at depths of 0-6" and 6-12". $NO_3^-$ and $NH_4^+$ analyses were done by 2M KCl extractions and the diffusion-conductivity (Carlson) method on air-dried samples. We monitor crop development by recording stand establishment, plant growth, yield and quality. Because processing tomatoes are the key cash crop of the rotation, tomato growth parameters and petiole nutrient concentration are monitored throughout the season. Recommended IPM scouting procedures are used to monitor insects and diseases to allow timely crop management decisions and to explain losses in yield and quality. We sample and sort weeds by species at harvest and estimate fractional cover visually throughout the summer growing season.

We measure crop yield with both hand and machine harvesting. Machine harvesting is done with commercial-size equipment on the center one-third of each plot, and hand harvesting is done in a measured area next to the machine-harvested strip. We report machine harvested yields for all crops except where machinery was unavailable or was not performing at a commercially acceptable standard.

Detailed accounts of all farming practices are maintained for every crop in each farming system to estimate production costs accurately, which lets us simulate the system's economic performance on a 2,000-A farm. We discuss the costs and benefits of specific cultural practices with growers at meetings held every two weeks.

## Results from the First Rotation Cycle

Yields from the first 4-year rotation cycle are presented in Table 2. Average yields for most conventionally grown crops are close to the Yolo County average. The analysis that follows highlights some apparent reasons for yield differences observed during the first 4-year rotation.

### Tomato

Tomato yield is a critical concern because of the key economic role the crop plays in whole farm sustainability (Klonsky, in press). Therefore, the significantly lower yield of low-input tomatoes in 1991 and of organic tomatoes in 1989, 1990 and 1991 may make these systems economically unacceptable during the transition phase. In 1989, vegetative growth was reduced in the low-input and organic tomatoes and fruit damage by insects was higher. The 1990 organic tomatoes yielded 20% less than low-input and conventional tomatoes. Soil sampling and plant growth analyses suggested that the reduction was caused largely by inadequate N supply from the vetch cover crop that preceded tomatoes in the rotation (see Scow et al., in press). Higher populations of pigweed (*Amaranthus* spp.), a preferred host of the armyworm (*Spodoptera exigua*), apparently aggravated the pest problems in organic tomatoes.

The conventional tomato yield of 45.6 ton/A in the 4-yr rotation in 1991 was [illegible] higher than the Yolo County average and significantly higher than the low-input and

Table 2. Crop yields for four farming systems during the first rotation cycle (1989-1992).

| Year | Farming System | | | | Yolo Co. average |
|---|---|---|---|---|---|
| | Organic | Low-input | Conv 4-yr | Conv 2-yr | |
| | Tomato (ton/A) | | | | |
| 1989 | 24.50b[2] | 30.92a | 34.33a | 34.2a | 30.2 |
| 1990 | 30.70c | 36.28b | 36.82ab | 39.6a | 28.8 |
| 1991 | 28.20c | 34.85b | 45.58a | 37.4b | 30.5 |
| 1992 | 42.66 [3] | 42.87 | 47.70 | 41.3 | 33.8 |
| | Safflower (lb/A) | | | | |
| 1989 | 1358b | 1343b | 2058a | — | 2320 |
| 1990 | 2070 | 2350 | 2160 | — | 2100 |
| 1991 | 1990 | 1879 | 2155 | — | 1740 |
| 1992[4] | — | — | 2575 | — | 1920 |
| | Corn (lb/A) | | | | |
| 1989[5] | 8360 | 10420 | 10160 | — | 9020 |
| 1990 | 10400 | 10000 | 9820 | — | 9640 |
| 1991 | 8140b | 8180b | 10120a | — | 9180 |
| 1992 | 9840b | 11840a | 9520b | — | 9800 |
| | Wheat (lb/A)[6] | | | | |
| 1989 | — | — | 4507b | 4916a | 5200 |
| 1990 | — | — | 4615 | 4961 | 4660 |
| 1991 | — | — | 5273 | 5485 | 5380 |
| 1992 | — | — | 4694 | 4498 | 4440 |
| | Beans (lb/A)[7] | | | | |
| 1990 | Y 2218a | Y 2330a | S 1934b | — | 1980 |
| 1991 | RK 1592 | RK 1457 | RK 1140 | — | 1780 |
| 1992 | Y 2830 | Y 2716 | Y 2442 | — | 1780 |

1 All yields are with machine harvesting unless otherwise indicated.
2 Differences between means followed by the same letter within a row are not statistically significant at the 5% level.
3 Organic tomato yields were adjusted based on hand harvest data because of large harvesting losses during calibration of the harvester.
4 Organic and low-input safflower was plowed under in 1992 and pink beans were planted, yielding 2,193 and 2,273 lb/A respectively.
5 No harvesting equipment was available in 1989, so hand harvested yields are reported.
6 All wheat yields are with hand harvesting, except 1992 yields are with machine harvesting.
7 All bean yields are with hand harvesting. Bean varieties: Y = Yolano Pink; S = Sutter pink; RK = Red kidney

organic yields (34.9 and 28.2 ton/A, respectively). We attribute these advantages to differences in plant nutrition, as shown by petiole $NO_3^-$ levels during growth and early fruiting, and to a greater abundance of weeds competing for limited nutrients in the low-input and organic treatments (Table 3). After the 1991 tomato harvest, we decided to use transplants in the low-input and organic tomatoes in 1992 to allow better weed control and greater N fixation and biomass production by letting the preced-

Table 3. Crop yield, petiole $NO_3^-$ and weed biomass for tomatoes in four farming systems for the 1991 and 1992 crop seasons.

| Farming System | Petiole $NO_3^-$ (ppm at early bloom) | | Weed biomass (lb/A at harvest, dry weight) | | Yield (ton/A) | |
|---|---|---|---|---|---|---|
| | 1991 | 1992 | 1991 | 1992 | 1991 | 1992 |
| Organic | 1530b | 6560b | 46 | 162a | 28.2c | 42.7 |
| Low-input | 1800b | 12220a | 40 | 212a | 34.9b | 42.9 |
| Conv. 4-yr | 4270a | 15470a | 0 | 16b | 45.6a | 47.8 |
| Conv. 2-yr | 4100a | 15150a | 0 | 44b | 37.4b | 41.3 |

[1]Differences between means followed by the same letter within a column are not statistically significant at the 5% level.

ing vetch cover crop grow longer. Also, N fertility in the organic treatment was enhanced by adding 2 ton/A of composted chicken manure (2% N) at transplanting and two foliar applications of fish emulsion and seaweed kelp fertilizers during crop growth. The low-input treatment received 9.6 lb/A of N as a starter at transplanting and 30 lb/A of N as $NH_4NO_3$ sidedressed. The 2- and 4-year conventional treatments received 6 and 9 lb/A of starter N respectively, and both were sidedressed with 120 lb/A of N.

There were no significant differences in tomato yields among systems for the 1992 harvest. As in previous years, the conventional yields were well above the county average. Therefore the absence of significant differences was due almost entirely to increases in the low-input and organic yields.

Table 4. Yield (lb/A) of cover crop dry matter of Lana woollypod vetch planted in two farming systems for 1991 and 1992.

| Crop | Organic | | Low-input | |
|---|---|---|---|---|
| | 1991 | 1992 | 1991 | 1992 |
| Vetch/tomato | 3913 | 3209[1] | 3582 | 3392[1] |
| Vetch/corn | 3846 | 4644 | 2877 | 4503 |
| Vetch/safflower | 3277 | — | 2448 | — |
| Oat-vetch seed[2] | | | | |
| Oat | 819 | 402 | 1630 | — |
| Vetch | 964 | 257 | 463 | — |

[1] 1992 dry matter values include biomass contributions of vetch, volunteer oats, and weeds at time of plowdown.

[2] Values are for seed yield (lb/A) in the rotation position following corn and before double-cropped dry beans.

## *Corn*

Corn yield was less variable than tomato yield among treatments and years. Significant yield differences occurred only in 1991 (higher conventional) and 1992 (higher low-input). This is inconsistent with results from other studies that have shown that corn is not a good crop to use during transition because it has a high N requirement and is vulnerable to reduced yields from weed competition (Sahs, 1986; Janke et al., 1991). These factors appear to have caused the decline in corn yields in 1991, when the 3,000 lb/A vetch cover crops in the organic and low-input systems were inadequately incorporated (Table 4 and Scow et al., in press).

In 1992, adequate N was available in all three systems, but weed pressure contributed to a yield decrease in the organic system (Table 5). For the cover crop to be incorporated and the following corn crop to be planted at the best time, the weather must be clear and machinery must be available to do field operations that allow establishment of the corn crop without supplemental moisture. In 1992, irrigation was needed to establish the corn in the organic and low-input systems, which led to heavy weed pressure. Weeds were managed with a contact herbicide in the low-input system, but this was not permitted in the organic system. Weed pressure in the organic system continues to be a problem, because allowed herbicides are not available.

The decreased corn yield in the conventional system may have been caused by the use of 60-in beds, rather than the 30-in beds used in the low-input and organic systems. Grower participants suggested that with

Table 5. Corn leaf tissue N, weed biomass and yield, 1992.

| Farming System | Leaf tissue N at silking (%) | Weed biomass at harvest (lb/A) | Yield (lb/A) |
|---|---|---|---|
| Organic | 2.4b[1] | 744a | 9840b |
| Low-input | 2.8a | 33b | 11840a |
| Conventional | 2.8a | 20b | 9520b |

[1]Differences between means followed by the same letter within a column are not significantly different at the 5% level.

60-in beds, different amounts of moisture are available to the corn roots that are oriented respectively toward the furrow and toward the inside of the beds.

### Other crops

Yields of safflower and dry beans have differed only slightly among systems. In 1989, safflower yield was significantly higher in the conventional than in the low-input and organic systems (Table 2). In 1990, yields of low-input and organic beans were significantly higher than the conventional bean yield. Beans also performed very well in 1992 as a replacement for a lost safflower crop. Obtaining a good stand of safflower following an N-fixing cover crop presents substantial challenges. Wheat yields in the 2-year and 4-year conventional systems were near the county average.

Several crops have been grown in the organic and low-input systems opposite winter wheat in the conventional systems, but we still do not have a reliable cash grain alternative to wheat. Four successive years of inadequate fall moisture and limited experience with stand establishment and harvesting equipment have led to inconsistent results with sweet white lupin (*Lupinus albus*) and oats/vetch seed crops. The challenges of managing winter cover and grain legume crops without herbicides or with short-lived, postemergent herbicides are partially offset by the option of planting or replanting crops of opportunity, such as spring barley (*Hordeum vulgare)* after lupin, and pink beans (*Phaseolus vulgaris*) after safflower.

## Whole Farm (Rotation) Results

Differences among the systems' management practices complicate the comparison of fertility and pest results for all crop-system combinations. However, the development and use of innovative agricultural equipment to manage cover crops and control weeds without chemicals is the kind of adjustment that farmers say is required in the transition to low-input or organic systems. The farming systems group gave heavy weight to the economic criteria of Klonsky (in pres) in evaluating the crops and production practices used during the first 4-year cycle. Prices received, especially the premiums received for certified organic commodities, exert a powerful influence.

The rotation of processing tomatoes, safflower, field corn, and wheat or a winter legume followed by double-cropped dry beans is a good system for comparing crop performance and yields. The management of N-fixing cover crops as a green manure or seed crop has generated new opportunities and new challenges that require "best farmer" management and flexibility to work within constraints of time and weather. The late winter/early spring management of cover crops has become a central research theme in the large companion plots next to the main experiment. These studies deal with residue management, seedbed preparation, supplemental manuring, and the retention of sufficient soil moisture for germination of tomato, corn and safflower with little or no herbicide.

Insects, diseases, and nematodes have hardly affected productivity, in part because corn, safflower, beans, and wheat do not require intensive pesticide use. Similarly, early processing tomatoes receive a good price and have less severe pest problems than late-planted tomatoes. Weed management, on the other hand, has been a problem in almost all crops in the low-input and organic systems.

The interdisciplinary group is focusing on several key issues as the second rotation cycle begins. Besides identifying the best cover crops for each system/year combination, we are more intensively monitoring several phenomena that affect soil fertility and plant nutrition, particularly the timing of the availability of N from the cover crop and its relation to crop growth and yield. Other critical issues are the long-term implications of weed control and the related demand for creative management and appropriate equipment. Some cultural practices in the low-input and organic systems must be done within a narrow time interval, which results in a constant race with the weather. We also are seeking scale-neutral management systems that can be used by large and small growers alike.

Evidence is available on the pros and cons of different rotation entry points in each system, but the choice will depend on individual growers' economic situation and the wide range of costs and returns for the five cash crops in the rotation. Organically grown tomatoes receive an attractive price, but current organic regulations require a minimum of three years without pesticides before certification. This suggests that field corn would be the best entry point for the organic system, because it would allow certified organic tomatoes to be sold by the third year. However, growers must consider the implications of this choice for pest control, especially weed management. Of greatest concern are the entry point and short-term economic viability of the low-input system, which has no price premiums to offset potential cost increases in managing weeds and maintaining adequate fertility for high yields.

## Companion Area Studies for Systems Experiments

An advantage of a large, multifaceted whole-system experiment is that it provides results about the interactions that make the whole system succeed. Such experiments also may represent true farming systems better. A major drawback, however, is the difficulty in understanding specific causal relationships because of the variability introduced by different farming practices. The Sustainable Agriculture Farming Systems Project has addressed this challenge by initiating research on important information gaps on an 8-A area next to the main experiment. Annually, 1.2 A is planted to each of the four summer cash crops of the rotation and managed at the low-input level. This provides a representative setting for experiments with materials, equipment, and practices that would disrupt the main experiment.

Our current research priorities are to identify a more suitable cover crop to follow tomato and precede safflower, and a cash crop to replace winter wheat in the low-input and organic systems. Following tomato in the companion area, six species or species mixes (Lana vetch, purple vetch, cowpea/Lana vetch, fava bean/Lana vetch, and sorghum/sudangrass) are being tested for biomass, total N production and assimilation, and weed competition. This seasonal niche is particularly difficult to fill because tomatoes generally are harvested too early for vetch and too late for cowpeas. Safflower is planted in early spring, reducing the time available for spring growth of a fall-planted cover crop. High residual soil N following tomatoes makes immediate planting of a cover crop attractive for efficient nutrient cycling in the low-input and organic systems.

Berseem clover, lupin, chickpea, bellbean/winter pea, barley/vetch, and an oats/vetch control are being tested in 1993-94 after corn and before beans in the companion plot (double cropped dry beans will be planted in June). The agronomic suitability of organic soft white spring wheat also will be tested in 1994, with various seeding rates and fertility levels (composted manure). The group will then decide if any of these options merits further testing.

## Information Dissemination

Results from the project are circulated by various means to interested growers, researchers, educators, pest managers, extension personnel, and the public. The most typical way is field visits and tours. Individuals and groups tour the project at least once per week. The experimental site also has brochures with a map and brief project history to encourage self-guided tours. Guided tours are provided by the research and production managers and by principal investigators or project cooperators.

Experimental plots of the project are a "living laboratory" and have become a model for teaching and instruction. During the first five years, six faculty members from Spain, Brazil, Italy, and Israel have spent sabbatical leaves with the project, contributing expertise and labor and gaining experience. Many graduate students have conducted M.S. and Ph.D. work on the plots. The experiment is routinely visited as a teaching/demonstration laboratory for U.C. Davis courses. Several of the principal investigators have been mentors to students from a U.C. Davis outreach program to provide research and career experiences to minority high school students.

The annual field day provides the most direct and immediate outreach to the public, researchers and growers. The 1993 field day, which offered lectures, plot tours, and demonstrations of soil biology and equipment, was attended by 150 participants from all over California. Special field days also are organized for specific topics, such as to demonstrate novel equipment for incorporating cover crops.

Faculty members and researchers associated with the project also have conducted off-station seminars for growers in the Woodland and Stockton areas and have participated in conferences organized by professional societies, private companies, and academic institutions. One faculty member used this project as a model in a two-week workshop on sustainable agriculture in Argentina in September 1993.

Information also is disseminated through more traditional channels, such as reports transmitted to all county offices in California through newsletters of the U.C. Sustainable Agriculture Research and Education Program. The extension specialists and cooperating farm advisers on the project each typically give 25 or more presentations per year to growers, advisers and commodity groups. Relevant information also is published in newsletters prepared by the project's farm advisers. Many county-based farm advisers are repeat visitors at annual field days, where they provide opinions and advice. Data from the first four years are currently being summarized in manuscripts for publication in disciplinary journals by each investigator. Also, the popular journal *California Agriculture* will carry a series of four papers covering research on soils, economics, and pests (Temple et al., in press; Scow et al., in press; Lanini et al., in press; Klonsky, in press).

## Conclusions and Implications

The many farmers, farm advisers, researchers, and students who meet every two weeks on this participatory project have invested substantial time to make "interdisciplinary" a meaningful part of our vocabulary. With farmers contributing to research and with researchers seeking to understand farming better, our farmer participants not only provide a reality check for the interventions and interpretations the researchers suggest, but also are role models for integrative and interdisciplinary education. Researchers have learned from growers some excellent educational tools for improving communication at county meetings and have gained a valuable insight about how growers perceive the transition "learning curve."

The agribusiness sector has become more interested and less skeptical as the project has evolved, in part because of the active way that growers and farm advisers have contributed to the research and educational process and the willingness of researchers to become students. Several agribusinesses contribute nominal support to the project, and their professionals are well represented at our annual field days and county meetings.

After the first rotation cycle, several trends are apparent, although more years are needed to reach definitive conclusions. Two key aspects of a successful transition are maintaining N fertility by skillful cover cropping and supplemental use of manures and other products, and adequate weed management. These challenges have multiple dimensions, and both interact with other aspects of the rotation. For example, sustainable N management will require skillful manipulation of legume and nonlegume cover crops, and timely and precise soil and residue management. Sustainable weed management also requires precise manipulation of moisture, fertility, and solar energy in ways that favor the crop over the weeds. Both objectives also require major attention to the weather, something that agriculturists have labored for decades to minimize in our farming practices.

Many of the results to date involve principles and processes of soil ecology, and more of our group's effort is being directed accordingly. It is too early to predict whether our results will contribute more to increased efficiency, input substitutions, or redesigned systems. Each probably will be appropriate, and their successes and failures no doubt will be observed in the soil.

Our preliminary results suggest that conventional, low-input, and organic systems will have nearly equal yields for most crops in most years. The biggest remaining question is the comparative economic returns of using different off- and on-farm inputs, including skilled management, to maintain yield and quality under the different systems. Also important is the larger issue of market incentives and regulatory disincentives for more sustainable production practices, particularly for commodities produces in more diverse crop rotations. Business skill, experience, and knowledge, combined with creativity and flexibility, continue to characterize outstanding farmers. Perhaps more patience will be required for successful transition where variables such as the weather are concerned, but today's best conventional farmers probably will be among the leaders of tomorrow's transition.

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