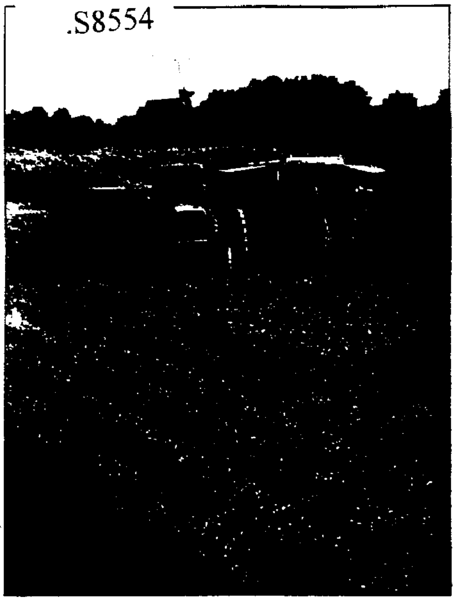

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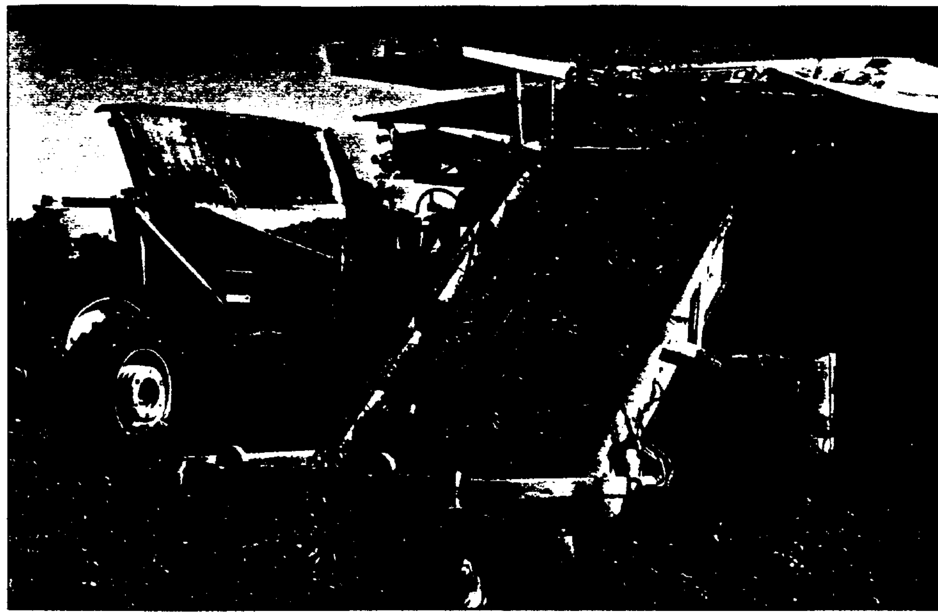

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The 20-acre main experiment compared conventional, low-input and organic management using a 4-year, five-crop rotation of processing tomatoes, safflower, corn and wheat followed by double-cropped dry beans. Processing tomatoes, shown being mechanically harvested, were the key cash crop of the rotation.

Conventional, low-input and organic farming systems compared

Steven R. Temple ❑ Oscar A. Somasco ❑ Mary Kirk ❑ Diana Friedman

Cover-crop nitrogen supply and weed management were the most important challenges facing low-input and organic farming systems when compared to conventional systems in the first 4 years of the Sustainable Agriculture Farming Systems project at UC Davis. Cover-crop timing and management using appropriate equipment were important for the success of transitional systems. The participation of local farmers ensured that optimal agricultural practices were used to manage all farming systems. Researchers regularly consulted grower-cooperators to determine "best farmer practices" of conventional, low-input and organic farming systems.

Steadily growing public concerns about pesticides, food safety, environmental quality, groundwater contamination, dependency on finite supplies of fossil fuels and soil and water conservation were underscored by publication of the National Research Council's 1989 book, *Alternative Agriculture*. Following publication, the U.S. agricultural community vigorously debated how relevant and representative the report had been. Questions surrounded the examples used by the NRC to compare the sustainability of farming systems with differing amounts of nonrenewable purchased inputs. In 1988 a group of farmers and UC researchers met at UC Davis to plan a large interdisciplinary project with the primary objective of comparing conventional, low-input, and organic farming systems with respect to the following factors:

1. The abundance and diversity of weed, pathogen, arthropod and nematode populations.
2. Differences in soil biology, physical and chemical properties and water relations.
3. Crop growth, yield and quality.
4. Economic viability.

As a corollary objective, the project was to evaluate known and novel farming practices that showed potential to reduce dependence on nonrenewable resources. Results from these studies would be distributed widely in an effort to facilitate a dialog about the adoption of more sustainable farming practices. Here we report results from the first 4 years of this 12-year project.

Although some features of this research are similar to work already reported or in progress at the Rodale Research Institute in Pennsylvania, and efforts in Maryland, Virginia, South Dakota, Nebraska, Colorado and Wisconsin, the combination of a Mediterranean climate, a relatively long (4-year, five-crop) rotation, and management of each system using "best farmer practices" makes this effort unique (see box, below).

Experimental design

The 20-acre main experiment compared results from farming a 4-year, five-crop rotation using conventional, low-input and organic management of processing tomatoes, safflower, corn and wheat followed by double-cropped dry beans (table 1). Due to inadequate alternatives for weed management and nitrogen fertilization of wheat for the organic and low-input treatments, a mixture of oats and vetch was substituted for wheat in those two systems, following corn and before double-cropped common beans. In addition to the five cash crops, the low-input and organic systems utilized nitrogen-fixing legume cover crops during the winter-spring season preceding tomatoes, safflower and corn.

The experiment was designed to run for two cycles of the crop rotation, after which future directions would be determined. Crop production was initiated late in 1988 on 1/3-acre plots replicated four times for each crop by system entry point of the rotation. Only the center third of each plot was used for yield measurements, to minimize border effects.

The economic analysis of the four systems and their respective crops was pivotal to the interpretation of project results. Costs and benefits of cultural practices were discussed at biweekly meetings with conventional and organic farmers, who emphasized the importance of tomatoes (and especially the higher-priced early-season tomatoes) on the overall profitability and equitable management of the different systems (for details, see page 35). Farmers were polled when poor performance of a crop required a cost/benefit analysis for destroying that crop and deciding to replant, the same or a different crop, or to leave the ground fallow.

In addition to the 20 acres occupied by crops in the main experiment, an 8-

Jack Kelly Clark

In addition to machine harvests, tomatoes were hand harvested to verify yield data.

Definitions of Farming Systems Treatments

The four farming systems all consisted of "best farmer practices" identified in the operation of progressive and economically efficient row-crop farms in the lower Sacramento Valley. Thus pest "scouting" and management based on IPM economic thresholds is a feature of all systems. Inputs, including water and sources of nitrogen fertilizer, were carefully monitored and judiciously managed to enhance the economic profitability of each system. Cooperating growers were regularly consulted for operational decisions.

"Best farmer practices." Management of each of the four systems had its inherent requirements for appropriate field machinery and timely operational decisions that responded to weather and the biotic challenges of farming. A group of grower-cooperators were regularly consulted on key farming decisions for all systems. For example, we discussed the benefits of field equipment operations, the practicality of preirrigating ground prior to fall planting or the wisdom of providing supplemental irrigation to winter crops in each system.

Conventional 4-year. The 4-year rotation used inorganic fertilizers, chemical weed control, Integrated Pest Management-based insect and disease control, and irrigation and tillage practices common among successful row-crop farmers in the Yolo County area.

Conventional 2-year. The 2-year rotation alternated wheat and processing tomatoes. Thit has been suggested for farming businesses seeking to maximize short-term economic returns by increasing the frequency of tomato harvests. The other three systems, all consisted of 4-year, five-crop rotations.

Low-input. Low-input maximized use of nitrogen-fixing legume cover crops and modest rates of supplementary manure or inorganic fertilizers. This treatment also attempted to replace long-lived pre-emergence herbicides with shorter-lived postemergence weed control. Chemicals wereused sparingly, and only when the agronomic or economic stability of the system was jeopardized, and tillage reductions were sought.

Organic. Organic practices complied with regulations of California Certified Organic Farmers (CCOF), and were focused on use of cover crops, limited use of composted manures, mechanical weed control, and insect management using biological control and infrequent applications of CCOF-approved products.

acre companion area contained larger (1.2-acre) blocks planted to the same five crops and managed like the low-input system. Better cover crop options, as well as improved practices for weed management, tillage and crop nutrition, were evaluated at the companion site by project researchers with a broad array of disciplinary interests.

Soil sampling, pest monitoring

Extensive soil samples were taken in order to monitor and recommend appropriate farming practices for crop nutrition, as well as to document changes in soil physical properties, microbiological activity, nematode and pathogen populations, and concentrations of toxic chemicals (for details, see pp. 20–26 and 27-33). Crop growth and development were compared by recording stand establishment, plant-growth parameters, yield and quality. Because processing tomatoes were the key cash crop of the rotation, tomato plant growth parameters such as flower and fruit numbers, plant height, foliage and fruit weight were monitored in greater detail, and tomato petiole nutrient analyses were conducted at three specific stages during crop growth. Insects and diseases were monitored, using recommended IPM scouting practices, to facilitate timely crop management decisions and to explain losses in yield and quality. Weeds were sampled and sorted by species at harvest, and sometimes at key opportunities during competition with crops. The center third of each plot was machine harvested with commercial-sized equipment. A hand harvest, stratified to representatively sample each plot, was done in the area adjacent to the machine-harvested strip for crops where equipment problems resulted in large harvest losses.

TABLE 1. Crops grown for each of the different rotation entry points in four farming systems

System	1989	1990	1991	1992
Conv 4	tomato	safflower	corn	wheat/bean
Conv 4	wheat	tomato	safflower	corn
Conv 4	corn	wheat/bean	tomato	safflower
Conv 4	safflower	corn	wheat/bean	tomato
Conv 2	tomato	wheat	tomato	wheat
Conv 2	wheat	tomato	wheat	tomato
Low-input	tomato	vetch/safflower	vetch/corn	oat-vetch/bean
Low-input	lupin	vetch/tomato	vetch/safflower	vetch/corn
Low-input	corn	lupin*/bean	vetch/tomato	safflower*/bean
Low-input	safflower	vetch/corn	oat-vetch/bean	vetch/tomato
Organic	tomato	vetch/safflower	vetch/corn	oat-vetch/bean
Organic	lupin*/barley	vetch†/tomato	vetch/safflower	vetch/corn
Organic	corn	lupin*/bean	vetch/tomato	safflower*/bean
Organic	safflower	vetch/corn	oat-vetch/bean	vetch/tomato

*A combination of poor crop stand and slow development (compared to weed competitors) resulted in disking under of crop and weed biomass as a green manure.
†Vetch cover crop was disked under and replanted late, resulting in a poor production of biomass.

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

	System				
Crop	Organic	Low-input	Conv 4-yr	Conv 2-yr	Yolo County average
Tomato (tons/acre)					
1989	24.50 b*	30.92 a	34.33 a	34.2 a	30.2
1990	30.70 c	36.28 b	36.82 ab	39.6 a	28.8
1991	28.20 c	34.85 b	45.58 a	37.4 b	30.5
1992	42.66	42.87	47.70	41.3	33.8
Safflower (lb/acre)					
1989	1,358 b	1,343 b	2,058 a	—	2,320
1990	2,070	2,350	2,160	—	2,100
1991	1,990	1,879	2,155	—	1,740
1992†	—	—	2,575	—	1,920
Corn (tons/acre)					
1989	4.18	5.21	5.08	—	4.51
1990	5.20	5.00	4.91	—	4.87
1991	4.07 b	4.09 b	5.06 a	—	4.59
1992	4.92 b	5.92 a	4.76 b	—	4.90
Wheat (lb/acre)					
1989	—	—	4,507 b	4,916 a	5,200
1990	—	—	4,615	4,961	4,660
1991	—	—	5,273	5,485	5,380
1992	—	—	4,694	4,498	4,440
Beans (lb/acre)‡					
1990	Y 2,218 a	Y 2,330 a	S 1,934 b	—	1,980
1991	RK 1,592	RK 1,457	RK 1,140	—	1,780
1992	Y 2,830	Y 2,716	Y 2,442	—	1,780

*Differences between means within a horizontal row followed by the same letter are not statistically significant at the 5% level.
†Organic and low-input safflower in 1992 were plowed under and pink beans were planted, yielding 2,193 and 2,273 lbs/acre, respectively.
‡Bean varieties: Y = Yolano pink; S = Sutter pink; RK = Red kidney

Yields evaluated

Yields from the first 4-year rotation cycle are presented in table 2. Average yields for most crops in the conventional 4-year system were close to Yolo County averages, suggesting that management of these semicommercial-sized plots was comparable to that of local growers. The crop-by-crop analysis that follows highlights some of the apparent reasons for yield differences observed during the first 4-year rotation, including those most frequently cited by farmers seeking to reduce conventional inputs.

Tomato. Tomato yields are important because of the economic role the crop plays in whole-farm sustainability (see pp. 34-42). Therefore the significantly lower yields of low-input tomatoes for 1991, and of organic tomatoes for 1989, 1990 and 1991, are a source of concern, indicating that these systems may not be economically viable during the transition phase. In 1989, we observed reduced vegetative growth in the low-input and organic tomatoes, as well as a higher incidence of fruit damaged by insects. The 1990 organic tomatoes yielded 20% less than the low-input and conventional tomatoes. Data from soil sampling and plant-growth analyses suggest the lower yield was largely due to inadequate nitrogen supply from the vetch cover crop that preceded tomatoes in the rotation (see pp. 20–26). Higher populations of pigweed, a preferred host of the armyworm, apparently worsened pest-management problems for the organic tomatoes.

A conventional tomato yield of 45.6 tons per acre in 1991 was 50% higher than the Yolo County average and significantly greater than yields registered for low-input and organic treatments (34.9 and 28.2 tons per acre, respectively). These advantages may be attributed to differences in plant nutrition, as evidenced by petiole NO_3 levels during growth and early fruiting, and to a greater abundance of weeds in the low-input and organic treatments competing for limited resources (table 3).

Concern was raised that we wouldn't be able to take advantage of market price incentives for early tomatoes if we delayed direct seeding of all tomato plots until May 9 to accommodate growth and incorporation of the vetch cover crop in the organic and low-input systems. Following the 1991 tomato harvest, the project group, including growers and farm advisors, met to develop a strategy to improve plant nutrition and weed management in the low-input and organic treatments. We decided to use transplants in the low-input and organic tomatoes in 1992, thereby permitting greater nitrogen fixation and biomass production by allowing the preceding vetch cover crop to grow longer without compromising the demand for early tomato deliveries. Weed control and water management were also facilitated by transplanting. Further, nitrogen fertility in the organic treatment was enhanced by the addition of 1.5 tons per acre of composted chicken manure (3% nitrogen) at transplanting and two foliar applications of fish emulsion and seaweed kelp fertilizers during crop growth. The low-input treatment received 9.6 pounds per acre of nitrogen as a starter at transplanting and 30 pounds per acre of nitrogen as sidedressed ammonium nitrate. The conventional 2- and 4-year treatments received 6 and 9 pounds per acre, respectively, of starter nitrogen and 120 pounds each of sidedressed nitrogen.

There were no significant differences among tomato yields for 1992. The conventional systems were direct seeded March 28 and the organic and low-input systems were transplanted April 14. As in previous seasons, conventional yields were well above reported county averages; the absence of significant differences is due almost entirely to increases in yield for the low-input and organic treatments. The utility of these measures to improve tomato yields must still be confirmed in subsequent years.

Corn. The performance of corn over treatments and seasons appears to be more consistent than that of tomatoes. Significant yield differences were only observed in 1991 (favoring conventional) and 1992 (favoring low-input). The 1991 corn yields of the organic and low-input systems were adversely affected by inadequate incorporation of the 3,000-pound vetch cover crop that preceded the corn (see tables 4 and 5, and pp. 20–26). In 1992 the yield advantage of the low-input over the conventional corn did not appear to be a result of nitrogen nutrition (table 4). Examining results from 1992, growers suggested instead that the 60-inch bed system used for conventional corn (two rows per bed) was less adequate than the single-row 30-inch beds used for organic and low-input corn, due principally to differences in the moisture available to portions of conventional corn root systems that are oriented toward the furrow or toward the

TABLE 3. Petiole NO_3 and weed biomass crop yield for tomatoes in four farming systems for the 1991 and 1992 crop seasons

	Petiole NO_3 (ppm @ early bloom)		Weed biomass (lb/acre @ harvest)*		Yield (tons/acre)	
System	1991	1992	1991	1992	1991	1992
Organic	1,530 b†	6,560 b	46	162 a	28.2 c	42.7
Low-input	1,800 b	12,220 a	40	212 a	34.9 b	42.9
Conv 4-yr	4,270 a	15,470 a	0	16 b	45.6 a	47.8
Conv 2-yr	4,100 a	15,150 a	0	44 b	37.4 b	41.3

*Dry weight.
†Differences between means within a vertical column, followed by the same letter, are not statistically significant at the 5% level.

TABLE 4. Percent N in ear leaf, yield, and weed competition for field corn grown under three farming systems during the 1991 and 1992 crop seasons

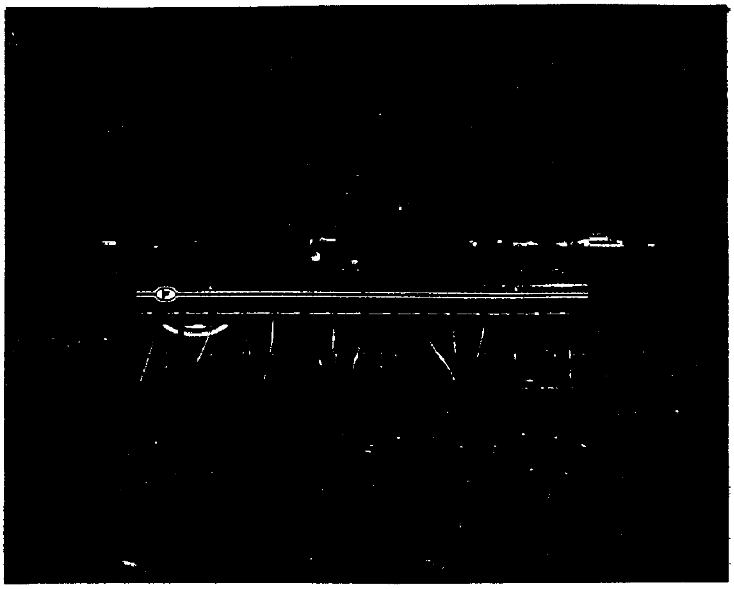
	Percent N (ear leaf @ silking)		Yield (tons/acre)		Weed biomass (lb/acre @ harvest)	
	1991	1992	1991	1992	1991	1992
Organic	2.4*	2.4 b	4.07 b	4.92 b	93	744 a
Low-input	2.4	2.8 a	4.09 b	5.92 a	46	33 b
Conventional	3.0	2.8 a	5.06 a	4.76 b	1	20 b

*Differences between means within a vertical column, followed by the same letter, are not statistically significant at the 5% level.

TABLE 5. Yield of cover crop dry matter of Lana woollypod vetch planted in two farming systems for 1991 and 1992

	Organic		Low-input	
Crop	1991	1992	1991	1992
	lb/acre			
Vetch/tomato	3,913	3,209*	3,582	3,392*
Vetch/corn	3,846	4,644	2,877	4,503
Vetch/safflower	3,277	—	2,448	—
Oat-vetch seed†				
Oat819	402	1,630	—	—
Vetch	964	257	463	—

*1992 dry matter values include biomass contributions of vetch, volunteer oats and weeds at time of plowdown.
†Values are for seed yield (lb/acre) in the rotation spot following corn and before double-cropped dry beans.



Courtesy of SAFS project

In the low-input and organic plots, cover crops such as lupin and vetch were drilled into residue using a no-till range drill.

inside of the 60-inch bed. Future corn crops will have 30-inch rows in all systems.

Yield differences in 1992 between organic and low-input corn, which were both supplied with nitrogen by a similar crop of vetch (table 5), are best explained by the effects of weed competition for nitrogen, light and water (see table 4 and pp. 27–33). The timing of cover crop incorporation and subsequent planting of corn requires clear weather and machinery to perform field operations that allow establishment of the corn without supplemental moisture prior to crop emergence. Failing this, the timely application of 2,4-D to low-input corn in 1992 resulted in a large yield advantage for that system over organic corn, for which no comparable management tool was available.

Safflower. Safflower was included in the rotation mostly for its demonstrated flexibility under different levels of management, and for its potential as a spring (largely rain-fed) crop that can be planted after killing winter weeds and well ahead of summer weeds. Only in 1989 were conventional safflower yields statistically superior to organic and low-input yields (table 2). However, in early 1992, organic and low-input safflower performed very poorly, and these crops were ultimately disked under and replanted with dry beans in order to retain the economic competitiveness of those two systems.

The most serious reservation about the utility of safflower in low-input/organic systems rests not in its yield potential. Like corn, safflower challenges the grower to skillfully manage the preceding nitrogen-fixing cover crop according to soil and weather conditions at the time of planting. The first 4 years of this study were characterized by little or no fall rain, so that most of the legume covers did not germinate until winter and put on little biomass before March, which is the accepted date for planting safflower. To obtain adequate cover crop growth, safflower would not have been planted until about April 15, which is too late for the crop. As a result, 1989–1992 winter cover crops were hard to accommodate with safflower planting and resulted in lower yields or crop failure (severe weed pressure). In 1992–1993, new options, such as the use of fall/winter legume mixes after tomato harvest, were evaluated in the companion area in the search for alternate management strategies (data not reported). Fall incorporation of animal manures favors winter weed growth and nitrogen loss, while February/March incorporation of covers and manures and planting safflower to moisture requires at least two weeks of favorable weather. Conventional planting in beds prepared in the fall and managed by means of winter chemical fallow are less subject to the vagaries of weather. We are still evaluating the methods we began for low-input and organic systems in 1992–1993.

Beans. Dry beans are a logical rotation crop for transitions toward low-input and organic farming systems. Manipulation of moisture and fertility should favor this crop over many of its weedy summer competitors, and excellent organic and pesticide-free bean crops have been produced by local growers and in the companion area of this project on a 1.2-acre parcel. The 1990 low-input and organic bean yields were significantly better than the conventional yield. The higher yields of the fuller-season pink variety, following the failure of grain lupin in the low-input and organic treatments, represented only a partial compensation for the loss of a winter cash crop, which was followed by a shorter-season, double-crop pink variety in the conventional system. In the 1991 and 1992 seasons, and using the same variety in all systems, the advantages of low-input and organic dry beans over the conventional treatment were not statistically significant. Beans performed very well in 1992 as a "catch" crop to compensate for the safflower loss in the organic and low-input systems, where the beans yielded 2,193 and 2,273 pounds per acre, respectively.

Winter crops. Wheat performed in the conventional 2- and 4-year systems as expected, with yields near local averages. Results from winter legumes and legume-grass mixtures in the organic and low-input systems are less consistent and reflect challenges reported by local growers and farm advisors during the planning stages of the project. The 1989, low-input lupin crop, planted on open ground in October 1988, yielded a respectable 2,169 pounds per acre, and with better harvesting equipment more of the 3,620 pounds per acre, hand-harvested yield would have been realized. But in the absence of fall rains and without either a protective corn residue or herbicides, the organic lupin plots had late and uneven germination, competed very poorly with winter weeds, and were disked under the following spring to plant a barley catch crop that competed favorably with spring weeds and yielded 1,823 pounds per acre. In 1990 the low-input and organic lupin were drilled into corn stubble using a no-till range drill. Without fall moisture, germination was poor and late, so that winter-spring weed competition was severe, and the lupin was disked under before a threatening amount of weed seed matured.

A decision was made in 1990 to drop winter lupin in the low-input and organic systems and to substitute an oat-vetch mixture as a green manure, green chop haylage or seed crop in the rotation spot before double-cropped beans. We continue to evaluate lupin as an alternative winter legume, but limiting fall moisture and strong competition from winter weeds may limit the crop's utility to only the low-input system. The 1991 vetch cover crop produced between 3,000 and 3,600 pounds per acre of dry matter and an estimated 125 to 155 pounds per acre of nitrogen prior to planting tomatoes, corn and safflower. The 1991 oat-vetch mixture yielded well in both systems (table 5), and was followed by double-cropped kidney beans. In 1992 the flexibility of the oat-vetch crop permitted the harvest of the low-input system as a 17.1 tons per acre green chop cash crop on May 1, while the organic oat-vetch was harvested on June 9 as a seed crop.

Comparing the systems

The absence of complete symmetry in management practices (varieties, planting dates, tillage practices, seeded versus transplanted, and actual units of nitrogen fertilizer) complicates the task of making specific comparisons of crop-system combinations. These differences are especially difficult to interpret where key pieces of agricultural equipment were not available to perform precise cultural operations in a timely manner. This was especially true in the management of "new" crops like lupin and the oat-vetch seed crop, and particularly for the organic and (to a lesser extent) the low-input systems, where fewer crop-saving practices are known and approved. The result was a higher incidence of failed crops. Grower-cooperators recommended that we incorporate these crops as green manure and replant with a catch crop (barley, dry beans) as a farmer would to reduce the negative impact of expended capital and lost crops on the overall economic viability of the rotation. The development and utilization of implements to better manage cover crops and nonchemical weed control are cited by farmers as components of the "learning curve" that transition demands of growers and researchers. Economic criteria discussed by Klonsky et al. (pp. 34-42) have been heavily weighted by the farming systems group in evaluating the adequacy of crops and production practices used during the first 4-year cycle. Prices received, and especially the premiums received for certified organic commodities, have a powerful influence.

From the standpoint of crop performance and yield, it appears that a rotation of processing tomatoes, safflower, field corn and wheat or winter legume, followed by double-cropped dry beans, is a good crop rotation on which to make systems comparisons. The use of nitrogen-fixing winter cover crops for green manure and as seed crops has merit, but also resulted in crop management challenges that required "best farmer" experience and flexibility to work within the constraints imposed by time and weather. The late winter/early spring management of cover crops, including residue management, seedbed preparation, supplemental manuring and the retention of sufficient soil moisture to germinate tomatoes, corn and safflower with little or no herbicide has become a central research theme for continuing studies in the large companion plots adjacent to the main experiment.

The interdisciplinary group is focusing on several key issues as the project enters the second rotation cycle. These include identifying the best cover crops for each system/season combination and observing phenomena that have an impact on soil fertility and plant nutrition, particularly the season-long monitoring of cover-crop-derived nitrogen fertility, crop growth and yield. The long-term implications of weed control, as well as the related demand for creative management and appropriate equipment, are critical. Some cultural practices of the low-input and organic systems have a relatively narrow window of opportunity in which repetitive or slow operations lead to a constant race with the weather. The project group continues to look for scale-neutral management systems that can be used by large and small growers alike.

Conclusions about the preferable crop with which to enter the rotation are still premature. The attractive premiums offered for organically grown tomatoes, and regulations that specify a minimum of 3 years without pesticides prior to certification, suggest that field corn would be the best entry point, but pest control (and especially weed management) implications of this choice must be considered. Choices will also depend on the grower's economic situation and a consideration of the wide range of costs and returns for the five cash crops in the rotation. The challenges of managing winter cover and grain legume cash crops without herbicides (organic), or with short-lived, post-emergence herbicides (low-input), are at least partially offset by the opportunities to plant or replant catch crops, such as spring barley after lupin and pink beans after safflower in this study.

Perhaps the most interesting result to date is the productivity of a group process in which farmers and farm advisors have joined campus-based researchers as full partners in planning, conducting and interpreting results from the study. It is apparent that the project could not approach "best farmer" systems comparisons without significant grower input, and that there is significant value in the interdisciplinary learning that takes place as the group seeks ways to improve and compare each of the four systems.

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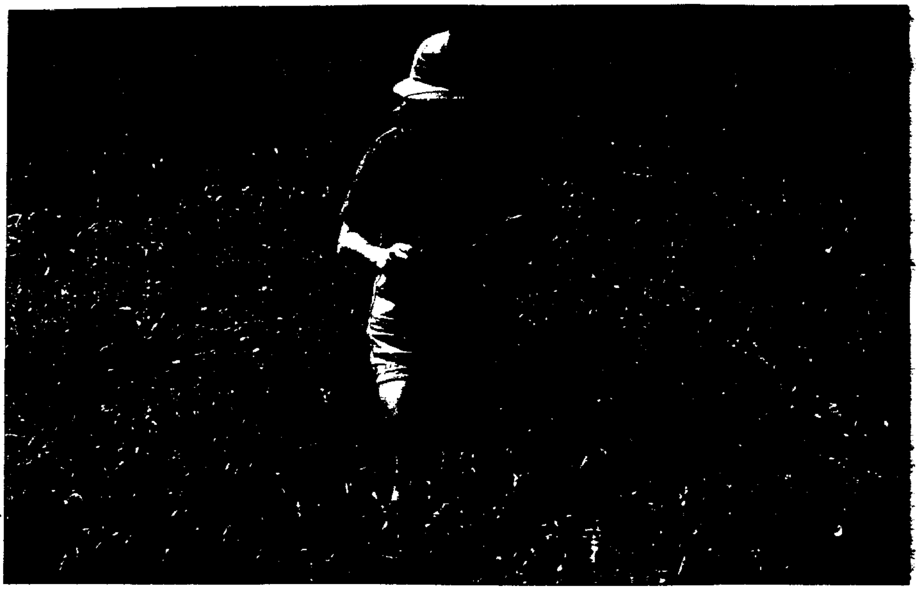

Jack Kelly Clark

Agronomist Diana Friedman takes tomato petiole samples. Plant tissue and soil samples were taken to assess the amount of nitrogen contributed by cover crops.

each farming system are given by Temple et al. (pp. 14–19). All soil samples were collected by pooling 20 to 30 cores of 2.5-centimeter diameter from each plot in all blocks of the study site. Soil for chemical analyses was collected at 0- to 30-centimeter depth in all plots in 1988 before the experiment started and again in 1992. Measurements included SO_4-S, total nitrogen, bicarbonate extractable phosphorus, ammonium acetate extractable potassium, saturated paste pH and percent organic carbon. Soil samples collected at a 0- to 15-centimeter or 0- to 30-centimeter depths were analyzed for nitrate and ammonium at different times over the growing season in 1990 to 1992. Crop tissue samples were collected from 20 plants per plot. Tomato petioles were sampled at the fourth leaf from the growing tip, during the plant growth stages of early bloom, 1-inch fruit diameter and fruit at first color. For corn, flag leaves at silking and basal corn stalks at physiological maturity were sampled and analyzed for NO_3-N. All soil and plant nutrient analyses were performed by the Division of Agriculture and Natural Resources Analytical Laboratory, UC Davis.

Microbial biomass carbon was determined in tomato plots by the chloroform fumigation-extraction method in soil samples collected from the top 15-centimeter depth. Soil samples for the annual inventory of nematodes were taken to a depth of 30 centimeters in all plots. Nematodes were extracted from a 300- to 400-cm^3 subsample of soil by elutriation and sugar centrifugation. For each sample, the total number of nematodes was counted and a subset of 200 to 300 individuals identified to genus and, where possible, species.

Soil biology shifts

Inputs and soil fertility. Baseline soil data collected in 1988 prior to establishment of the experiment showed no significant differences among plots. Table 2 summarizes baseline data for all crops and all farming systems. During the subsequent 4 years, soils in the different systems have received inorganic fertilizer (conventional 2-year, conventional 4-year and low-input), crop residues (all systems), cover crops (organic and low-input) and manure or compost (organic) (table 3). Dry matter, and hence carbon, inputs were highest in the organic and low-input systems. Fertilizer inputs in both conventional farming systems more than compensated for nitrogen removal in harvested material, assuming zero loss by denitrification and leaching. The estimates of nitrogen input to the organic and low-input systems assumed that the leguminous cover crop obtained 50% of its nitrogen from fixation of atmospheric nitrogen and the remaining 50% from soil. Based on this assumption, external nitrogen inputs in the organic system barely compensated for nitrogen removal, and in the low-input system removal exceeded external inputs over the 4 years. Thus, the assumption that 50% of the cover crop nitrogen came from nitrogen fixation may have been an underestimate and warrants further investigation.

By 1992, various soil chemical properties reflected differences in inputs, and these values are shown in table 4 for all crops combined. Values for pH and percent nitrogen were consistently higher in the organic and low-input than conventional plots. Levels of manganese were lower, whereas organic carbon, phosphorus and potassium were significantly higher in the

TABLE 2. Baseline soil data in all plots in 1988

Parameter	Value
pH	6.9
Electrical conductivity (EC)	0.77 mmhos/cm
Organic carbon	0.79 %
Phosphorus (P)	12.1 ppm
Potassium (K)	277 ppm
Calcium (Ca)	1.8 meq/L
Magnesium (Mg)	3.5 meq/L

TABLE 3. Dry matter and nitrogen inputs into soil in tomato plots by farming system, 1989–1992

		Nitrogen			
		External inputs			
System	Dry matter total input	Inorganic	Organic*	Cycled plant N†	Removed at harvest
	tons/acre	lb/acre			
Conventional 4-year	17.8	612	0	382	506
Conventional 2-year	14.6	488	0	270	440
Low-input	21.4	61	333	417	494
Organic	24.2	0	407	461	384

*External organic inputs for low-input and organic calculated as organic amendments + 0.5 ¥ cover-crop nitrogen (i.e., portion derived by nitrogen fixation).
†Soil-derived nitrogen returned to soil in form of plant residues. Calculated for low-input and organic systems as crop residue + 0.5 ¥ cover-crop nitrogen.

organic than conventional 2-year plots. Although statistically significant, some of these differences may not be important agronomically. There were no significant differences in cation exchange capacity, sulfate, electrical conductivity, calcium, magnesium and zinc. The fact that soils in the low-input plots showed an increase in percent nitrogen relative to conventional plots suggests, as discussed above, that there was greater nitrogen fixation by the cover crops than estimated in the nitrogen budget presented in table 3. The low-input and organic systems derive 85% of their nitrogen from cover crops, rather than approximately 50%, as estimated, illustrating that the nitrogen budget is particularly sensitive to assumptions about nitrogen contributions from cover crops.

Nitrogen availability, perhaps combined with early season weed pressure (see pp. 14-19 and 27-33), may be an important factor in determining tomato yields during the transition to organic production. Prior to 1992, tomato plants in the organic system typically appeared stunted and yellow early in the season, did not compete well with weeds (see pp. 27-33) and had yields lower than tomatoes grown in the conventional system (table 5). Soil nitrate levels in the organic tomatoes in 1990 and 1991, however, were higher than or equivalent to levels in the conventional system on the dates measured (table 6). In 1992, when organic and conventional yields were comparable, nitrate levels in organic plots were also higher than or equivalent to levels in the conventional plots.

Tomato petiole nitrate analysis indicated that nitrogen was deficient in all systems in 1991, whereas it was deficient in only the organic system in 1990 and 1992. Since yields were comparatively high in the conventional 4-year system in 1991, it is unlikely that plants were truly nitrogen-deficient and suggests either that the petiole test is unreliable or that samples were actually taken later than early bloom that year. Furthermore, organic plants had the lowest petiole nitrate in all years, even in 1992, when yields were comparable among all systems (table 5). To test critically the reliability of petiole nitrate as an indicator of nitrogen sufficiency in tomatoes, we are currently growing plants in both organic and conventionally managed soils that have received different levels of nitrogen inputs.

For corn, the percent nitrogen at silking agreed reasonably well with yields in 1990 and 1991 (table 5). Lower yields in organic and low-input systems in 1991 were probably due to the decision to use a reduced tillage

TABLE 4. Differences in soil properties among farming systems across all crops in 1992

Parameter	Organic	Low-input	Conventional 4-year	Conventional 2-year
pH	7.3 a*	7.2 a	7.1 b	7.1 b
Total nitrogen (%)	0.089 a	0.090 a	0.083 b	0.083 b
Manganese (ppm)	23.6 a	24.3 ab	24.8 ab	27.0 a
Potassium (ppm)	323 a	311 a	299 ab	279 b
Phosphorus (ppm)	19.3 a	17.2 a	14.3 b	15.1 b
Organic matter (%)	1.60 a	1.62 a	1.48 ab	1.39 b

*Indicates Duncan grouping. Means with the same letter are not significantly different among systems at the P = 0.05 level.

Table 5. Crop nitrogen tissue test levels, mid– to late season soil nitrate pools and yields of tomato and corn for 1990–1992 in different farming systems

System	Tissue test level 1990	Tissue test level 1991	Tissue test level 1992	Crop yield 1990	Crop yield 1991	Crop yield 1992
Tomato	.... *NO_3 petiole (ppm) early bloom*			.... *tons/acre*		
Organic	7,420 b*	1,530 b	6,560 b	30.7 c	28.2 c	42.7
Low-input	12,490 a	1,800 b	12,230 a	36.3 b	34.9 b	42.9
Conventional 4-year	12,730 a	4,280 a	15,480 a	36.8 ab	45.6 a	47.1
Conventional 2-year	13,190 a	4,800 a	15,150 a	40.0 a	37.4 b	41.3 ns†
Corn	... *% nitrogen ear leaf at silking*					
Organic	2.97	2.4	2.4 b	5.2	4.1 b	4.9 b
Low-input	2.87	2.4	2.8 a	5.0	4.1 b	5.9 a
Conventional 4-year	2.99	3.0	2.8 a	4.9	5.1 a	4.8 b
	ns	ns		ns		

*Indicates Duncan grouping. Means with same letter are not significantly different among systems at P = 0.05 level.
†ns indicates that means are not significantly different.

TABLE 6. Nitrate concentrations in soil in corn and tomato plots during 1990–1992

Date	Concentration (ppm) Organic	Low-input	Conventional 4-year	
Tomato				
1990 (0–30 cm)				
3/25	2.7 a*	6.2 ab	8.2 b	—
6/24	12.9	19.7	12.4	ns†
8/6	5.9	7.8	4.0	ns
1991 (0–30 cm)				
8/28	21.2	21.4	19.0	ns
1992 (0–15 cm)				
3/31	6.1	9.2	6.3	ns
4/16	5.6 a	4.9 a	3.3 b	—
7/2	27.9 a	23.1 ab	17.7 b	—
9/12	23.4	24.1	17.9	ns
Corn				
1990 (0–30 cm)				
3/25	3.4 a	6.2 ab	9.6 b	—
5/6	34.3 a	38.2 a	14.3 b	—
6/24	23.2	30.0	19.6	ns
8/6	20.2	17.5	25.8	ns
1991 (0–30 cm)				
8/28	10.6 b	10.8 b	23.3 a	—
1992 (0–30 cm)				
4/17	29.7 a	23.7 b	17.3 c	—
5/27	34.3 a	32.2 a	10.0 b	—
10/27	20.5	22.6	22.7	ns

*Indicates Duncan grouping. Means with the same letter are not significantly different among systems at the P = 0.05 level.
†ns indicates that means are not significantly different.