Crop-yield and economic comparisons of organic, low-input, and conventional farming systems in California's Sacramento Valley

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Abstract. *We compared the crop yields and economic performance of organic, low-input, and conventional farming systems over an eight-year period based on research from the Sustainable Agriculture Farming Systems (SAFS) Project in California's Sacramento Valley. The SAFS Project consisted of four farming-system treatments that differed in material input use and crop rotation sequence. The treatments included four-year rotations under conventional (conv-4), low-input, and organic management, and a conventionally-managed, two-year rotation (conv-2). The four-year rotations included processing tomato, safflower, corn, and bean and a winter grain and/or legume double-cropped with bean. The conv-2 treatment was a tomato and wheat rotation. In the low-input and organic systems, inorganic fertilizer and synthetic pesticide inputs were reduced or eliminated largely through crop rotation, legume cover crops, composted manure applications, and mechanical cultivation.*

All crops, except safflower, demonstrated significant yield differences across farming systems in at least some years of the experiment. Yields of tomato and corn, the most nitrogen (N)-demanding crops in the rotations, responded most years to the farming-system years treatments, while bean and the winter grain/legume displayed treatment differences less often and instead tended to vary more with yearly growing conditions. Nitrogen availability and/or weed competition appeared to account for lower crop yields in the organic and low-input systems in some years. The economics of all farming systems depended mainly on the costs and profits associated with tomato production. The most profitable system was the conv-2 system due to the greater frequency of tomato in that system. Among the four-year rotations, the organic system was the most profitable. However, this system's dependence on price premiums leads to some concern over its long-term economic viability. Among the low-input cropping systems, corn demonstrated clear agronomic and economic advantages over conventional production methods. Based upon these findings, we suggest that future research on organic and low-input farming systems focus on developing cost-effective fertility and weed management options based upon improved understanding of N dynamics and weed ecology.

Key words: sustainable agriculture, alternative agriculture, economic analysis

Introduction

A fundamental goal of alternative agriculture, including organic and low-input farming systems, is to reduce non-renewable resource use and environmental degradation while maintaining productivity and profitability. Although there is great interest in pursuing this goal, there is uncertainty and risk in adopting unconventional production practices. Recent studies from Maryland (Abdul-Baki et al., 1996), Kansas (Diebel et al., 1993), South Dakota (Smolik et al., 1993; 1995), California (Drinkwater et al., 1995), and North Carolina (King and Hoag, 1998) have shown that alternative systems can perform as well as conventional systems agronomically and/or economically throughout the United States. However, other studies have demonstrated that reliance solely on organic methods, particularly for vegetables and fruits, can lead to substantial reductions in yield and profit (Pimentel, 1993; Sellen et al., 1995; Nelson and King, 1996).

Although long-term, comprehensive records are not available, recently reported statistics indicate substantial growth in the organic farming industry in California. According to 1992-1993 records, there were 1,159 organic growers farming 18,418 ha, with gross sales exceeding $75 million. Industry experts, however, estimate that the number of growers increased by 25% per year between 1992 and 1995

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(Klonsky and Tourte, 1995). Moreover, gross sales of organic foods nationwide more than doubled during that same period (Mergentime and Emerich, 1996; Scott, 1997). By contrast, the total number of farms in California declined slightly while net farm income remained relatively steady during this period (California Department of Food and Agriculture, 1997).

The degree to which California farmers are adopting low-input production methods is difficult to assess. Although there is clear evidence that increasing numbers of growers are using or are planning to use low-input practices in fertility and pest management (Grieshop and Raj, 1992), statewide material input expenses are increasing at a much greater rate than is total gross farm income. Total manufactured input expenses of fertilizers, lime, and pesticides increased by 19, 35, and 22%, respectively, from 1992 to 1995 (California Department of Food and Agriculture, 1997). Moreover, state records indicate that total pesticide use in California continues to increase (California Department of Pesticide Regulation, 1996). Thus, while there are numerous examples of farmers experimenting with or adopting more environmentally-sound practices in California (Auburn, 1994), reduced dependence on purchased inputs is not widely apparent at the state level.

In this paper we report results from the Sustainable Agriculture Farming Systems (SAFS) Project at the University of California at Davis, which is experimentally evaluating the transition from conventional to low-input and organic farming practices in California's Sacramento Valley (see Temple et al. [1994] for a detailed description of the SAFS Project). The major crops of the region, based on area planted, are rice (*Oryza sativa*), wheat (*Triticum aestivum*), processing tomato (*Lycopersicon esculentum*), corn (*Zea mays*), and safflower (*Carthamus tinctorius*) (California Department of Food and Agriculture, 1997). The Sacramento Valley accounts for nearly a quarter of California's organic hectarage (Klonsky and Tourte, 1995). Most of this land is in vegetable, fruit, and/or nut production, while field crops account for about 18% of the planted area. Here we compare the agronomic and economic performance of conventional, low-input, and organic farming systems over the first eight years of the project.

Materials and Methods

Farming-system descriptions

The Sustainable Agriculture Farming Systems (SAFS) Project was established on an 11.3-ha site in 1988 to study agronomic, economic, and biological aspects of conventional and alternative farming systems in California's Sacramento Valley (Fig. 1). The Sacramento Valley has a Mediterranean climate, with most rainfall occurring during the winter months and relatively little during the growing season. Thus, irrigation is needed for most crop production.

The SAFS Project consists of four farming-system treatments that differ primarily in crop rotation and use of external inputs (Fig. 2). These include four-year rotations under conventional (conv-4), low-input, and organic management, and a conventionally-managed, two-year rotation (conv-2). All of the four-year rotations include processing tomato, safflower, bean (*Phaseolus vulgaris*), and corn. The conv-2 treatment is a tomato and wheat rotation. During this study beans were double-cropped with winter wheat in the conv-4 system, while in the low-input and organic treatments, beans followed a winter grain/legume crop which was either harvested for seed, cut as hay or green chop, or incorporated as green manure. In 1989 and 1990 this crop was lupine (*Lupinus alba*); however, a biculture of oats (*Avena sativa*) and woolypod vetch (*Vicia dasycarpa*) was grown from 1991 to 1996. Vetch (*Vicia* spp.) cover crops were grown during the winter preceding all other cash crops in the low-input and organic systems. There were four replications of each treatment and all possible crop rotation entry points were represented. Thus, there was a total of 56 plots, each measuring 0.12 ha, arranged in a randomized block design.

All farming systems used "best-farmer management practices" determined through discussion among researchers and staff, consultation with growers cooperating on the project, and market conditions. The conv-4 and conv-2 treatments were managed with practices typical of the surrounding area, which included the use of synthetic fertilizers and pesticides. Thus, the conventional tomato, corn, and wheat crops received approximately 175, 225, and 180 kg/ha of N, respectively, as urea or ammonium nitrate. Safflower and bean crops generally did not receive fertilizer. The organic tomato and corn crops received 5-7 t/ha of composted poultry manure several weeks prior to planting, which generally supplied 150-200 kg/ha of N. Organic bean, safflower, and oats/

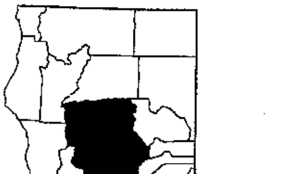

Figure 1. The Sacramento Valley region of California (dark area) comprised of Butte, Colusa, Glenn, Sacramento, Solano, Sutter, Tehama, Yolo, and Yuba Counties.

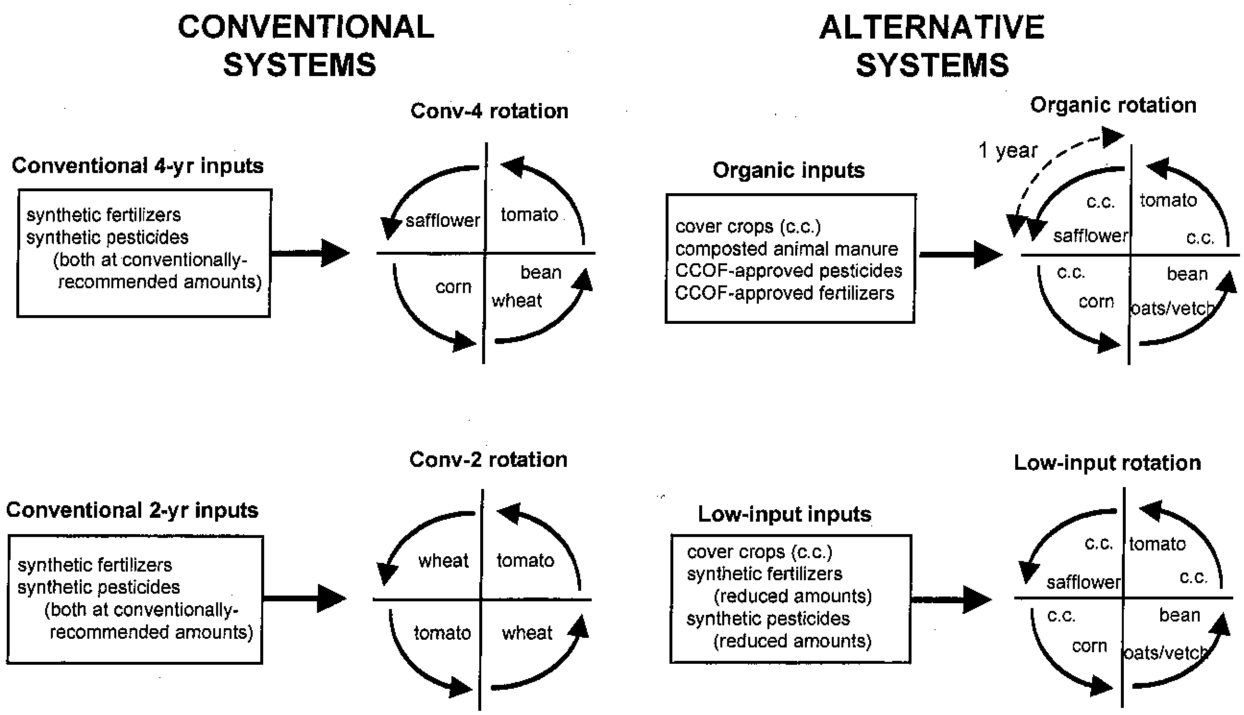

Figure 2. Graphical description of the four farming system treatments comprising the Sustainable Agriculture Farming Systems (SAFS) Project based upon differences in inputs and rotations.

vetch crops did not receive composted manure applications.

Decisions to use pesticides in these treatments were based upon common practices in the area as well as University of California integrated pest management (IPM) guidelines. In the low-input system, fertilizer and pesticide inputs were reduced primarily by using legume cover crops to improve soil fertility, and mechanical cultivation and cover cropping for weed management. The organic treatment was managed according to the regulations of California Certified Organic Farmers (CCOF). Therefore, no synthetic chemical pesticides or fertilizers were used. Instead, management included the use of cover crops, composted animal manure, mechanical cultivation, and minimal use of CCOF-approved products (CCOF, 1995).

Summer cash crops in all systems were furrow-irrigated in a similar manner, though differences in the timing of soil preparation, cultivation, and harvest activities caused some variation in irrigation scheduling. Tomatoes in all systems were typically sprinkler-irrigated immediately after planting or transplanting, and furrow-irrigated throughout the remainder of the growing season. Winter cover crops in the organic and low-input systems and wheat in the conventional systems were usually irrigated after planting in the fall to achieve establishment, but winter precipitation provided most of the water used by these crops.

Crop-yield and economic measurements

Yields of all cash crops from 1989-1996 were determined each year using commercial-scale machinery and small-scale hand harvests. In general, statistical comparisons were made using data from machine harvests, which consisted of the yield from the center one-third of each plot. Hand-harvest data were usually used to verify machine-harvest data, but occasionally used for statistical treatment comparisons when problems were noted in the machine harvest due to equipment failures. Statistical comparisons for tomato, corn, safflower, and bean yields were made using Analysis of Variance (ANOVA) followed by the Student-Newman-Keuls (SNK) test for mean separation when significant differences were found ($P \leq 0.05$). Yield comparisons of wheat and oats/vetch crops, which were represented in only two of the four farming system treatments, were made with t-tests. An important aspect of yield is temporal variability, which is of particular interest in comparing alternative to conventional systems because of the potential implications for farm income when adopting non-conventional practices. Yield variability was assessed by calculating the coefficient of variation (CV) for each cropping system for the first four years (1989-1992), second four years (1993-1996), and the entire eight-year period (1989-1996). Again, statistical comparisons of CV across treatments were made with ANOVA and SNK tests, or t-tests. Published and unpublished studies conducted at the SAFS site on individual crops (corn and tomato) and specific disciplines (soil fertility, plant nutrition, pest management, etc.) were used in the interpretation of crop-yield data.

The economic performance of each cropping system and farming system was quantified using the Budget Planner computer program (Klonsky and Cary, 1990; Klonsky and Livingston, 1994). This program generates costs, returns, and profits and simulates the economic performance of a hypothetical 810-ha farm. The actual costs of material inputs and labor were based upon current prices within the region. American Society of Agricultural Engineers (ASAE) formulas were used to calculate equipment costs for fuel, lubrication, and repair. The economics of field operations were derived from costs for labor, materials, and equipment; and field operation time was based on the use of commercial-sized equipment. This approach produced budgets representative of real-farm conditions rather than budgets based on the disproportionately large amount of time needed to manage small, experimental plots. All crop yields were based upon experimental treatment means. The land area of each hypothetical farming system was divided equally among all crops in the rotation. For example, cropland in the conv-2 farming system was split between tomato and wheat each year.

Total costs and profits were compared graphically among treatments with descriptive statistics. Total costs included operating costs (all production practices including planting, pest management, harvesting, etc.), cash overhead (land rental, property taxes, and other business expenses), and non-cash costs (depreciation and opportunity costs for equipment, irrigation systems, tools, and buildings). Gross returns were generated from the average plot yields multiplied by the commodity farm-gate price. The farm-gate prices were obtained from local and regional buyers at the time of harvest. Gross returns for the organic system were calculated two ways, with conventional prices and premium prices for organic commodities, to examine the economic viability of both markets. Net returns (profits or loss) were calculated by subtracting total costs from gross returns.

Results

Crop yields

All crops, except safflower, demonstrated significant yield differences across farming-system treatments in at least some years of the experiment. Yields of tomato and corn, the most nitrogen (N)-demanding crops in the rotations, responded differentially to the treatments during most years, while bean, wheat, and oats/vetch crops displayed treatment differences less often and instead tended to vary more with yearly growing conditions than with farming-system effects (Fig. 3).

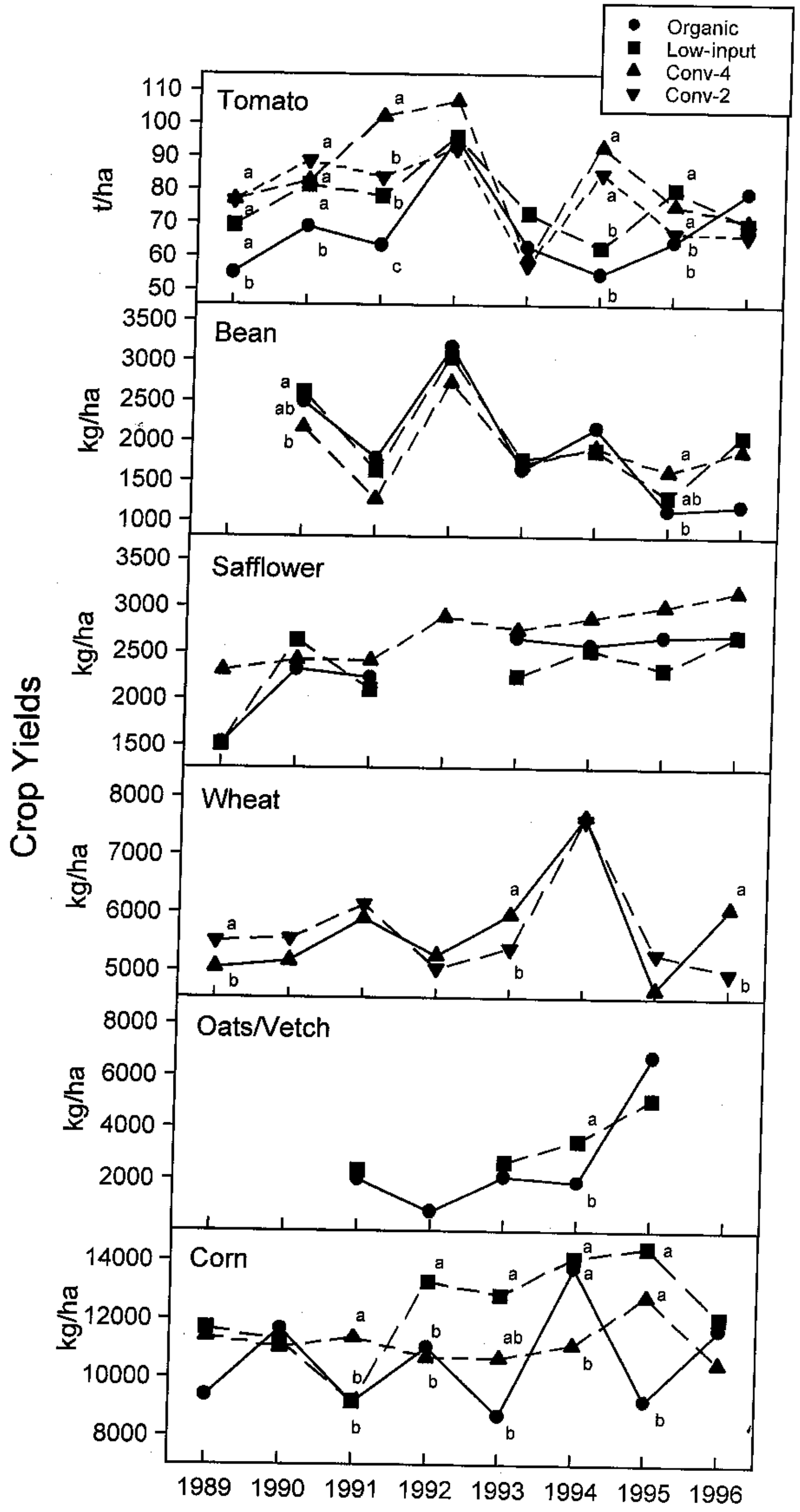

Figure 3. Yields (kg/ha or t/ha) of the SAFS Project cropping systems, 1989-1996. Different letters indicate significant differences between farming system treatments (ANOVA, SNK, P<0.05).

Table 1. Mean coefficient of variation (%) for crop yield (a measure of yield variability) in the four SAFS Project farming systems for three periods: 1989-1992, 1993-1996, and 1989-1996.

Crop	Organic	Low-Input	Conv-4	Conv-2
		1989-1992		
Tomato	26	15	16	12
Bean	29	30	36	—[1]
Safflower	8	10	13	—
Corn	21a[2]	16ab	8b	—
Wheat	—	—	17	13
Oats/Vetch	NA[3]	NA	—	—
		1993-1996		
Tomato	38	36	42	44
Bean	40	21	12	—
Safflower	21	21	16	—
Corn	22a	11b	12b	—
Wheat	—	—	21	21
Oats/Vetch	61a	31b	—	—
		1989-1996		
Tomato	19	21	17	19
Bean	30	26	39	—
Safflower	26	30	9	—
Corn	21a	15ab	10b	—
Wheat	—	—	20	17
Oats/Vetch	62a	39b	—	—

[1] Indicates that crop is not part of the farming system.

[2] Means with different letters indicate significant differences (Analysis of variance, Student-Newman-Keuls test, P ≤0.05).

[3] Crop not grown or harvested for seed.

Tomato yields in the conv-4 system tended to be the highest among the four farming systems, averaging 83 t/ha, while those of the organic system tended to be the lowest. Organic tomato yields were significantly lower in five of eight years, three in the first rotation and two in the second, and averaged 16.5% less than those of the conv-4 system over the eight-year period. In contrast, low-input tomato yields were significantly lower than conv-4 yields in only two of the eight years and averaged 6.3% less over the entire period (Fig. 3). Similarly, yields in the conv-2 system averaged 6.7% less, but were significantly lower in only one year. No statistically significant difference in yield variability among treatments was observed (Table 1).

The two most important factors in explaining tomato yield variability over the eight years of the SAFS study were differences in N source and availability among treatments and the switch from direct seeding (1989-1991) to transplanting (1992-1996) in the organic and low-input systems. The conventional and low-input systems received about 175 and 100 kg/ha of N annually as inorganic fertilizer, respectively. About 10% of this was applied at planting while the rest was side-dressed. Nitrogen derived from the previous cover crop was intended to substitute for inorganic fertilizer in the low-input system. By contrast, the organic system received less than 2 kg/ha of N as organic fertilizer (fish meal and kelp) which was applied at planting or as a foliar spray. A combination of cover crops and composted manure was intended to provide most of the required N to the crop in this system. During the first two years of the project, tomato plants in the organic system appeared to suffer from N deficiency, and to a lesser extent, weed competition (Scow et al., 1994). The decision to use transplanting was made in consultation with cooperating farmers to take advantage of the N-generating and weed-suppressing effects of the cover crops. By using transplants, legume cover crops could be allowed to grow longer in spring, leading to greater N-fixation and better weed suppression prior to planting. Moreover, the transplants had an advantage over early-season weeds.

In the first year of using transplants (1992, the last year of the first rotation), yields in the organic and low-input systems improved markedly (Fig. 3). Yields declined, however, in 1993 in all systems as a result of poor growing conditions throughout the region, but were still statistically similar across treatments. In 1994 a viral infection in the transplants, originating in the greenhouse, resulted in poor vegetative growth and reduced yields in the low-input and organic systems. Low-input tomato yields improved in 1995 and were similar to those of the conv-4 system; however, intensive plant and soil analyses conducted throughout the growing season indicated that the organic system was N deficient despite estimated inputs of 80 kg/ha of N from the previous cover crop and 125 kg/ha of N from composted poultry manure. Slow N mineralization rates and N immobilization by soil microflora appeared to account for the problem (Cavero et al., 1997; Clark et al., 1999). In an effort to compensate for N unavailability the manure application rate in the organic system was increased dramatically in 1996. In addition to 115 kg/ ha of N from the preceding cover crop, approximately 22.4 t/ha of composted poultry manure was applied, supplying an additional 308 kg/ha of N. Tomato plants in the organic system still showed some signs of early-season N deficiency according to conventional indicators (petiole nitrate at "first bloom," "one-inch fruit," and "first color"), but nevertheless reached their second highest yields of the eight-year period. Tomato yields in 1996 were statistically similar across the four treatments (Fig. 3).

Corn showed significant treatment effects in five of the eight years of the study, but yield patterns differed from those of tomato in that the low-input system, averaging over 12,300 kg/ha of grain, had the highest average yield among the four-year-rotation farming systems (Fig. 3). Low-input corn yields averaged 10.6% higher than conv-4 yields over the entire eight years and 18.6% higher over the second four-year rotation. Organic corn yields, by contrast, averaged 5.0% lower than the conv-4 yields over the eight years.

Significant differences in corn yield variability were also found (Table 1). During the first four-year rotation, yields in the organic system were significantly more variable than those of the conv-4 system. During the second four-year rotation, yield variability in the low-input system declined somewhat while that in the conv-4 system increased slightly. Consequently, there was again no significant difference in yield variability between these two systems, but yield variability for the organic system remained relatively high and was significantly greater than the other systems. Comparison of corn yield variability over the entire eight years showed all three systems differing statistically from each other, with the conv-4 system having the lowest variability and the organic system, the highest.

Differences in corn yields across the farming system treatments appeared to be linked in part to N availability. The most striking, and perhaps most important, observation over the eight-year period was the dramatic increase of low-input corn yields beginning in 1992 (Fig. 3). Prior to 1992, composted animal manure had been used to supplement cover crop-derived N in both the organic and low-input systems. In 1992 the manure was replaced in the low-input system with side-dressed, supplemental inorganic N fertilizer, used at about one-half the rate of the conv-4 system. Thus, while the conv-4 corn system received 180-230 kg/ha of N annually as inorganic fertilizer, the low-input system received 80-140 kg/ha. Detailed tissue and soil analyses conducted from 1993 to 1995 indicated that N deficiency was a problem in the organic system due to the unpredictability of N mineralization and immobilization (Friedman et al., 1999). This deficiency was overcome in the low-input system by the addition of the inorganic N fertilizer.

Weed competition also was identified as an important factor contributing to corn yield differences among the treatments. Although weed pressure was relatively similar and stable in the low-input and conv-4 systems, it was more variable and difficult to manage in the organic system. Attempts were made to incorporate the cover crop and plant the corn while there was still adequate soil moisture remaining from the winter rains. In some years, however, irrigation was necessary to establish a strong corn stand and this sometimes resulted in a strong weed stand as well. Weeds were especially problematic in the organic system in 1993 and 1995 (Lanini et al., 1994; Clark et al., 1998a), years that resulted in relatively low corn yields in that system (Fig. 3). Herbicide use was the primary means of weed management in the conv-4 system, while the organic system depended exclusively upon mechanical cultivation. The low-input system relied on a combination of both tactics and used 60% less herbicide (based upon the amount of active ingredient applied) than the conv-4 system and still achieved equally effective weed control.

The differences in corn yields between the conv-4 and low-input systems did not appear to be linked to N availability. Friedman et al. (1997, 1999) concluded that the use of cover crops in the low-input system provided benefits beyond the N contribution. They suggested that water availability to the low-input corn crop may have been superior to that of the conv-4 system because of reduced soil compaction and greater water infiltration resulting from the cover crop.

Bean yields were relatively similar across farming systems throughout the study (Fig. 3). Yields in the conv-4 system averaged 1,905 kg/ha, while those of the organic and low-input systems were slightly higher, averaging 1,941 and 2,047 kg/ha, respectively. Significant treatment effects were found in only two of the seven years, 1990 and 1995, in which beans were grown (Fig. 3). In both of those years differences in bean varieties and lengths of growing seasons may also have been responsible for yield differences. Bean varieties were chosen each year based upon the length of the growing season following the harvest of the winter grain/legume crop and, in the organic system, the premium price offering. In 1990, "Yolano" beans were grown in the organic and low-input systems, while "Sutter" beans were grown in the conv-4 system. Similarly, in 1995 "Red Kidney" beans were grown in the organic and low-input systems, while "Midnight Black" beans were grown in the conv-4 system. In all other years the three systems had the same bean variety, either "Midnight Black" or "Yolano." Heavy weed pressure in the organic system in 1995 and 1996 appeared to contribute to lower yields in that system as well No significant differences in bean yield variation were found (Table 1).

Safflower yields showed a slight, ye steady, increase over the course of the study in all three systems. Although significant treatment effects were not detected the conv-4 system generally had the highest yields (Fig. 3). Over the eight years of the study, crop yields in all systems ranged from about 1,500 to 3,000 kg/ha. No significant difference in yield variation was detected among systems; however, the conv-4 system had the lowest variability over the eight years (Table 1). In 1992, the safflower crop in the organic and low-input systems was tilled in because of a combination of heavy weed pressure and a poor crop stand. In order to minimize economic losses in these farming systems, beans were planted as a substitute.

Wheat yields in the conv-4 and conv-2 systems showed significant differences in three of the eight years of the study (Fig. 3). However, average yields over the entire period were nearly identical. The conv-4 system averaged 5,723 kg/ha, while the conv-2 system averaged 5,688 kg/ha, a 0.6% difference. In addition, no difference in yield was found between the systems. One noteworthy point is the relatively high wheat yields in both systems in 1994. This was a particularly favorable year for wheat production throughout the Sacramento Valley region.

Due to the use of different best-farmer management alternatives in the organic and low-input systems, including incorporation, green chop, and cutting for hay, seed yields in the oats/vetch crop could be directly compared in only four of the eight years of the study. Average yields in the low-input and organic systems in those four years were 3,389 kg/ha and 3,179 kg/ha, respectively, a 6.6% difference. A significant yield difference was found in one of the four years compared (Fig. 3). Yield variability in the organic system was quite high (Table 1), due primarily to the dramatic yield increase between 1994 and 1995 (Fig. 3). Excessively wet conditions in 1995 provided a favorable environment for oat growth, leading to yields that were more than double those of any previous year.

Economics

The economics of each farming system depended primarily upon the costs and returns associated with tomato production. The total costs of tomato production ranged from about $2,000/ha to over $4,500/ha, while the total costs of other crops in the rotations ranged from less than $200 to just under $2,000/ha (Fig. 4). Moreover, tomato costs clearly showed the most substantial differences between farming systems. Total tomato production costs in the organic and low-input systems were substantially greater than those of the conv-4 and conv-2 systems throughout the study. All other crops incurred relatively similar costs across farming-system treatments. Several notable exceptions include the organic and low-input safflower crops in 1992, which were tilled in due to a poor stand and heavy weed competition and replaced by beans, and the organic corn crop in 1996, which had to be replanted due to a poor stand, apparently caused by seedling pests including seedcorn maggot (*Delia platura*) and wireworms (Elateridae). Differences in the costs of winter grain/legume crops among treatments were due to differences in crop species (wheat versus oats/vetch or lupine) rather than to farming-system effects.

Several factors contributed to the relatively high costs of tomato production in the organic and low-input systems compared to the conv-4 and conv-2 systems. Clearly, the most important factor was the use of transplants rather than direct seeding. A comparison of operating costs among the four tomato cropping systems from 1993 to 1996 showed that planting costs in the organic and low-input systems were nearly three times greater than those of the conv-4 and conv-2 systems (Table 2). Others factors contributing to higher costs in the organic and low-input systems were cover crop and weed management practices. It should be noted that cover crop economics were evaluated only on N contribution (substitution for fertilizer) and weed suppression (substitution for herbicide, cultivation, and/or hoeing). Long-term benefits, including increased soil organic matter and nutrient storage, which have been documented at the SAFS site (Clark et al., 1998b), as well as reduced likelihood of erosion, were not in-

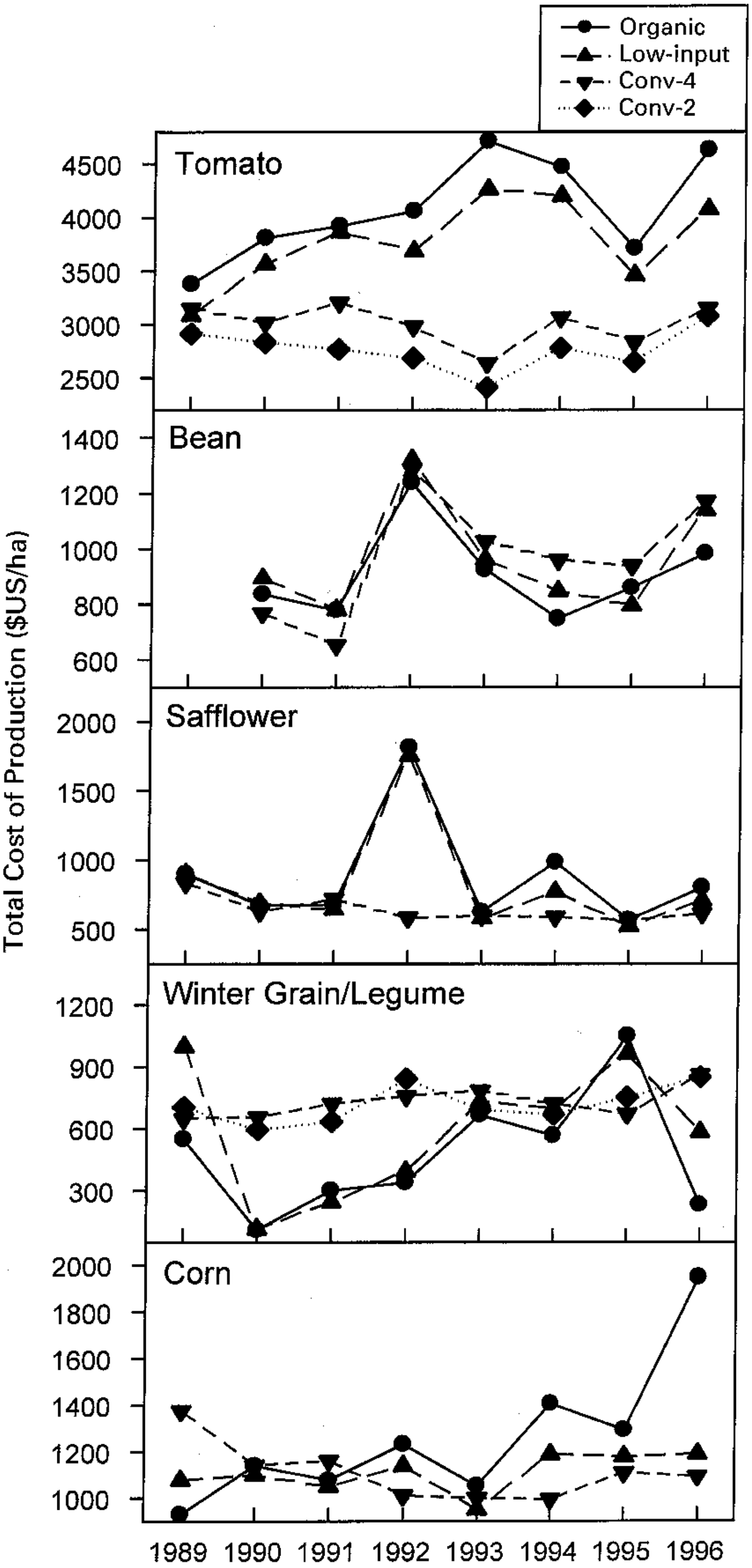

Figure 4. Total production costs ($US/ha) associated with each crop of the four SAFS farming-system treatments, 1989-1996.

Table 2. Average operating costs, total costs, gross returns, and profits ($US/ha) for tomato management practices in the four farming systems of the SAFS Project, 1993-1996.

Managment practice	Organic[1]	Low-Input	Conv-4	Conv-2
Ground preparation	94	94	111	119
Planting	1005	1005	358	366
Fertility management	343	106	106	106
Cover crop management	156	156	0	0
Weed management	571	571	412	427
Insect pest management	0	0	12	12
Disease management	0	0	0	0
Irrigation	188	168	109	109
Harvest	613	613	610	605
Residue management	12	5	5	12
Interest	100	86	52	52
Total operating costs	3082	2804	1808	1775
Total costs	4331	4001	2924	2732
Gross returns	5267	4078	4159	3842
Profits	936	77	1235	1110

[1] Calcuated for the organic system receiving premium prices.

cluded in the accounting. There was greater dependence upon hand hoeing, a relatively expensive weed management practice typically used in processing tomatoes, in the organic and low-input systems compared to the conventional systems. One additional practice that contributed to higher costs in the organic system was the use of purchased composted manure. Consequently, fertility management costs in the organic system were about 60% higher than those of the other farming systems (Table 2).

Tomato also showed the greatest range in net returns (profits and losses) among the cropping systems (Fig. 5) and contributed the most to profits in all farming systems, except for the organic system without price premiums. Tomato crops in the conv-4, conv-2, and organic (with premiums) systems were profitable in all years of the study, with average net returns of $1,725/ha, $1,625/ha, and $2,119/ha, respectively. Low-input tomato crops were profitable in six of the eight years, but averaged only $605/ha. Without price premiums, the organic system would have been profitable in only four of the eight years and averaged a loss of $69/ha because of the high costs of production.

Following the tomato crop, bean and corn crops were generally the next most profitable components of the four-year rotations. Bean crops were profitable in the three farming systems in all years, except in the organic system without premiums, in which net returns were positive in five of the seven years. Beans were most profitable in the organic system with premium prices, averaging $645/ha (Fig. 5). By contrast, average net returns for the conv-4, low-input, and organic (without premiums) systems were $122/ha, $254/ha, and $200/ha, respectively. Clearly, high premium prices for organic beans contributed significantly to profits in the organic system. The relatively low profitability of beans in the conv-4 system was due to higher operating costs (Fig. 4), primarily in fertility and pest management.

Corn was most profitable for the low-input system due to relatively moderate costs and high yields. Net returns in this system averaged $380/ha. Average annual profits for corn in the organic (with premiums) and conv-4 systems were $276/ha and $249/ha, respectively. Corn in the organic system without premiums averaged a loss of $27/ha.

Safflower and the winter grain/legume were generally the least profitable crops in the rotations. Safflower was profitable in the conv-4 and organic (with premiums) systems in six of eight years and averaged net returns of $220/ha and $118/ha, respectively. However, due to crop losses in 1992, safflower crops in the low-input and organic (without premiums) systems averaged losses of $24/ha and $50/ha, respectively, despite being profitable in five of the eight years.

Winter grain/legume crops in the conv 4 and conv-2 systems (wheat) were profitable in four and five years of the study respectively, and averaged profits of $53 60/ha. Similarly, the winter grain/legume crop in the low-input system (lupine o oats/vetch) was also profitable in five o eight years and averaged $249/ha. By contrast, it produced positive net returns in the organic systems in only two of eight years and averaged losses of $113/ha and $157/ha for the system with and without premiums, respectively. It should be noted, however, that this multipurpose crop was harvested as a cash crop in only six of eight years in the low-input system and only five years in the organic system.

Due to the critical importance of tomato in all of the farming systems, the general patterns in whole-farm costs were similar to those observed in tomato; costs were higher in the organic and low-input systems compared to the conv-4 and conv-2 systems (Fig. 6). The dramatic increase in whole-farm costs in the organic and low-input systems in 1992 was largely due to the shift from direct seeding to transplanting tomatoes and the complete loss of the safflower crops and subsequent replanting to beans in those treatments. The conv-2 system was more costly than the conv-4 system throughout the study because half of its cropland was planted to tomato each year.

The most profitable farming system over the eight years was the conv-2 system due to the greater frequency of tomato in that rotation. This system averaged $840/ha over the eight years. Among the four-year rotations, the organic system with price premiums was most profitable, averaging $740/ha, while the organic system without price premiums was unprofitable, averaging losses of $31/ha. The conv-4 was the second most profitable four-year rotation, averaging $589/ha, while net returns in the low-input systems were $358/ha.

Discussion

Research on dynamic agricultural systems typically creates some difficulties in clearly identifying the causes of observed patterns. However, systems research also provides opportunities, unavailable in more reductionist or single-discipline

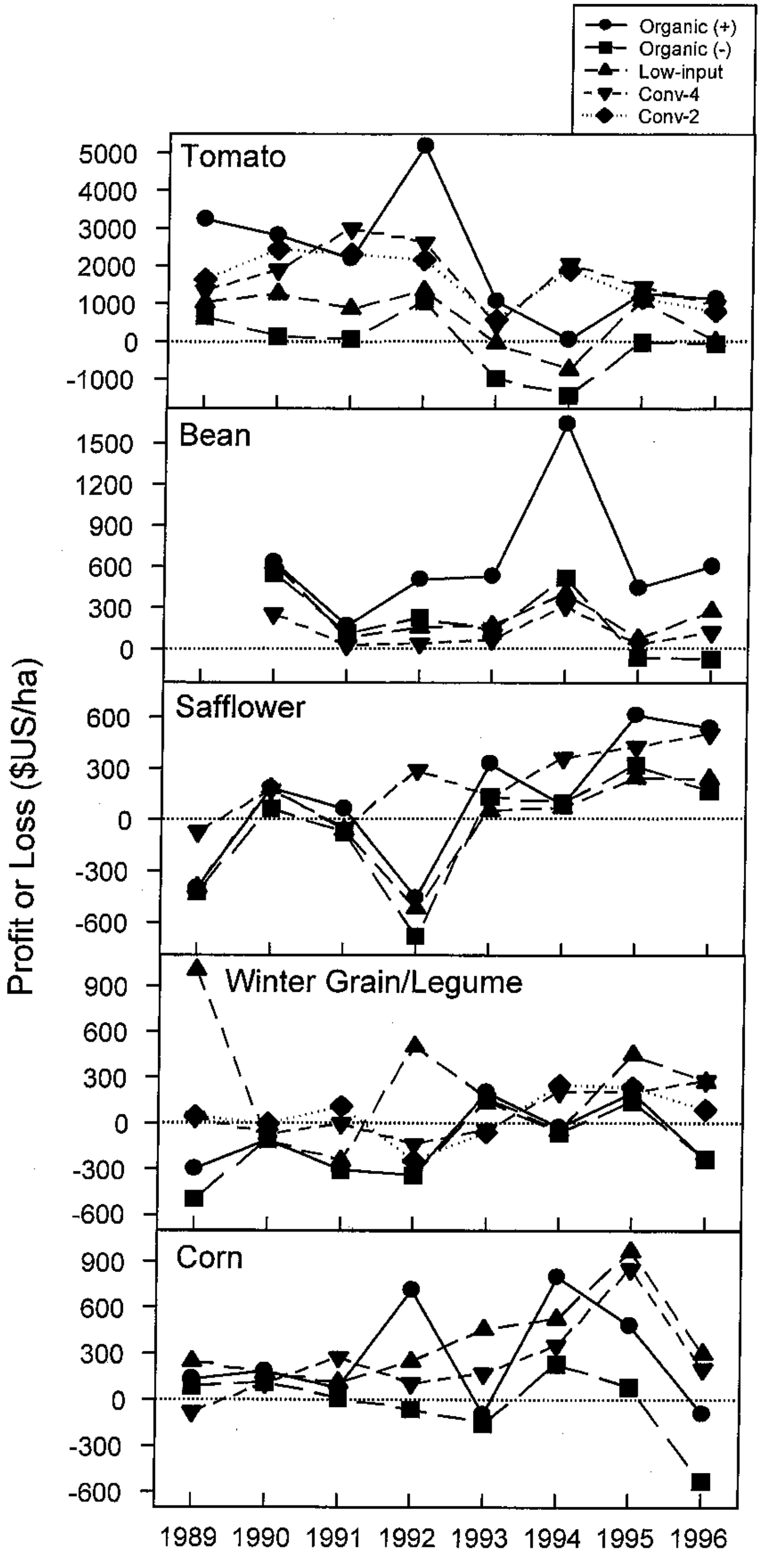

Figure 5. Profits or losses ($US/ha) associated with each crop of the four SAFS farming-system treatments, 1989-1996. Numbers for the organic system are presented with (+) and without (–) premium prices.

studies, to observe the interactions of multiple factors in agroecosystems. Through a combination of long-term, descriptive and analytical data collection on crop yields and management practices, and more in-depth, disciplinary studies at the SAFS site, major factors affecting the crop yields of these farming systems were identified. In addition, the economic viability of management practices, cropping systems, and farming systems was assessed.

The findings of this study provide a number of insights into future possibilities for the adoption of low-input and organic cropping and/or farming systems in California's Sacramento Valley. Although many factors, both within and beyond the farm, may influence adoption, two key questions are critically important: 1) What are the effects on crop yields? and 2) What are the effects on farm income? Addressing these questions, especially the latter, in small-plot experiments has limitations because of variability in farmer experience and skills, environmental conditions, and economic markets (Lockeretz, 1989). However, such experiments also provide opportunities often not possible with on-farm studies, such as replication, precise field measurements, and long-term comparisons. Thus, cautious extrapolation can be used, if only qualitatively, to gain a greater understanding of the potential positive and negative consequences of alternative agricultural systems.

Among the four crops represented in both the conventional and alternative farming systems of the SAFS Project, tomato and corn yields displayed substantial treatment effects, while bean and safflower yields were less affected. Detailed analyses of the tomato and corn crops (Cavero et al., 1997; Friedman et al., 1997; Clark et al., 1999; Friedman et al., [unpublished manuscript]) have identified N deficiency and weed competition as the most important factors leading to reduced yields in the organic and low-input systems at the SAFS site.

Other studies on conventional and alternative corn production have had similar findings to those of the SAFS Project. Lockeretz et al. (1981) reported that corn yields on organic farms in the Midwest averaged 8% less than on conventional farms. Similarly, Liebhardt et al. (1989) found that corn yields in systems that de-

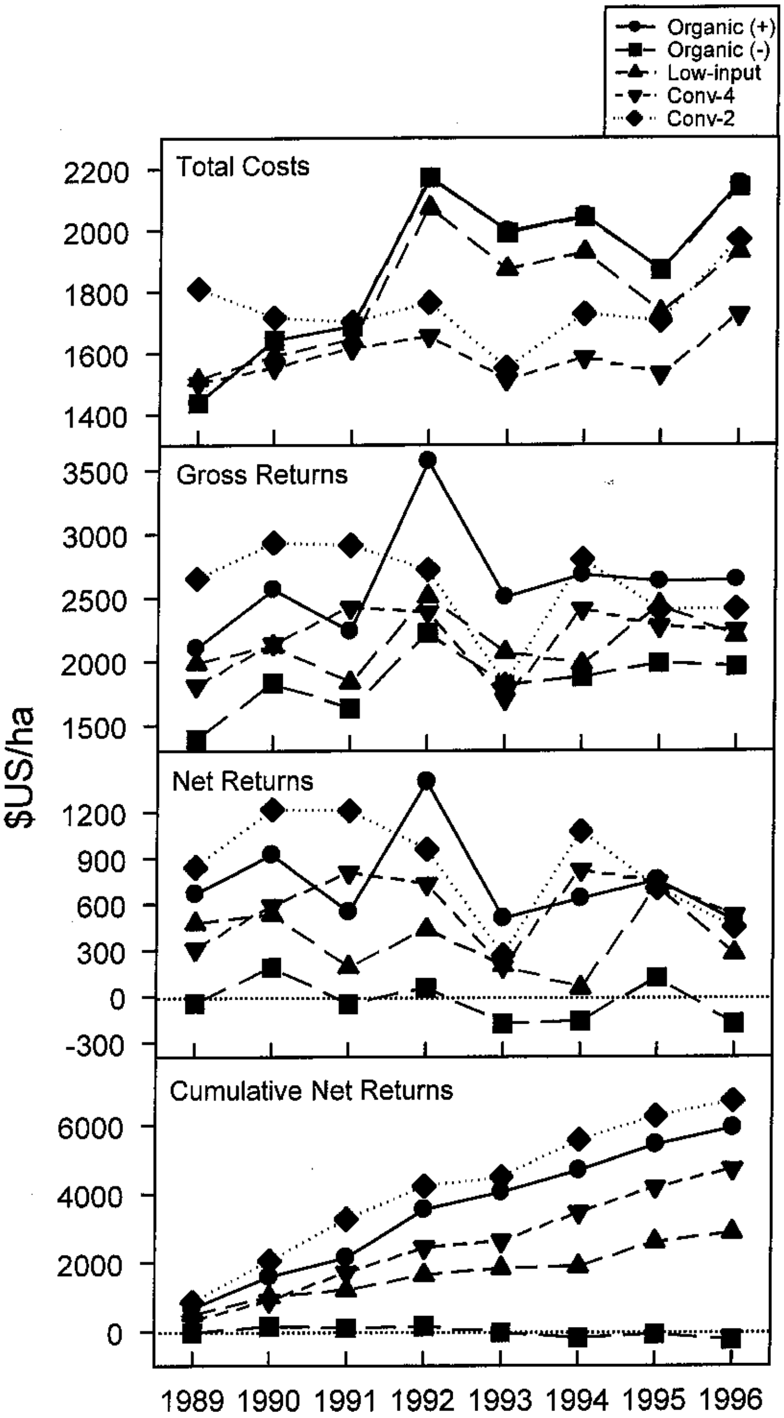

Figure 6. Whole-farm total costs, gross returns, net returns, and cumulative net returns ($US/ha) associated with the four SAFS farming system treatments, 1989-1996. Numbers for the organic system are presented with (+) and without (–) premium prices.

pended upon animal manure or legume cover crops for N were 25% less than in conventional systems that used inorganic N fertilizer. In the SAFS Project, the organic corn system, which depended upon legume cover crops and composted animal manure for N, performed somewhat better than the alternative systems in the aforementioned studies, averaging yields only 5% lower than conventional yields, although they were considerably more variable from year to year. However, yields in the low-input system, which used 50% less inorganic N fertilizer than the conv-4 system, were the highest among the three treatments. Furthermore, the low-input system produced the highest net returns in three of the four years during the second rotation. Based on these results, the low-input system appears to hold promise for corn production in the Sacramento Valley. And, with 40,000 ha grown in the region, the reduction of inorganic N fertilizer by 50% and herbicides by 60% could have substantial positive environmental benefits as well.

Most comparisons of conventional and organic and/or low-input tomato systems have focused on fresh-market rather than processing production. Moreover, the findings of these studies have been highly variable. Studies in eastern North America have reported 45-55% yield reductions under organic management (Sellen et al., 1995; Brumfield et al., 1995). By contrast, Drinkwater et al. (1995) found no significant differences in tomato yields among commercial organic and conventional farms in California's Central Valley and concluded that biological processes on these organic farms compensated for the lack of synthetic chemical inputs. We would expect the findings of the SAFS Project to have greater similarity to those of Drinkwater et al. (1995) than to studies conducted in eastern North America, due to the extreme differences in climate, pest pressures, and production practices between the regions. However, the results of the SAFS Project do indicate that dependence solely on legume cover crops and composted animal manure for N needs can be risky due to the unpredictability of N mineralization, immobilization, and plant availability. The use of supplemental inorganic N fertilizer, used at 60% or less of the rate used in the conv-4 treatment, brought yields in the low-input system within 5% of those for the conv-4 system.

Production costs in both the organic and low-input systems were substantially greater than those of the conv-4 and conv-2 systems, largely because of the use of transplants and greater dependence on hand weeding. Thus, the importance of premium prices for the economic viability of these systems is clear (Table 3). In fact, high premium prices for the organic tomatoes throughout this study made this the most profitable cropping system per hectare despite the high production costs.

Table 3. The average and range for conventional and organic premium prices ($US/t) in the lower Sacramento Valley, California, 1989-1996.

Crop	Conventional prices		Organic premium prices	
	Average	Range	Average	Range
Tomato	57	52-61	90	73-105
Corn	120	105-154	144	113-198
Bean	526	485-684	761	529-1323
Safflower	319	281-353	490	331-1103

Without the premiums the organic tomato system would have been unprofitable. The low-input tomato system, which did not have the advantage of premium prices, made 70% less profit than the organic system (with premiums) despite averaging 10% greater yields.

The dependence of organic tomato production on price premiums naturally leads to questions regarding the long-term economic viability of the system. As long as market demand for organic processing tomato continues to increase, premium prices should remain high. However, widespread adoption of organic methods would eventually lead to lower prices (Batie and Taylor, 1989). It should be noted that the price for organic tomatoes declined from $105/t in 1989 to $73/t in 1996. Because of this, we have some concerns regarding the use of high-cost transplants in the organic and low-input systems and the dependence upon imported, animal-manure compost in the organic system. If premium prices continue to decline the use of these production practices would have to be reconsidered.

Assumptions regarding the source and cost of manure can also have a dramatic effect on the outcome of economic comparisons. All manure inputs in this study were assumed to be purchased from off-farm sources. If, instead, disposal costs were assumed for the manure source, fertility management costs in the organic corn and tomato systems obviously would be less (Karlen et al., 1995). Such a scenario seems unlikely for the Sacramento Valley.

Bean yields and profits over the eight years indicate good short-term and long-term potential for low-input and organic systems. The economic performance of organic beans with and without premium prices makes this a good candidate as a transition crop. Relatively low production costs and high premium prices made this crop highly profitable in the organic system. Even without premium prices, the organic system was more profitable than the conv-4 system over the eight years.

Based on the SAFS study, safflower appears to hold only limited potential in organic and low-input farming systems in the Sacramento Valley. In 1992, the complete loss of this crop, which typically yields only marginal economic returns in good years, resulted in economic losses that could not be recouped in the low-input and organic (without premiums) system over the other seven years of the study. Even with the addition of premium prices (Table 3), this crop was only marginally profitable over the eight years in the organic system. Thus, safflower may not be a recommendable crop during the transition to organic production.

The economic performance of the winter grain/legume crop showed substantial variability among farming systems largely because of the differences in crop species and management options. Wheat, a common crop in the Sacramento Valley, provided only marginal profits for the conv-4 and conv-2. The winter grain/legume crop in the organic system was unprofitable as a cash crop because it was harvested and sold in only five of eight years. In the other three years it was incorporated as a green manure preceding beans and costs were included, but the value of the benefits was not directly measured. By contrast, the winter grain/legume crop in the low-input system was profitable largely because it was sold as seed, hay, or green chop in seven of the eight years of the study. On farms with livestock within a short transportation distance, this cropping system could have an important role in producing feed; however, without livestock nearby its value is somewhat questionable.

Conclusions

The whole-farm profit comparisons demonstrate the economic incentive for a two-year rotation with tomato, a common cropping strategy in the Sacramento Valley for conventional growers. The primary concerns about this system are the potential for increased disease pressure and/or degradation of soil structure. Although such problems have been apparent, they have not yet resulted in important crop-yield or economic losses. Among the four-year rotations in the SAFS study, the organic system with premium prices was the most profitable. Thus, it is a potentially viable farming-system option for the Sacramento Valley, with the current market demand for organic products. This system's dependence on price premiums leads to some concern over its long-term economic viability as more growers begin transition to organic methods, particularly if demand does not continue to increase at its current pace. Yield comparisons indicate that the transition to organic production may be somewhat problematic for crops with high N demands, such as tomato and corn. Bean appears to be a reliable and profitable crop during and following the transition. The conv-4 farming system generally had the lowest costs but ranked third in profitability. The low-input system performed well agronomically but had relatively high costs. Among crops in the low-input system, corn demonstrated clear agronomic and economic advantages over conventional production methods. Furthermore, environmental advantages may accrue from increased adoption of this cropping system throughout the region. Based upon the research at the SAFS site, we suggest that future research on organic and low-input farming systems focus on developing cost-effective fertility and weed management options based upon improved understanding of N dynamics and weed ecology.

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Canada Introduces National Organic Standard

The Government of Canada has introduced a new National Standard of Canada for Organic Agriculture that "can be recognized and applied in markets around the globe," according to John Manley, the Minister of Industry who is responsible for the Standards Council of Canada. "For Canadian producers of organic agri-foods produce, this will translate to greater and easier access to international markets that demand these kinds of standards."

The standard was developed through the Canadian General Standards Board's Standards Committee on Organic Agriculture, which includes various technical experts, and announced through the Standards Council of Canada, which promotes efficient and effective standardization. The standard "outlines principles for organic agriculture that endorse sound production and management practices to enhance the quality and sustainability of the environment and ensure the ethical treatment of livestock."

Specifically, it prohibits the use of ionizing radiation in the preservation of food, prohibits the use of genetically engineered or modified organisms, encourages maximum use of recycling, and encourages maximum rotation of crops and promotion of biodiversity.

The scope of the standard includes production plans and records; crop and livestock production; production requirements for maple products, honey, greenhouse crops, mushrooms, sprouted plants, and wild and natural products; the production and processing of organic products; and the packaging, labeling, storage, and distribution of organic food products.

"This new National Standard of Canada will provide consumers with a consistent meaning for 'organic,' helping them to make more informed choices," said Lyle Vanclief, Canadian Minister of Agriculture and Agri-Food.

An abstract of the Standard is available on the Internet at www.pwgsc.gc.ca/cgsb; to order copies of the entire Standard (listed as CAN/CGSB-32.310), contact CGSB Sales Centre, Ottawa, Canada K1A 1G6; (819) 956-0425; e-mail ncr.cgsb-ongc@pwgsc.gc.ca.

Consumers Union Calls for Labeling of Modified Foods

Consumers Union, in *Consumer Reports* (September 1999), has recommended that "all foods containing genetically engineered ingredients be labeled as such, including milk with recombinant bovine growth hormone," and that the USDA "set a single, national standard for certified-organic food that excludes genetically engineered food from the definition." The *Consumer Reports* article examined genetically modified foods, tested "everyday groceries," and revealed that "genetically engineered foods are already on supermarket shelves."

Although "U.S. consumers are largely unaware of the issue," its effects on them include the U.S.'s "collision course" with the European Union over genetically modified foods, and "environmental questions over genetically engineered crops [that] have taken on a new urgency....What happens if a hybrid 'superweed' emerges that withstands herbicides?"

Genetically engineered foods "should be subject to a mandatory federal human-safety review before they hit the market," according to the story. It also calls for "thorough, mandatory safety reviews of genetically engineered plants and animals before they are released into the environment," and recommends that EPA require "more rigorous resistance-management plans. Innovations like 'terminator' technology, which produces sterile seeds, should not be used until society has found a way to carefully consider their profound environmental and societal implications." For now, the magazine says, consumers who want to avoid genetically modified foods "have little choice but to buy organic."

Bugs May Become Resistant to Bt Cotton Faster Than Expected

University of Arizona scientists have written in *Nature* that some insects may be able to develop resistance to genetically modified "bug-proof" cotton plants more quickly than expected, according to an article in *The Wall Street Journal* (August 5, 1999). "The peer-reviewed laboratory study, which is being published in today's issue of the science magazine *Nature*, signals that some genetically modified plants might become obsolete sooner than their inventors had planned," the article said.

Farmers this year are planting 3.5 million acres of bug-resistant cotton, which contains a gene transplanted from *Bacillus thuringiensis*, or Bt. "The potential problem exposed by the University of Arizona study is that the mating cycle of its Bt-resistant bugs was out of synch with that of regular pink bollworms," according to the article. "That suggests any Bt-resistant bugs that develop in the wild might only be able to mate with each other, which could trigger a population explosion of their kind."