ture map, it was anticipated that well 3 would be a producer like wells 1 and 2. However, well 3 was a dry hole, and it was recognized that a three-dimensional seismic survey would improve the structure map required for locating additional productive wells.

Figure 5 shows the field layout for the three-dimensional survey in relation to the contour map obtained by the two-dimensional seismic survey. A total of 14 rectangles (1.2 by 2.0 km) were surveyed. Receiver groups and sources were both spaced at 134-m intervals. Each dot in the surveyed rectangles indicates the location of a seismic trace. Figure 6 is a three-dimensional migrated section extracted from the seismic data base along a traverse through several wells. It shows that well 3 is actually situated over a structural low; since oil and gas usually migrate to a trap in a structural high, this explains why well 3 did not produce. The contour map for the Agua Caliente horizon generated from the three-dimensional seismic data is shown in Fig. 7. Although well 3 is clearly misplaced, the three-dimensional survey outlined a drillable structure north of well 3 that was entirely missed by the two-dimensional seismic method.

Conclusions

The three-dimensional seismic method contributes to the cost-effective delineation and development of petroleum reserves. Dense sampling of the subsurface ensures that small features, which are becoming increasingly important as producers, are detected and outlined correctly. In areas where access to the land is difficult, the three-dimensional method still provides seismic coverage to meet exploration objectives. Accurate mapping of the reservoir configuration allows engineers to determine an optimum field development plan that minimizes the number of dry wells.

References and Notes

1. W. S. French, *Geophysics* **39**, 265 (1974).
2. P. Hubral [*ibid.* **41**, 233 (1976)] gives a solution to the problem of deriving the material velocity and reflector depth for a three-dimensional layered model of the earth from surface measurements of normal incidence time T_0 and normal moveout velocity V_{NMO} measured along the seismic survey line. Hubral's method can also be used to predict V_{NMO} in the direction required for normal moveout of seismic traces whose source-receiver pairs do not fall on the survey line.
3. J. G. Hagedoorn [*Geophys. Prospect.* **2**, 85 (1954)] describes a method of migration based on the complementary properties of wave front curves and diffraction curves. This method is applied to two- and three-dimensional migration of reflection events by means of graphs prepared for specific velocity distributions within the earth.
4. J. F. Claerbout, *Fundamentals of Geophysical Data Processing: With Application to Petroleum Prospecting* (McGraw-Hill, New York, 1976), pp. 236–246. Finite-difference solutions of migration are implemented by transforming the wave equation to a coordinate system that moves along with the upgoing wave front. The resulting partial differential equation is then approximated for the cases of wave fronts approaching the surface with an angle smaller than 15° or smaller than 45°.
5. W. A. Schneider [*Geophysics* **43**, 49 (1978)] shows that downward continuation of the wave field $u(x, y, 0, t)$ recorded on the surface of the earth and application of the imaging principle based on the "explosive reflector model" leads to the following expression for the three-dimensional migrated wave field in the Cartesian image space x, y, z:

$$V(x, y, z, 0) = -\frac{1}{2\pi}\frac{\partial}{\partial z}\iint dx_0 dy_0 \frac{u(x_0, y_0, 0, R/C)}{R}$$

where $R = \sqrt{(x - x_0)^2 + (y - y_0)^2 + z^2}$ and C is the velocity of the compressional waves in the medium. The explosive reflector model assumes that the normally incident wave field estimated by means of the CDP method can be simulated by the hypothetical experiment of placing explosives on the reflecting interfaces. The strength of these sources is proportional to the reflection coefficients and, at time zero, all explode simultaneously generating a wave field that propagates upward with half the velocity C of the medium.
6. R. H. Stolt [*Geophysics* **43**, 23 (1978)] published the following expression for the migrated wave field:

$$V(x, y, z, 0) = (2\pi)^{-3/2}\int dk_x \int dk_y dw \times \frac{U\left(k_x, k_y, w\sqrt{1 + (k_x^2 + k_y^2)C^2/4w^2}\right)}{\sqrt{1 + (k_x^2 + k_y^2)C^2/4w^2}} \times e^{i(xk_x + yk_y - 2wz/C)}$$

where U is the triple Fourier transform of the normally incident wave field u recorded on the surface of the earth:

$$U(k_x, k_y, w, 0) = (2\pi)^{-3/2}\int dx \int dy \times \int dt\, u(x, y, 0, t)\, e^{-i(xk_x + yk_y - wt)}$$

This migration algorithm can be implemented efficiently on the digital computer with fast Fourier transforms. Application of this method to media with variable velocity C requires adjustment of the recorded data by means of a stretch operation.
7. This case history is adapted from B. F. Giles, J. A. Kerfuss, and M. R. Bone (paper presented at the annual meeting of the Society of Exploration Geophysicists, Calgary, Canada, in September 1977 and is published with permission of the Occidental Petroleum Company).

Organic Farming in the Corn Belt

William Lockeretz, Georgia Shearer, Daniel H. Kohl

Widespread use of chemicals—manufactured fertilizers, as well as synthetic herbicides, insecticides, and other pesticides—is one of the most characteristic features of the modern agricultural era. This period, dating roughly from World War II, has been marked by rapid and fundamental changes in agricultural production methods. Because agricultural chemicals have enabled farmers to obtain higher yields per unit of land with lower labor requirements and lower overall production costs, their use has become a standard feature of most of the country's major agricultural systems. Total use of fertilizers and pesticides has increased more than sevenfold since 1945 (*1*).

Despite the generally accepted benefits that fertilizers and pesticides provide, an initial period of unimpeded adoption and continuously increasing use was followed by a closer examination of their full range of implications and a growing concern over some of their unforeseen consequences. Thus, a recognition in the 1960's of the unintended effects of insecticides on nontarget organisms, possibly including man, eventually led to the banning in the 1970's of several important ones, especially chlorinated hydrocarbons. Nitrogen fertilizers have been implicated in some agricultural areas as a significant contributor to high nitrate levels in drinking supplies (often exceeding the U.S. Public Health Service recommended limit) (*2*). Finally, manufacture of virtually all major fertilizers and pesticides requires considerable inputs of fossil fuels (*3*).

Because of these concerns, farmers, agricultural researchers, and extension workers in the past several years have

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0036-8075/81/0206-0540$01.50/0

shown a greater interest in ways of using fertilizers and pesticides more efficiently and in giving a larger role to nonchemical alternatives, such as biological control of insect pests or fertilization with organic wastes. But the dominant place of chemical methods of fertilization and pest control remains unchallenged. The prevailing view seems to be that regardless of environmental and energy concerns, fertilizers and pesticides are an indispensable part of productive and profitable agriculture and that their use could not be sharply curtailed without drastic adverse consequences. A small minority of farmers has questioned this position, however, and farms without using either modern inorganic fertilizers or synthetic pesticides, a system that is commonly called "organic farming." In view of the virtually universal acceptance of agricultural chemicals, it is not surprising that such a radical departure from prevailing practices has been strongly criticized. Predictions of the consequences of its adoption on a large scale have ranged from a sharply lower standard of living, to a need for a massive return of labor to the country, to widespread famine and starvation (*4*). Critics and advocates of organic farming, the latter most commonly found outside the mainstream of agricultural research, have frequently exchanged very harsh accusations. This may help explain why very little research has been done on organic farming as a system of commercial agriculture (in contrast to home gardens or hobby farms), although there has been considerable work on ways of partially reducing the use of chemicals.

Summary. A small minority of farmers in the Midwest produces crops on a commercial scale without using modern fertilizers and pesticides. On the basis of a 5-year study, it appears that these farmers have more in common with the majority of farmers in the region than with certain stereotypes of organic farmers. Their farming practices (other than chemical use), the size and labor requirements of their farms, and the production and profitability they achieve differ from those of conventional farmers by considerably less than might be expected on the basis of the fundamental importance of chemicals in modern agricultural production. Compared to conventional methods, organic methods consume less fossil energy and cause less soil erosion, but have mixed effects on soil nutrient status and grain protein content.

For environmental and energy reasons, this situation began to change somewhat in the mid-1970's, with research being conducted on the economics, energy efficiency, and social context of organic farming (*5*). The first and most intensive such study, summarized in this article, examined commercial organic farms in the Midwest from 1974 to 1978 from a range of viewpoints. Specific results from this work have been reported previously, including those on economic profitability and energy use (*6–8*), crop yields (*9, 10*), crop quality (*11*), and organic farmers' motivations and social relations (*12, 13*). In this article we integrate these separate investigations in order to present as thorough an overview as possible of organic methods as applied to a major type of farm in one of the nation's leading agricultural regions.

Frequently, organic farming is discussed as though the only choices were "all or nothing." That is, such discussions typically are concerned with what would happen if all farmers began farming with completely organic methods. In the study reported here no attempt was made to answer this question. The results of the study are limited to a particular type of farm in a particular region, and all the data concern the performance of actual organic farms when such farms comprise probably less than 1 percent of all the farms in the region. Because of aggregate effects that are not manifest under such conditions (such as changes in crop prices when there are changes in the overall supply of various crops), no attempt was made to extrapolate the results to hypothetical situations in which either appreciable numbers of farms or all farms made major changes toward the practices used on the farms we studied. Nevertheless, the results give a qualitative indication of what some of the possibilities might be for the development of less chemical-intensive agricultural systems, and are relevant to the question of whether intensive use of chemicals always is essential for economically competitive farming.

Social Aspects of Organic Farming

Organic farming is commonly regarded as one facet of a broader "alternative agriculture" movement whose followers diverge from the mainstream in many more ways than simply in their fertilization and pest control practices (*14*). This view is shared by many supporters, as well as many critics, of organic farming. The former consider it as part of an approach to agriculture that is less resource-intensive, more sustainable, more personally rewarding, and less mechanized (*15*). Critics, in contrast, frequently assume that organic farming is simply old-fashioned farming, or that its advocates are people with a peculiar metaphysical outlook and little or no prior farming experience who are not interested in making money from farming (*16*).

We used a mailed questionnaire to examine the background, attitudes, and motives of 174 organic farmers in the Corn Belt. All of these farmers produced field crops (and usually livestock as well) on a commercial scale, which we took to mean at least 40 hectares (100 acres) (*12*). In general, except for their fertilization and pest control practices, these farmers were more like their neighbors who farmed conventionally than like the stereotypic organic farmers described by either supporters or critics (*13*). Over 80 percent of them had previously farmed with conventional methods, thus contradicting the common image of them as "back-to-the-landers." They were about the same age as their conventional counterparts in the Corn Belt (median about 50 years, with about one-fifth below 40 and one-fifth over 60). Therefore, they typically were neither older farmers who never got around to adopting modern chemicals and other modern methods nor members of any youthful counterculture movement.

The organic farmers who had formerly used conventional methods converted to organic farming for a variety of reasons. By far the most common reason (mentioned by three-quarters of the sample) was a specific perceived problem or concern about chemical use, such as the health of their livestock or of their family, problems with their soil, or the ineffectiveness of chemicals. Far fewer (about one-third) mentioned a generalized dislike of chemicals, a concern about the environment, or religious principles. About half of the sample was influenced by proponents of organic farming, most often dealers for organic fertilizers and soil amendments. On the average, the farmers in our sample had adopted organic methods in 1971, or 6 years before they responded to our questionnaire.

The advantages they reported having experienced with organic methods were similar to their reasons for originally deciding to farm organically. However, we have no way of knowing whether their reports resulted from an independent

Table 1. Economic performance of organic and conventional farms. The data are averaged over all cropland (including rotation hay and pasture, soil-improving crops, and crop failures).

Year	Value of production ($/ha)		Operating expenses ($/ha)		Net returns ($/ha)	
	Organic	Conventional	Organic	Conventional	Organic	Conventional
1974*	393	426	69	113	324	314
1975*	417	478	84	133	333	346
1976*	427	482	91	150	336	333
1977†	384	407	95	129	289	278
1978†	440	527	107	143	333	384

*Data from 14 organic and 14 conventional farms (*7*). †Data from 23 organic farms in 1977 and 19 in 1978; county-average data for conventional farms (*8*).

evaluation after gaining some experience with their newly adopted methods, or were merely another manifestation of the views that first led them to adopt organic methods. In any case, the presumed advantages for their families' health and that of their livestock were by far the most frequently cited benefits, each being mentioned by about half of the sample. Soil quality, the environment, and religious factors were each mentioned by about one-fourth of the respondents. Only one of the four most frequently mentioned disadvantages was an agronomic one: weed problems. The other three were social or institutional in nature: difficulty in finding markets for organic products; lack of up-to-date information sources; and low opinion of organic farming on the part of others.

Thus, organic farmers of the type we studied seemed to be motivated more by pragmatic considerations than philosophical or ideological ones, although ideological considerations did play a role in their thinking. They resembled the majority of commercial farmers both in their heavy use of purchased inputs, including full-size machinery, and in their use of conventional marketing channels rather than specialty outlets (*13*). Close similarity to the majority of farmers also characterized most of their production methods and the results they obtained.

Farming Practices

Data on organic farming practices were obtained from three sources: a mail survey concerned with some basic features of 363 organic farms in the western Corn Belt (Illinois, Iowa, Nebraska, Missouri, and Minnesota), conducted from 1975 to 1978 (*12*); a study from 1974 to 1976 of the economics and energy use of crop production on 14 organic and 14 conventional farms in the same region (*6*, *10*); and a similar study in 1977 and 1978 of 23 organic farms, primarily in Iowa (*8*). In all three studies, the organic farms were required to have field crops as the main crop enterprise and to have a minimum total size of 40 ha. "Organic farming" was defined almost strictly in negative terms, that is, no use of any of the following: inorganic nitrogen fertilizer or urea, acidified phosphorus fertilizer (superphosphate or triple superphosphate), conventional potassium fertilizer (muriate of potash), or synthetic herbicides or insecticides. (The only exception was that the farmer might use occasional spot applications of herbicides on an intractable weed problem.) No requirements were imposed concerning what positive steps, if any, were taken for fertilization and pest control. However, most of the organic farmers did take one step aimed at supplying fertility: they frequently added an "organic fertilizer." We made no attempt to evaluate the efficacy of such soil amendments of low nitrogen, phosphorus, and potassium content, but the cost of such fertilizers was considerable.

The organic farmers did not attempt to compensate for the nonuse of standard fertilizers and pesticides by adopting radically different practices from those generally used by conventional farmers. Differences between organic and conventional practices were, in many instances, ones of degree, even for weed control, insect control, and fertilization, areas in which one would expect the largest differences in practices between the two groups, since they are the areas where the two groups differ by definition.

Weed control. Compared to conventional farmers, the organic farmers used more mechanical cultivation of row crops (corn and soybeans) to control weeds. However, it also was not uncommon for conventional farmers to use mechanical cultivation in addition to herbicides (*17*). The conventional farmers typically did not use herbicides on other important crops, including hay, oats, or wheat.

Insect control. The organic farmers mainly used crop rotation, not exotic biological control techniques, to combat major pests. Organic farmers were not alone in their nonuse of insecticides. Almost half of the conventional farmers whose corn yields we measured did not use insecticides on their corn; in this respect they were similar to corn producers in general (*18*). The nonusers were apparently satisfied that rotation, particularly of corn and soybeans, gave adequate control.

Fertility. The organic farmers often applied commercial organic amendments that typically contain very low concentrations of plant nutrients. Livestock manure was applied, as available, on both organic and conventional farms. The rate of application of manure on the organic and conventional livestock farms was nearly identical (*6*). This rate provided only a small portion of the nutrient requirements of the crops (*19*). Most of the nitrogen fertility on organic farms apparently was provided by growth of legumes. Although conventional farmers used commercial nitrogen fertilizers, those who had livestock also grew a considerable amount of legume forage (*20*). Thus although the two groups of farmers differed with respect to the kinds of commercial fertilizers they applied, other practices related to fertility were similar, the difference being one of emphasis.

Farm type. Management that relies on legume forage to supply nitrogen fertility naturally leads to a mixed crop and livestock operation, since it is simpler to use the forage for one's own livestock than to sell it. Not surprisingly, therefore, nine-tenths of the organic farmers in our survey had a substantial quantity of livestock, most commonly beef cattle, hogs, or dairy cows (*12*). Among conventional Corn Belt farmers, about half receive more than 50 percent of their income from livestock (*20*). Thus the type of enterprise in which the organic farmers are most commonly engaged is also common among conventional farmers. However, the conventional farmers have more flexibility in the sense that they can choose to have either a mixed crop and livestock operation or a cash grain enterprise, whereas strong pressures tend to restrict organic farmers to the former.

Crop mix. Although our three sources of data differed from each other slightly on this point, in part because of differences in geographic distribution within the Corn Belt, they all yielded the same qualitative conclusion: on the conventional mixed grain-livestock farms, the leading crops (in descending order of importance) were corn, soybeans, hay, oats, and wheat; on the organic farms, the order of hay and soybeans was reversed. On the conventional farms, an additional 15 to 20 percent of the cropland was in corn or soybeans compared to the organic farms, but about 10 percent less was in oats (planted as a nurse crop for legume forage) and wheat.

Farm size. The median size of the 363 organic farms with at least 40 ha was 86 ha (*9*). This is about 18 percent below that of all crop-livestock farms with at least 40 ha in the same region in 1974 (*20*).

Equipment. The median size of the organic farms' largest tractor was 80 horsepower, and more than four-fifths of these farms had at least one tractor over 60 horsepower (*12*). We found only negligible differences in the sizes of major harvesting machinery, tractors, and tillage implements (*21*).

Labor requirements. With their high degree of mechanization, the organic farms required slightly more labor than conventional farms: 12 percent per unit value of crop produced, or 3 percent more per unit of land (*6*). The organic farmers did not use exceedingly labor-intensive methods, such as picking off insects by hand. Both organic and conventional farmers resorted occasionally to hand-weeding of soybeans. The difference in labor inputs reflected the differences in crop mix and cultivation, rather than fundamental differences in production methods or machinery.

Table 2. Measured crop yields on organic and conventional farms (*10, 25*).

Crop	Number of measurements	Years	Yield (metric tons/ha)		
			Organic	Conventional	Difference
Corn	26	1975 to 1978	6.45	7.00	− 0.55 (8 percent)
Soybeans	7	1977 to 1978	2.44	2.57	− 0.13 (5 percent)
Wheat	4	1977 to 1978	1.88	3.28	− 1.40 (43 percent)

Economic Performance

We conducted two studies of the income, costs, and profitability of crop production on organic and conventional farms. The first, which covered the crop years 1974 to 1976, involved 14 organic crop-livestock farms in a five-state region (Illinois, Iowa, Minnesota, Nebraska, and Missouri); each such farm was matched with a nearby conventionally operated crop-livestock farm that was chosen to be roughly comparable in size and soil type (*7*). The second study dealt with 23 organic farms in 1977; 19 of these farms were also studied in 1978 (*8*). In this study, comparative data on conventionally operated farms were obtained from county-level statistical reports of yields and harvested area of major crops, from crop production budgets (*22*) and from the *1974 Census of Agriculture* (*20*).

Farms in the first study were found by word of mouth. Those in the second study were drawn from the sample obtained by the mail survey mentioned earlier, but included only farms located in Iowa, Illinois, and Minnesota that met the following criteria: (i) they raised beef or hogs, or both, but had no other major livestock enterprise; and (ii) their soil had been mapped. In addition, the organic farms in both studies had been managed organically for at least 4 years. The 14 organic and conventional farms in the first study had an average size of 172 and 194 ha, respectively; the 23 organic farms in the second study averaged 95 ha compared to 96 ha for all beef- and hog-producing farms in the same counties.

In both studies, data were initially collected through personal interviews with each participant, after which we used a series of mailed data forms. Additional interviews with the participants were conducted between the two crop years of the second study. For each field on each farm, including meadow in rotation with cultivated crops, but not permanent pasture (*23*), information was obtained on the following: yields; applications of fertilizers, manures, and other materials; tillage, cultivation, and harvesting operations; and seeding rates and varieties used. The results in this article are averages over all the cropland on each farm, including cultivated crops, rotation meadow, soil-improving crops, and crop failures.

Gross value per hectare was computed from reported yields and statewide market prices, regardless of whether the crop was sold or was consumed by livestock on the same farms, and regardless of whether the organic crops were sold at a premium. Operating costs included direct or variable costs only: materials, labor, fuel, equipment repairs, seeds, and crop drying. No fixed or overhead expenses were included. They were assumed to be similar on the two kinds of farms because of the similarity in implements and land value (*21*). Labor was charged at the prevailing wage rate, regardless of whether the work was done by hired labor or by the farm family.

The main results of these studies are summarized in Table 1. From 1974 to 1977 the organic farms produced between 6 and 13 percent less market value per hectare of cropland than the conventional farms. At the same time, however, their operating costs were also lower by about the same amount. Consequently, the two groups' income from crop production after operating costs were deducted were within 4 percent of each other each year from 1974 to 1977. The picture was somewhat different in 1978, when the organic farms' gross income per hectare was 17 percent below that of the conventional farms. While their operating costs continued to be lower, this was not enough to offset the wider gap in gross income, and returns on the organic farms were an average of 13 percent below those of the conventional farms. In relating these figures on income per hectare to data for whole farms, it should be recalled that organic farms on average were about one-fifth smaller, according to our survey of 363 organic farms.

The difference between the results of 1978 and those of the other 4 years is probably a result of growing conditions. In 1978, conditions in the study region were very favorable, whereas there was serious drought in at least part of the region during each of the previous years. One can expect that when weather conditions are unfavorable there is less advantage in using agricultural chemicals (especially fertilizers), since other factors, such as soil moisture, limit yields. We present further evidence that this partly explains our results in our description of crop yields.

Crop Yields

Yields of corn, a crop that usually receives the heaviest fertilizer and pesticide applications under conventional management, typically were about 10 percent lower on the organic farms. Soybeans, which in the Corn Belt usually receive phosphorus, potassium, and herbicide but little or no nitrogen or insecticide, yielded about 5 percent less on the organic farms. The two groups' yields were about equal for oats and hay, which do not usually receive chemicals, except for light fertilizer applications on oats. The biggest difference was in wheat (a relatively insignificant crop on these farms), for which organic yields were about one-fourth lower. Thus, with the exception of wheat, which in the Corn Belt typically receives a complete fertilizer application but no herbicides or insecticides, the amount by which yields of various crops were lower on the organic farms was consistent with the importance on conventional farms of chemicals in the production of each crop: highest for corn, less for soybeans, negligible for oats and hay.

The data from which these conclusions are drawn were obtained over a period of 5 years from five different states. For corn, for example, we had 81 separate data points. However, these data were obtained from farmers' reports, not actual measurements, and the organic and conventional farms were only qualitatively matched by soil type and location. Therefore, we also conducted field measurements of crop yields under more carefully controlled conditions. Each data point consisted of a yield measurement on a pair of neighboring (frequently adjacent) organic and conventionally managed fields of the same soil type, where the two farmers used the same variety and planted on or close to the same day (*24*, *25*).

The results (see Table 2) corroborate the conclusions based on farmers' reports of yields. On organic farms the yields were much lower for wheat, moderately lower for corn and slightly lower for soybeans than those of conventional farms. For corn, we had sufficient data to examine this comparison in more detail. There was a significant correlation ($r = .58$; $P < .002$) between the proportional difference in yield on the two kinds of fields (conventional yield minus organic yield divided by the average) and the growing conditions in the particular location in the particular year, as measured by the deviation of the countywide corn yield from the 10-year county average. That is, when conditions were better than average, yields on conventionally managed fields were generally higher than those on the organic farms by more than the overall average of 8 percent; under poorer conditions, yields from the organic fields came closer to or even exceeded those of the conventional fields (Fig. 1). Yields on three of the 26 fields on organic farms exceeded 10 metric tons per hectare (159 bushels per acre), which would be considered an exceptionally good yield on any farm.

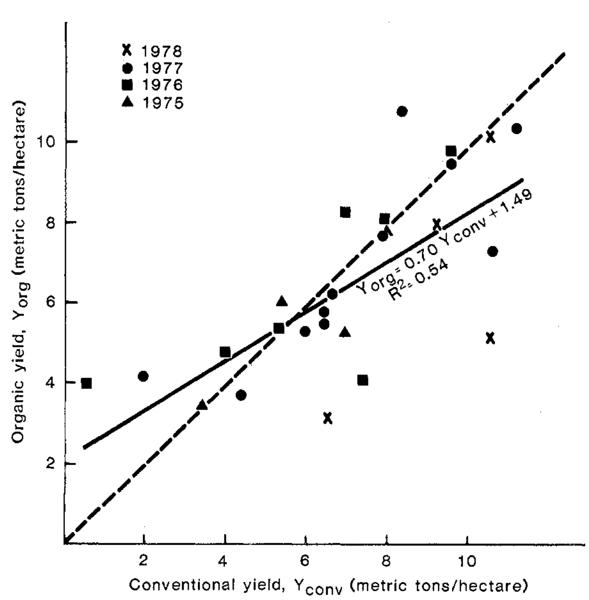

Fig. 1. Corn grain yields on 26 matched pairs of organically and conventionally managed fields. The solid line is the best fit. The dashed line represents equal yields on the two kinds of fields (*10*).

Energy Consumption

Although organic farming is generally less energy-intensive than conventional farming (*3*), some of this saving is offset by the greater reliance of organic farmers on mechanical cultivation for weed control and by the lower yields on organic farms. We examined the overall energy requirements of crop production using the data collected for the studies of economic performance.

Since the two groups of farmers raised different relative amounts of crops, the results were aggregated for all the cropland on each farm, just as was done with the economic data. Also in analogy with the economic analysis, we ignored energy associated with capital equipment, limiting the computations to annual inputs: fuel for tillage, planting, and harvesting equipment; fuel for crop drying; and energy to manufacture fertilizers, pesticides, and other materials. Because the two groups differ in the value of crops produced per unit area, energy intensiveness was computed per unit value of production, rather than per unit area (*26*).

The results of this analysis are shown in Table 3. The pattern remains very similar through the 5 years covered by the two studies: the organic farms required about two-fifths as much fossil energy to produce one dollar's worth of crop. This difference arises from two main sources (*27*). First, energy consumption for corn is much lower on the organic farms, primarily because of nonuse of manufactured nitrogen fertilizer. Second, a greater fraction of cropland is in corn on the conventional farms, which contributes significantly to their higher energy intensiveness, since corn is the most energy-intensive crop.

Effects on Crop Quality and Plant Growth

The comparative nutritive value of crops raised by organic and conventional methods is a subject of considerable controversy, one on which the available evidence is extremely limited. We have examined the crude protein content of corn, wheat, and soybeans raised under both systems, as well as the amino acid composition of the corn protein. The samples used in these analyses were obtained from a subset of the fields used in the crop yield measurements. Consequently, within each organic-conventional pair, neighboring fields were matched by soil type, variety, and planting date.

The only clear difference in nutritive value occurs with corn, where the conventionally raised grain was consistently higher in crude protein (Table 4). For soybeans and wheat, differences within a pair went in both directions, and the average differences between the two samples were small and not statistically significant.

The corn grain samples were analyzed for 16 amino acids. In terms of fraction of protein content, the organically raised samples were significantly higher ($P < .01$) in lysine (2.27 compared to 2.02 percent), an amino acid that limits the nutritive value of corn grain for monogastric species (*28*). The protein from organically grown corn was also higher in methionine, histidine, threonine, and glycine but lower in leucine and phenylalanine. However, in terms of fraction of total grain weight, none of the amino acids were higher in the organically grown grain. Moreover, in terms of the quantity produced per unit of area, the organically raised samples were significantly lower in all amino acids except methionine (*11*), since the grain yields per unit area and the protein content of the grain were both lower (see Tables 2 and 4).

Inadequate nitrogen availability on the organically managed fields could have caused the different amino acid patterns in the two sets of samples and could have been the factor that limited yields (*28*). A lack of nitrogen is also suggested by the crude protein content of the organic, but not the conventional, corn grain being slightly below the level usually achieved with adequate nitrogen (*29*). Moreover, the difference between the two fields' crude protein content was positively correlated with difference in yield. Presumably, a modest addition of nitrogen to the organically managed cornfields would reduce their yield disadvantage relative to conventional fields, while keeping a large portion of the advantage of the organic methods (lower production costs and lower energy consumption).

The lower nitrogen supply on the organically managed fields may have been why they largely avoided two other problems: stalk lodging (plants that have fallen over) and *Diplodia* stalk rot. Both of these problems were twice as prevalent on the conventional cornfields. An average of 10 percent of the conventionally grown corn plants on 25 fields had lodged, compared to 5 percent on the matched organic fields; 24 percent of plants on 14 conventional fields were affected by *Diplodia*, compared to 13 percent on the organic. Both of these differences were statistically significant ($P < .02$ and $P < .05$, respectively) (*10*).

Soil Nutrients and Erosion

Under conventional practice, inorganic fertilizers with a high available nutrient content are used both to provide the nutrients needed immediately for each year's crop, as well as to maintain the long-term levels of nutrients in the soil. In the conventional mixed crop-livestock farms of the type we studied, application of commercial inorganic fertilizers commonly occurs along with manure applications and rotations with legume forage. In contrast, organic farmers use legume forage as the primary source of sustained soil fertility (along with small amounts of on-farm manure, purchased rock phosphate, and proprietary organic soil amendments of low nitrogen, phosphorus, and potassium content).

We examined possible differences in soil nutrient status resulting from these different practices by sampling soils from 30 pairs of fields used in the corn, wheat, and soybean measurements already described. Five pooled replicates per field were analyzed for total organic carbon content, total nitrogen, available phosphorus (Bray P_1 and P_2), exchangeable potassium, cation exchange capacity, and pH (organic carbon only was measured on an additional five pairs) (*30*).

The results are summarized in Table 5. The only difference that was statistically significant ($P < .05$) was the slightly higher organic carbon content on the organic fields. There was a weaker indication ($P < .1$) of higher nitrogen and lower available phosphorus (as measured by P_1 but not P_2) on the organic fields, with no other differences significant at the $P < .1$ level.

Although the soil analyses indicated no deficiency in available potassium on organic fields, and only a small deficiency in available phosphorus, over the long term these nutrients will probably become increasingly deficient, since a nutrient balance analysis revealed that more phosphorus and potassium were being removed with the crop than were being applied (*31*).

The nutrient status of the soil is also strongly affected by erosion (*32*). The two kinds of farms differed in two ways that affect soil erosion by water, a significant problem in the Corn Belt (*33*). The organic farmers were far less likely to use the moldboard plow, preferring instead the chisel plow or other reduced tillage methods (*7*). Since the moldboard plow turns all crop residues under, it leaves the soil much more vulnerable to erosion (*34*). Also, as noted earlier, the organic farmers had more land in rotation meadow, which is a very effective soil conservation strategy, than did the conventional operators.

We analyzed the effect of differences in rotations (but not tillage practices) for the 14 pairs of farms in the first economic study, using the universal soil loss equation (*35*). Averaging over all the cropland on each farm, we estimated that for a given set of physical conditions (soil type, slope, slope length, and rainfall), water erosion was about one-third less for the rotations used on the organic farms. This difference was consistent throughout the sample: in all but one pair, the expected erosion rate was lower on the organic farm. Because we did not have adequate information on the physical factors, and did not take tillage dif-

Table 3. Energy consumption of crop production on organic and conventional farms. See footnotes to Table 1 for sources of data.

Year	Energy consumption per unit of market value (Mcal/$)		
	Organic	Conventional	Ratio
1974	1.8	4.3	0.42
1975	1.7	3.8	0.45
1976	1.8	4.8	0.38
1977	1.9	5.1	0.37
1978	1.8	4.1	0.44
Average	1.8	4.4	0.41

Table 4. Average crude protein content of grains from organic and conventional farms (range given in parentheses).

Crop	Number of measurements	Average protein content*		
		Organic	Conventional	Difference
Corn	19	8.99 (6.63 to 11.06)	10.13 (7.88 to 11.56)	− 1.14† (−3.00 to −0.19)
Soybeans	7	41.62 (39.19 to 44.19)	42.06 (40.06 to 44.50)	− 0.44 (−5.31 to +1.19)
Winter wheat	4	14.25 (12.19 to 16.06)	14.12 (12.69 to 15.56)	0.13 (−0.62 to +1.19)

*Percentage total $N \times 6.25$. †$P < .001$ by two-tailed t-test.

Table 5. Soil measurements on matched organically managed and conventionally managed fields (*10*). The measurements were conducted on 30 pairs of fields, except in the case of organic carbon which was measured on 35 pairs. N.S., not significant.

Soil property	Organic		Conventional		Difference	P
	Mean	Range	Mean	Range		
Organic carbon (%)	2.35	0.97 to 4.41	2.21	0.76 to 6.30	0.14	< .05
Total nitrogen (%)	0.233	0.109 to 0.422	0.221	0.080 to 0.588	0.012	< .1
Ratio of carbon to nitrogen	10.25	8.45 to 12.37	10.28	8.41 to 11.73	−0.03	N.S.
Available phosphorus						
P_1 (ppm)	25.2	5.9 to 72.1	33.8	2.2 to 121.0	−8.6	< .1
P_2 (ppm)	69.8	12.7 to 185.4	69.7	16.2 to 195.0	0.2	N.S.
Exchangeable potassium (ppm)	137.0	21.9 to 436.6	148.2	58.3 to 322.8	−11.2	N.S.
Cation exchange capacity (meq./100 g)	27.8	9.9 to 45.1	27.2	10.7 to 49.2	0.6	N.S.
pH	6.50	5.77 to 7.90	6.38	5.33 to 7.95	0.12	N.S.

ferences into account, we cannot quote the results in terms of actual soil loss. However, because the farms in each pair were matched by location and to some extent by soil type, the effects of these physical factors are approximately the same for the two members of each pair. (This analysis also does not consider any differences in the physical state, and hence the erodibility, of soil of a given type resulting from different management practices.) Had we taken into account differences in tillage on the two kinds of farms, the differences in erosion estimates would have been greater, since the organic farmers used less erosive tillage methods.

Significance of Results

The commercial-scale organic farmers in our studies made little use of methods that most farmers would regard as exotic; rather, as alternatives to chemical fertilization and pest-control methods they used rotations with legume forages and other practices similar to those found on many Corn Belt farms, but relied more heavily on these techniques than did conventional farmers. Because of the heavier reliance on legume forage as a nitrogen source, organic farmers may not be able to choose an exclusively cash grain operation, whereas for better or worse conventional farmers have this choice.

Slightly lower gross production per unit of cropland on the organic farms was largely offset by comparable reductions in operating expenses, so that crop production was about equally profitable on the two types of farms except in a year that had extremely favorable weather. The exact comparison appears to depend on growing conditions, with the organic farms doing relatively better under the abnormally poor conditions of the mid-1970's, but relatively poorer when conditions improved in 1978. Except for wheat, a minor crop in the Corn Belt for which organic farms had much poorer yields, yields of most organically raised crops generally ranged from about the same to about 10 percent lower than on the conventional farms.

A consequence of the organic farms' production methods is that less fossil energy is required per unit of crop output, so that these farms would be less severely affected by a deteriorating energy situation. Another benefit is that soil erosion is significantly reduced under the crop rotation and tillage methods used on the organic farms (although this benefit could also be obtained by conventional farmers who chose to use the same tillage methods and rotations while still using conventional chemicals). In soil nutrient status the picture was mixed, with the organic farms showing slightly higher levels of organic carbon and nitrogen but lower available phosphorus. With regard to crop quality, both the lower crude protein content in the organic grain and the different amino acid balance indicated a nitrogen deficiency. Organically managed cornfields showed a clear advantage with regard to lodging and *Diplodia* stalk rot.

Since our present agricultural system, in which agricultural chemicals are a key element, is one that basically works—indeed, that works very well by several important criteria—it is not surprising that most researchers apparently assume that these chemicals will continue to have a major role in any future agricultural system. Consequently, most research on alternative systems is concerned with relatively minor adjustments in the use of agricultural chemicals. The results of our studies suggest that this view may be too cautious and that a better approach might be to determine how far we can and should move in the direction of reduced agricultural chemical use. The organic farmers we studied had fared reasonably well without chemical fertilizers and pesticides and without the benefit of the scientific and technical assistance routinely available to farmers following more accepted practices. That their performance might have been better had they used just modest amounts of fertilizer is indicated by the protein content of the organically managed corn. Thus there may be intermediate systems that, from the combined viewpoints of productivity, profitability, and resource use, would prove more attractive than either of the two systems we studied.

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Rural Africa: Modernization, Equity, and Long-Term Development

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Summary. Prospects for rural development in sub-Saharan Africa appear to be much poorer than in the rest of the developing world, especially since the oil price increases. If present trends continue, African dependence on food imports will increase. Despite the rhetorical acknowledgment of the importance of the agricultural and rural sector, most African countries are not giving that sector the needed priority in their policies and budgets. Indeed, the rural sector is heavily taxed for the support of urban modernization. Large investments by foreign donors in the rural sector have had little overall effect. Donors need to adopt a longer perspective on development and to make greater efforts to promote indigenous capacities for policy, planning, and administration. Their investments need to be geared more to broad-based higher education and training and to transport and communications.

Within less than a decade Africa is facing a second severe food crisis. The poor crop can yet again be explained as a result of drought. But the continent's growing vulnerability to crop failures is by no means unexpected. In most African countries it appears to be part of a long-term trend. Data on African countries, especially for subsistence production, are too poor to permit precise estimates, but annual rates of increase of major staple food crops in sub-Saharan Africa in 1960 to 1975 seem to have been only about 2 percent, compared with almost 3 percent in Asia and over 3.5 percent in Latin America (*1*; *2*, p. 33, table 3). Productivity increases in hybrid maize in some selected areas, such as the highlands of Kenya, were impressive. However, on the whole, increase in the production of major cereals and root crops—maize, sorghum, millets, and cassava—came about through increase in the area under cultivation brought about by expanding population, rather than through gains in productivity per unit of input. This is in sharp contrast even to South Asia, which is generally perceived as laggard in development but where substantial productivity gains were experienced in food crop production in the 1970's. Per acre yields of many subsistence food crops appear to have stagnated or even declined in many African countries, as for instance in Ghana, Mali, Nigeria, and Sudan.

Because of higher population growth, annual rates of increase in production required to meet consumption needs by 1990 are also estimated to be higher for sub-Saharan Africa, about 4.5 percent, compared with not quite 4 percent for Asia and less than 3 percent for Latin America (*2*, p. 22, table 1). If present trends continue, Africa will increase its dependence on food imports both over time and relative to other developing continents. Undernourishment is expected to become far more widespread, even though alternatives to cereals and staples, such as bananas and other fruit, fish, and animal products, have been far more important sources of calories in many parts of Africa than in South Asia, which has similar per capita incomes. Indices of ill health and infant mortality are already among the highest in the developing world and are not expected to decline significantly in the next decade.

Export crop production has been more varied among African countries since independence. Production of cotton, tobacco, cocoa, and coffee rose significantly in some countries until the 1960's (*3*), but during the 1970's, production of major export crops has either been stagnant or declined in many countries. Nigeria, for instance, became a substantial net importer of edible oils, of which it was previously a net exporter. Groundnuts in Mali, cocoa in Ghana, cotton in Sudan, cotton, sisal, coffee, and cashews in Tanzania all provide examples of stagnancy or decline in production.

Rural-urban income disparities are already high in Africa, the ratios typically ranging between 1:4 and 1:9, compared with many countries in Asia with ratios of 1:2 and 1:2.5. But because agricultural sectors have been stagnant or slow growing even relative to the poorly performing industry and services sectors, these disparities are worsening in many cases. Kenya, Malawi, and the Ivory Coast are the few exceptions where until recently growth has been impressive, but there the distribution of benefits between agriculture and industry, and within agriculture, have been particularly unequal. The World Bank's *World Development Report* of 1979 estimates the annual growth of per capita incomes in low-income African countries—meaning those where annual per capita income is less than $300—to be only 0.2 percent during the 1970's, compared with 2 percent in low-income Asia. Even the middle-income African countries experienced per capita income growth rates of only 2.8 percent per annum, compared with 5.6 percent in the corresponding countries in East Asia and the Pacific (*4*).

Worse yet, prospects for overall economic growth in low-income Africa are seen as much poorer than in the rest of the developing world. The *World Development Report* projects the likely growth rates of per capita income in low-income Africa during the 1980's to be 1 percent,

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0036-8075/81/0206-0547$01.75/0