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ORGANIC AND CONVENTIONAL FARMING COMPARED

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FOREWORD

Organic farming and gardening are subjects that generate much emotion among some members of the general public, recurring coverage by the media, and occasional attention by members of the Congress. Because the scientific information required to place the issues in perspective is little appreciated and generally overlooked, the CAST Board of Directors authorized the development of a report to provide the needed background. The multidisciplinary task force of scientists assembled to address the issues met in St. Louis, October 18 to 20, 1978, to prepare a first draft. The first draft gave only minor emphasis to organic gardening as such, and this approach has been carried through to the final publication. The scientific principles discussed in connection with organic farming apply equally to organic gardening, however, and so organic gardening, is by no means overlooked.

The task force included 24 scientists with collective expertise in agricultural economics, agricultural engineering, agronomy, animal science, dairy science, entomology, food science, horticulture, nematology, plant pathology, poultry science, rural sociology, soil science, soil testing and plant analysis, veterinary medicine, veterinary toxicology, and weed science.

Several successive drafts of the report were prepared by the chairman and were returned to members of the task force for review and comment. The report was then edited by Jon A. Smith, with assistance from the CAST staff, and additional drafts were returned to task force members for review and comment before the final draft was reproduced for publication.

On behalf of CAST, I thank members of the task force and all the others who gave of their time and talents to prepare, review, and comment on this report as a contribution of the scientific community to public understanding. Thanks are due also to the employers of task force members who made the time of their employees available at no cost to CAST. And finally, thanks are due to members of CAST. The unrestricted contributions they have made in support of the work of CAST have financed the report.

The report is being distributed to members of Congress, the U.S. Department of Agriculture, the media, and institutional members of CAST. Individual members may receive a copy on request.

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Charles A. Black
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SUMMARY

Conventional and organic farming have much in common. They differ principally in the use of modern chemical technology. Conventional farmers use commercial fertilizers, pesticides and animal feed additives to increase productivity, but organic farmers prefer to use natural resources.

Organic farming, though ancient in principle, was described as a system prior to World War I by Sir Albert Howard. He taught that, except for "natural" products such as phosphate rock and limestone, importation of plant nutrients from off the farm for application to the soil is to be avoided. This judgment about the acceptability of naturally occurring chemicals has now been expanded by many in the organic movement to include the issue of safety. They regard natural chemicals as safe, and chemicals that are artificial, synthesized or processed as hazardous and therefore to be avoided. This view is scientifically erroneous.

Sir Albert Howard regarded the return of organic matter to the soil as the basis of permanent soil fertility. This concept has some validity for natural ecosystems, but it is inapplicable to the needs of modern society in which the harvested portion of crops is removed from the land and part of the organic matter and plant nutrients is not returned.

The organic farming movement has expanded to encompass an alternative agricultural system based upon less technology; more self reliance; and opposition to the trend toward larger farm enterprises, displacement of small farmers, and the deterioration of some rural institutions.

Organic farmers prefer to use leguminous crops, a natural resource, to supply part of the nitrogen needed for their cropping systems, whereas conventional farmers supplement or replace the legume nitrogen with fertilizer nitrogen, which nowadays is produced in factories. For conventional farmers, this is essentially a matter of economics because they can replace legumes with more profitable crops. In earlier years, when nitrogen fertilizer was relatively expensive, conventional farmers also used legumes to supply nitrogen; they still do where it is economical.

Both conventional and organic farmers use various mechanical, biological and other means to control pests, including weeds, insects, disease-causing agents and nematodes. Conventional farmers use synthetic pesticides as needed for pest control, but organic farmers prefer to avoid them.

Both conventional farming and organic farming are largely powered by fossil fuels, but conventional farmers use more energy per acre than do organic farmers, largely because they use fertilizers and pesticides. These products, mainly nitrogen fertilizers, consume about 1 percent of the energy used nationally but about 40 percent of the energy used in agricultural production. Conventional farmers use the extra energy primarily because it is economically advantageous.

In conventional farming, extensive use is made of nutritional supplements in animal feeds. Further increases in production efficiency are achieved by use of hormonally active substances. Certain drugs approved by the Food and Drug Administration are used to protect animal health and to increase production efficiency. Use of these substances is generally unacceptable to organic farmers.

If organic farming were widely adopted, the current price advantage to certain organic farmers from supplying a specialty market (made up of persons willing to pay relatively high prices for foods produced by "organic" or "natural" methods) would disappear. At the same time, there would be an increase in (a) income to farmers in the aggregate, (b) costs of food to consumers, (c) land values, (d) demand for (and wages of) farm labor and (e) soil erosion. In the long run, the balance of payments earned by export of agricultural products would decrease. These effects would flow from the decrease in production and the cultivation of additional more strongly sloping land that is less suited to production of row crops than the land now cultivated.

Both organic and coventional farmers are served by most current agricultural research, but research on commercial fertilizers and pesticides mainly benefits conventional farmers. In earlier years, most of the research done was on subjects that are now considered part of organic farming.

Organic gardening is considerably more attractive and feasible than is organic farming. The reasons are (1) the ease with which the organic matter grown in the garden may be supplemented with organic matter grown elsewhere, (2) the feasibility of manual weed control, (3) the ability to choose those fruits, vegetables and ornamentals that can be grown satisfactorily without pesticides and (4) the ability to purchase the needed products without suffering a financial disaster if the yield is poor or if part of the produce is destroyed by pests.

OVERVIEW

In crop and livestock production practices, conventional and organic farming have more in common than not. The principal divergence is in the use of modern chemical technology. Conventional farmers use fertilizers, pesticides and animal feed additives where they seem useful, but organic farmers prefer to avoid them.

The competitive, free enterprise system encourages individual conventional farmers to adopt technological innovations that increase their production and make it more efficient. In recent years, a number of the innovations have involved use of chemicals.

Many current proponents of organic farming would like to see less free play of market forces (which have led to larger farms), less specialization, and less dependence on technological inputs in farming. They would like to reduce the displacement of small farmers and what they see as a decline in some rural institutions.

The goal of organic farming was initially to formulate the best possible system for producing food in areas where neither transportation nor money was available to acquire production aids such as commercial fertilizers from outside sources. Overlaid on the original objective of organic farming, however, was the judgment that, except for "natural" products such as phosphate rock and limestone, importation of plant nutrients from off the farm for application to the soil is morally undesirable. In modern years, this judgment has been extended to include use of agricultural chemicals in general.

The organic movement commonly uses the word "organic" as a synonym for "natural," and it regards "organically grown" food as superior nutritionally to conventionally grown food. Scientifically, natural substances are not necessarily organic, and organic substances are not necessarily natural. As far as is known, conventionally grown plants are just as organic and just as nutritious as are organically grown plants, and both absorb virtually all of their supply of nutrients from the soil in inorganic forms.

The judgment about the acceptability of naturally occurring chemicals for use in agriculture has now been expanded by many in the organic movement to include the issue of safety. Natural chemicals are regarded as safe; chemicals synthesized by humans are considered hazardous. Scientifically, if a specific chemical compound is synthesized in a living organism, it is identical to the same compound synthesized in a laboratory. Where or how the chemical is synthesized is irrelevant as far as its properties and effects are concerned. A given use or a given human exposure produces identical effects irrespective of the origin of the chemical. For example, the "natural" methanol or wood alcohol that occurs in strawberries is the same as the "synthetic" methanol produced industrially by combining carbon monoxide and hydrogen. Methanol from both sources would cause blindness if ingested in excess, but the methanol in strawberries is safe because it occurs only in traces and would be ingested only in nontoxic amounts even if one were to eat nothing but strawberries.

Scientifically, hazard is determined by the toxicity of a substance and the exposure to it. Whether the substance is of natural or synthetic origin is irrelevant. Some natural chemicals, including organic chemicals synthesized by living organisms, are extremely toxic to humans, and some are essentially inert in the human body. The same is true of chemicals synthesized in laboratories or factories.

The judgment that importation of plant nutrients in the form of natural substances such as phosphate rock and limestone is a desirable practice, whereas importation of nutrients in the form of commercial or "artificial" fertilizers is not, is to be regarded as an arbitrary distinction, not a scientific distinction. Both organic and conventional farmers use limestone on their soils when needed; organic farmers and some conventional farmers use phosphate rock.

The founder of organic farming, Sir Albert Howard, considered that the basis of permanent soil fertility is the return of organic matter to the soil. This is a concept with some validity for natural ecosystems, but it is inapplicable to the needs of modern society in which the harvested portion of crops is removed from the land and part of the organic matter and plant nutrients is not returned. Under current practices, the amount of organic matter returned to the soil is frequently greater in conventional farming than in organic farming because of the greater yield.

Organic farmers prefer to use phosphate rock and potassium salts as mined to provide supplemental phosphorus and potassium, whereas conventional farmers use mostly processed forms in commercial fertilizers. Commercial phosphorus fertilizers have greater solubility and availability to plants than does phosphate rock, and they often contain phosphorus in higher concentration. Commercial potassium fertilizers contain potassium in higher concentration than do potassium salts as mined, but both are relatively soluble and available to plants.

To meet nitrogen needs, organic farmers prefer to use leguminous crops, which have the capability to remove nitrogen gas from the atmosphere and convert it to nitrogenous compounds useful to the crop. The nitrogen left behind by leguminous crops supplies part of the needs of the succeeding nonleguminous crops, and the cropping system is built around the legumes as a source of nitrogen. Conventional farmers used to follow the same practice because commercial nitrogen fertilizer was too expensive to compete with legume nitrogen. After World War II, fertilizer nitrogen became available in increasing quantities at relatively low prices. To meet the nitrogen requirements of their nonleguminous crops, many conventional farmers then substituted fertilizer nitrogen for a part or all of the legume nitrogen and added extra fertilizer nitrogen to the extent that seemed economically advantageous. The result has been a more than tenfold increase in amount of nitrogen fertilizer used per year and a decrease in use of legumes to supply nitrogen.

Nitrogen and other nutrients are returned to the soil in animal manure in both conventional and organic farming, but manure returns only a part of the nutrients removed by crops. The total amounts of nitrogen, phosphorus and potassium added in manure are small in comparison with the amounts of these nutrients supplied in commercial fertilizers.

Synthetic pesticides were of little significance in agriculture in Sir Albert Howard's time, but they are of great significance today in conventional farming. Organic farmers, however, prefer not to use them.

On most farms, the principal agricultural pests are weeds. Both conventional and organic farmers use a variety of weed-control practices, and conventional farmers make extensive use of herbicides. Herbicides are applied both to prevent weeds from emerging and to kill those that have already emerged. Herbicides are most useful for controlling weeds that cannot be killed by mechanical cultivation--weeds that grow in crop rows and in crops that are not cultivated. Weed control by herbicides is especially important for small-seeded crops that would otherwise require hand labor to remove the weeds growing in the rows.

Both conventional and organic farmers use a variety of methods to control insects. Insecticides are usually used by conventional, but not organic, farmers to control insect infestations that have already developed. The desirable practice is to make applications only when the infestations are sufficient to cause significant economic losses if not checked. The current trend toward integrated pest management or IPM, which attempts to put together the optimum combination of practices for insect control, is a trend away from reliance on chemicals. Insecticides are used when needed, however, and so integrated pest management is not acceptable to organic farmers who avoid their use.

The most important biological means of controlling insect, disease and nematode pests is development of resistant crop varieties. This technique has had greatest success in controlling diseases, and it is used by both conventional and organic farmers. Some vegetable crops are susceptible to diseases for which there is no feasible control except fungicidal sprays, and only conventional farmers can grow these crops successfully. Also, treating seed with a small amount of an appropriate fungicide improves seedling establishment, especially in years when the soil is cool and wet at planting time. At present there is no effective substitute for such seed treatment.

Nematodes that attack crop roots can be controlled to some degree by crop rotation and suitable tillage (resistant varieties are available for a few crops), but use of nematicides often results in increased crop yields that could not have been achieved by any alternative method.

In conventional farming, chemical sprays are sometimes used near harvest to cause plants to dry out or to drop their leaves. With a number of crops, including cotton, potatoes, beans and sorghum, this practice has several economic and biological advantages. Chemicals are used also to protect fruits and vegetables from diseases that cause decay; this permits shipment of fresh produce from one section of the country to another for year-around availability.

The produce from organic growers is often sold at relatively high prices to persons who are willing to tolerate imperfections in return for assurance that commercial fertilizers, pesticides and additives have not been used. Although analyses of "organic" products for pesticide residues indicate that the faith of consumers in the claims is not well placed, the residues, which are monitored by the Food and Drug Administration, have been found in only very small quantities and present no significant hazard to public health.

As energy became a national issue, so also it became a basis for debate of conventional vs. organic farming. Both conventional and organic farming are largely powered by fossil fuels, but conventional farmers use more energy per acre than do organic farmers. Of principal concern in the debate is the energy used for fertilizers and pesticides because organic farmers prefer not to use these products. Fertilizers accounted for an estimated 33 percent of the total energy input in production agriculture in the United States in 1974, and the production of pesticides accounted for 5 percent. Agricultural production consumed 3 percent of the total amount of energy used in the United States, which means that fertilizers and pesticides accounted for about 1 percent of the energy used. As may be inferred from the next paragraph, however, adopting organic farming methods would not decrease the national energy utilization by 1 percent if additional land with lower yielding capability were farmed to make up for the lower yields obtained with organic farming.

Adoption of organic methods by farms now using a mixed grain-livestock system would result in decreases in crop yield estimated at 15 to 25 percent per acre if there were little or no change in cropping pattern. If nonlivestock farms were to adopt organic methods there would be a considerably greater decrease in total U.S. yield of the high-value crops because the acreage of these would be reduced by introduction of legumes into the crop rotation to supply nitrogen. To offset a 15 percent decline in production on present land from adoption of organic farming methods would require 18 percent more of the same kind of land to produce the output obtained by conventional methods. Because currently this amount of the same kind of land is not available, the additional land would be less productive, and more of it would be needed. If legumes were to become part of the cropping sequence on intensively cropped, nearly level land, more row crops would have to be planted on the sloping land to maintain the output; this would mean increased erosion.

In conventional farming, extensive use is made of nutritional supplements in animal feeds. Mineral and other nutritional supplements increase animal productivity, and they are of greatest importance in feeds for poultry and swine. In cattle feeding, considerable use is made of urea as an economical, nonprotein source of nitrogen. The minerals and nonprotein nitrogen used to improve the nutritional quality of animal diets in conventional farming improve also the quality of the manure as fertilizer because much of the quantity of the nutrient elements supplied in the feed is excreted in the manure.

Further increases in production efficiency are achieved in modern conventional animal agriculture by use of hormonally active substances. Some of these substances increase the rate of gain and reduce the amount of feed required per pound of body weight gained by 10 to 15 percent.

Certain drugs are now approved by the Food and Drug Administration for use to protect animal health and to increase production efficiency. Drugs are useful in both conventional and organic systems of farming, but organic farmers prefer not to use them.

If organic farming were widely adopted, the price advantage to organic farmers from supplying a specialty market would disappear, but the income to farmers in the aggregate would increase, and the costs of food to consumers would increase. The principal reason is that total production from the land under cultivation at the time of the change would decrease, and the percentage increase in price of agricultural products would exceed the percentage decrease in production. Increased net farm income would lead to higher land values throughout the United States. Thus,

current landowners would benefit, but additional financial constraints would be imposed on the entrance of potential new farmers.

Widespread adoption of organic farming would encourage cultivation of additional, less productive land that is not now cultivated. The additional labor required to farm this land, plus whatever increase in labor intensity might be needed for use of organic methods on land previously cultivated by conventional methods, would cause the demand for, and wages of, farm labor to increase. Exports of agricultural products would be adversely affected. One national model indicates that, in 1980, the amount of wheat plus corn available for export would be 4.6 billion bushels under conventional farming and 0.9 billion bushels under organic farming. In the long run, the price increases resulting from decreased production would encourage importing countries either to increase their own production or to seek other sources, thus reducing the dollar value of U.S. agricultural exports and increasing the balance-of-trade deficit.

Both organic farmers and conventional farmers are served by most current agricultural research, but research on fertilizers and pesticides mainly benefits conventional farmers. In earlier years, much research was done on subjects that are now considered part of organic farming.

Now receiving emphasis in fundamental nitrogen research is the means of developing the capability of nitrogen fixation in nonleguminous plants. Although success in this endeavor is not soon anticipated, it would put the controversy between organic and conventional farming in quite a different light than that in which it is viewed at present.

Considerable research is being conducted also on "conservation tillage" methods. Except for the use of herbicides, some of these methods are more "organic" than the usual organic farming in that they use less tillage (and, hence, produce less rapid decomposition of soil organic matter) and produce more legumes than the usual organic farming.

Organic gardening is more attractive than organic farming. The most important distinction is the ease with which the organic matter grown in the garden itself may be supplemented by organic matter derived from other sources. The organic matter contains plant nutrients and reduces the need for fertilizers. If there is much extra organic matter, it is best handled by composting it temporarily.

A second distinction between organic gardening and organic farming is that gardening without use of herbicides to control weeds is much easier than farming without herbicides because weeds can be controlled manually and by mulch systems on the small areas involved. A third distinction is that organic gardeners have greater freedom of choice than do organic farmers in the fruits, vegetables and ornamentals they grow. Organic gardeners can select the plants they can grow satisfactorily without pesticides. A fourth distinction is that, if the yield is poor or if part of the produce is destroyed by pests, the organic gardener can purchase the needed products without suffering a financial disaster.

INTRODUCTION[1]

The basic concern of this report is the agricultural systems by which food and fiber are produced. Agricultural systems have been evolving through the years with the introduction of technology that has been adopted because of the profitability it offered to individual producers. The outcome of the continuing adoptions of new technology in the competitive, free-enterprise system, however, has been the transfer of most of the financial benefit to consumers in the form of low prices for food purchased domestically, plus additional national income from food exports.

During the past three decades, changes in agricultural technology have been pronounced, and much of the increased productivity that has occurred is a consequence of use of chemicals. With these changes has developed increasing public concern about the safety and quality of the food and about the systems by which food is produced. Agricultural production systems have been questioned on such grounds as their direct effects on long-term soil productivity and energy utilization as well as their indirect effects on wildlife, water quality and other aspects of environmental quality.

Viewed by some as an important, if not essential, substitute for conventional modern agriculture with its industrialization and technological inputs is an alternative system of agriculture, commonly termed "organic." Organic farmers, by and large, accept without question the advances in applied genetics and biology, and accept to varying degrees the mechanization, but prefer to avoid the use of chemical technology. In the words of Robert Rodale (State of New York, 1972), a journalist who is regarded as the current leader of the organic movement in the United States,

> Organically grown food is food grown without pesticides; grown without artificial fertilizers; grown in soil whose humus content is increased by the additions of organic matter; grown in soil whose mineral content is increased with applications of natural mineral fertilizers; has not been treated with preservatives, hormones, antibiotics, etc.

The "organic" movement is controversial, and the scientific, economic and sociological bases for conventional farming and organic farming are not well known to many persons who are concerned with the controversy. Hence, the purpose of this report is to provide factual information on the subject that should be helpful as a basis for understanding and rational decision-making.

We shall discuss first the evolution of the two systems. Next we shall discuss their commonality, the problems that exist in terminology and value judgments, and the scientific basis of what we perceive as the principal controversial issues. Then we shall discuss the implications of increased adoption of organic farming methods, and organic farming research. At the end, we shall discuss organic gardening. The reason for considering organic gardening separately from organic farming is that, although organic gardeners tend to share Rodale's philosophy about the way food should be produced, the physical and economic circumstances related to organic gardening are different from those of organic farming. In other words, organic gardening is not to be regarded as small-scale organic farming.

EVOLUTION OF FARMING SYSTEMS

This document is concerned primarily with the agronomic, economic and environmental aspects of conventional and organic farming systems. Insofar as feasible, broader sociological implications are taken into account; but these are less well researched, exceedingly complex, and far more controversial. As an aid to understanding the differences between conventional and organic farming, it may be helpful to review the origins of, and motivations behind, the two systems.

Conventional Farming

The production methods currently employed in much of U.S. commercial agriculture developed in response to a market economy based on profit incentives. Through the competitive, free-enterprise system, agriculture has been encouraged to move in the direction of greater production and greater efficiency of production, specifically:

1. To produce food in greater quantity and with better quality. The food supply in the United States has consistently met the needs of our increasing population and has provided for continuing improvement in the quality of the diet. In many countries, nutritional deficiencies from inadequate food supplies are still leading causes of disease and misery.

2. To substitute machinery and pesticides for human and animal labor. The consequence has been a reduction of drudgery, the release of workers for industrial and other manpower needs, and the release of land to produce food for humans instead of feed for work animals.

3. To increase per acre yields on cropland. The consequence has been less need for farmland and greater availability of land for other purposes including forests, parks, conservational areas, home sites, highways and industry.

4. To broaden the available food selection. The consequence has been an improvement in the nutritional quality of the diet and an enhancement of the pleasure of eating.

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[1] While this report was in galley proof, a USDA publication on the same subject appeared in print (Papendick et al., 1980).

5. To protect food commodities from insects, diseases and nematodes. The consequence has been improved capability to transport the commodities considerable distances and/or to store them for long periods so their use is not limited to local consumption soon after harvesting. Today, there are often great distances between where food is produced and consumed. (Of course, many vegetables and most fruits are still most flavorful when harvested fully ripe and eaten at once.)

Despite their willingness to adopt new technologies that help to keep them competitive, conventional farmers continue to associate good soil management with maintenance and improvement of soil fertility, with addition of organic matter to the soil, and with use of soil conservation practices. For economic reasons, however, neither conventional farmers nor organic farmers in the aggregate use the best soil conservation practices available.

Organic Farming

The organic farming concept, though ancient in principle, was enunciated as a defined system prior to World War I by Sir Albert Howard, Director of the Institute of Plant Industry in Lahore, India. His goal was fundamentally economic: to formulate the best possible system for producing food in areas where neither transportation nor money was available to acquire production inputs such as fertilizers from outside sources. The contemporary organic farming movement in the United States traces to J. I. Rodale (now succeeded by his son, Robert) who began publishing a magazine on the subject in 1942.

As an aid in understanding the arguments for organic farming, it is helpful to consider the social movements from which organic farming is derived and by which it is reinforced. Organic farming in the contemporary context may be regarded as part of a larger social movement that has been termed the "alternative agriculture movement;" this includes the "biodynamic/French intensive method" (Jeavons, 1977, 1979) and numerous unnamed variations.

This movement emerged on the heels of environmentalism in the late 1960s, although alternative agriculture has had a longstanding constituency. The larger movement is rooted in two major social concerns of its proponents: (1) that techniques of modern agriculture involve significant environmental and health risks (e.g., in the words of Robert Rodale (State of New York, 1972) "Agriculture is now a major source of pollution in this country, and we are not going to want that to continue. The organic method is the only non-polluting form of agriculture....") and (2) that the structure of modern agriculture (i.e., increasing farm size, specialization, uprooting of farm people) has undesirable social consequences for some people and rural communities (Goldschmidt, 1978; Perelman, 1977).

A principal characteristic of social movements is that they seek social change away from present institutional arrangements; this desire for change tends to be interpreted by "outsiders" as being irrational and unnecessary. However, it should be kept in mind that most social movements tend to emerge in response to needs perceived to be legitimate by their leaders.

Typically, the advocates and detractors of a given movement make claims and arguments for their cause that may be interpreted as 'extreme.' Critics and defenders of U.S. agriculture tend to follow this pattern as they seek to support their points of view. Further, each side tends to inflate the claims made by the other to make its refutations and counter-arguments more persuasive. As a result, both organic and conventional agriculture must be evaluated in a somewhat less polarized sense than is apparent at first glance.

Generally, the alternative agriculture movement includes a complex collection of persons and organizations, as well as practices, goals and tactics. The production practices of organic farmers are incredibly varied--depending largely on the stage of transition away from use of chemical technology, size of the farm operation, nature of markets, climate, soil, etc.

Garth Youngberg (1978) argues that "Alternative agriculturalists are not well organized." They have no national umbrella organization and virtually lack state- or Washington-based lobbyists. In fact, most movement adherents tend to be skeptical of such a centralized organization approach on ideological grounds.

This lack of movement organization is surprising considering the apparent number of movement supporters; for instance, over one million persons subscribe to *Organic Gardening*. However, the actual number of organic farmers is small--probably 15,000 or less (see Youngberg, 1978). Much of the support for the alternative agriculture movement is from persons skeptical about the safety of conventional food, certain consumer groups, research and advocacy organizations, and some environmentalists.

COMMONALITY OF CONVENTIONAL AND ORGANIC SYSTEMS

Although the controversy between proponents of organic and conventional systems of farming may at times become heated, the fact is that there is more commonality between the systems than might be inferred from the arguments. For example, to comment on Rodale's (State of New York, 1972) description of the system by which "organically-grown food" is produced, we would note that "natural mineral fertilizers" that perform satisfactorily are used by some conventional farmers as well as organic farmers. Limestone, a naturally occurring substance, is applied to acid soils by both conventional and organic farmers. Limestone is a source of calcium and, often, magnesium as well. Organic matter is added to soil in both conventional and organic farming. In both conventional and organic farming, the soil "humus" is derived from plant materials and from animal manures, which in turn were derived from plant materials.

Rodale's description of the system for producing organic food is couched in terms of technological inputs rather than actual operations, and it tends to obscure the fact that neither conventional farming nor organic farming is a distinct entity. Farming involves many practices, and these vary with the circumstances and with the farmer, whether the individual

concerned is regarded as a conventional farmer or an organic farmer. Moreover, certain practices that are appropriate for the conditions and objectives of the operation tend to be common to both conventional and organic farmers. These practices include returning crop residues and animal manures to the soil; growing leguminous crops; using similar breeds of livestock, types of machinery, crop varieties, and methods and rates of planting; and using similar times and methods of harvesting, drying, storing and marketing the products.

ORGANIC AND SCIENTIFIC TERMINOLOGY

The crux of Rodale's description of the system by which organically grown or organic food is produced is the negative parts that apply to chemical technology and serve to define organic farming in terms of nonuse of such technology. We shall now examine in brief the organic and scientific terminology as related to the chemical technology of agriculture, an exercise that will lead to further appreciation for the considerable commonality of organic and conventional farming.

The terms "natural" and "organic" are often used interchangeably in the terminology of organic farming, but not in the terminology of science. In the terminology of science, organic chemistry is the branch of chemistry that deals with carbon compounds. Many such compounds occur in nature, and many are synthesized in laboratories and factories. (Certain simple compounds of carbon such as carbon monoxide are generally considered to be inorganic.) But many inorganic or "nonorganic" compounds also occur naturally, and they occur along with organic compounds in many substances, including our bodies, foods and soils. Hence, in scientific terminology, natural compounds are not necessarily organic, and organic compounds are not necessarily natural.

When chemistry was in its infancy, chemists did indeed believe that organic compounds could be produced only in the presence of a vital force found in living organisms, and it was in those days that the term "organic chemistry" was developed. This misconception fell in 1828, however, when the German chemist Wöhler synthesized urea, an organic compound, in the laboratory.

Urea may be used to illustrate certain scientific inconsistencies in terminology and judgments made by those associated with organic farming. Urea is a natural organic waste product of human and animal metabolism that contains 47 percent nitrogen by weight. It is present in animal excreta as voided and, hence, according to Rodale's definition of organically grown foods quoted in the introduction of this report, it should qualify as a natural, nonartificial nitrogen fertilizer for producing organically grown foods. According to the same definition, however, the urea that is synthesized in factories, which is chemically identical to the urea produced by human and animal metabolism and is widely used as a nitrogen fertilizer in conventional farming, is not an acceptable nitrogen fertilizer for producing organically grown foods because it is "artificial."

To carry the analysis one step further, the urea in both animal manures and commercial fertilizers undergoes rapid enzymatic hydrolysis in the manure or the soil to ammonium carbonate. The ammonium is transformed further to nitrate, and most of the urea-derived nitrogen absorbed by plants is taken up as nitrate. The ammonium and nitrate derived from urea produced in fertilizer factories are indistinguishable from the ammonium and nitrate derived from urea produced in humans and animals, and both these ions are inorganic, not organic. Therefore, in scientific terminology, the organically grown food produced with urea derived from animals as a nitrogen source is actually "inorganically grown."

Although the various plant nutrients behave differently, there is no evidence that "organically grown" plants are organically nourished. The evidence is that they are mostly inorganically nourished and that the same is true whether plants are grown by conventional or organic farming methods.

The nutrients that are essential for plant growth are present in living plants partly in organic form and partly in inorganic form, and the same is true when the plant residues are added to the soil either directly or after passage through animals. If present initially in soluble inorganic forms, the nutrients added to the soil in these organic materials mix promptly with the inorganic forms of the same nutrients in the soil solution; or they mix gradually if they are present initially in organic forms and are changed to inorganic forms during decomposition by the microorganisms that live in the soil. The quantities of the nutrients supplied by the soil, previous generations of plants, manure and commercial fertilizers all contribute to a mixture of inorganic nutrients that nourishes the next generation of plants. The potassium, for example, that is present in the soil solution is chemically the same, whether it comes from one of these sources or another, and plants do not distinguish among the potassium ions they absorb from the various sources.

Under some circumstances, certain micronutrients such as iron and zinc can be applied to soils and absorbed by plants more effectively in simple synthetic organic forms (chelates) than in inorganic forms because of rapid interaction of the inorganic forms with the soil to reduce their solubility, but it is not known that such a mechanism mediates the uptake of these elements by plants growing in soils in the absence of added chelates. If it does, it should operate under both conventional and organic farming.[2]

There is no evidence that humus as such is required for plant growth. Higher plants and certain microorganisms can make good growth on solutions of inorganic nutrients (hydroponic cultures) to which no organic matter is added.

Finally, we turn to "organic food," which is a product of organic farming. In scientific terminology, foods are composed of chemicals. Most foods contain many chemicals, and most of these are organic chemicals, whether the foods are produced by conventional farmers or organic farmers. For example, more

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[2] The combined results of 47 experiments in six southeastern states show that the iron content of turnip greens increased significantly with the organic matter content of the soil (Speirs et al., 1944).

than 100 organic chemicals have been identified in the tomato (Buttery et al., 1971), and more than 150 in the potato (Talburt and Smith, 1975).

Plants may absorb simple, soluble organic substances through the roots, but such substances are not normally present except in trace quantities in soils, whether conventionally farmed or organically farmed, and they are not known to be absorbed in more than trace quantities by plants. Virtually the total amount of the organic chemicals that constitute upwards of 95 percent of the dry weight of most plants (and all of that produced in plants grown on solutions of inorganic nutrient salts) is synthesized by the plants themselves, and there is no evidence that conventionally grown and organically grown plants differ in this regard. Thus, as far as is known, conventionally grown plants are just as organic in the scientific sense as are organically grown plants. Moreover, there is no evidence that plants synthesize a different set of organic compounds when they are organically grown than when they are conventionally grown.

Although organically grown foods are sometimes said to be superior in nutritive value to conventionally grown foods,[3] this allegation has yet to be sustained experimentally.[4] The available evidence, obtained from chemical analyses and animal feeding trials, indicates that the nutritive value of organically grown and conventionally grown foods is about the same (Appledorf et al., 1973, 19 ,[5] Arnon et al., 1947; Brandt and Beeson, 1951; College of Agriculture, Michigan State University, 1955; Schuphan, 1974).

Additional experiments with ample supplies of nutrients but different modes of pest control would supply information on the implications of the pest-control aspects of organic versus conventional methods for food quality. As may be inferred from page 18 of this report, there is no evidence that residues of modern pesticides in foods have any detrimental effect on human health. There is ample evidence, however, that numerous illnesses and deaths of domestic animals and humans caused by mycotoxins in feeds and foods could have been prevented by suitable use of pesticides and decontamination treatments (Diener et al., 1979).

ISSUE NO. 1: SOIL FERTILITY

According to an article written by Robert Rodale (1973),

> the basis and enduring foundation of the organic farming system (Sir Albert Howard) created was the placing of first priority on the building of soil fertility more by completing the cycle of organic life, and less by using fertilizers imported from other regions... It was Sir Albert Howard's special contribution to emphasize that the continual and enthusiastic replenishment of soil organic matter could create a permanently productive kind of agriculture that didn't need to rely on imports of fertilizer from outside the farm to maintain fertility year after year. He did recommend the use of mild and natural soil conditioners--such as limestone and phosphate rock--to supplement the release of nutrients from the average soil's impressive store of insoluble reserves.

Quoting from the book *The Soil and Health* by Sir Albert Howard, Rodale continued:

> Having exhausted the possibilities of production from his own fields, he (the farmer) has actually had the temerity to transfer to those fields the stored-up natural wealth, representing centuries of accumulation, lying many thousands of miles away. The importation of feeding stuffs, of guanos and manures of all kinds from distant parts of the world is only robbery on a vast scale. It is not necessary to claim that every national agriculture must be completely self-contained: This would be a great pity. But the tide has been all one way.

Although the view that importation of nutrients and feedstuffs (which contain nutrients) is robbery is inconsistent with the recommendation that phosphate rock and limestone be imported for addition to soil,

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[3] For example, in a public hearing on organic foods (State of New York, 1972), Robert Rodale testified that "... there are many factors that influence the nutritional value of food and many of these factors are part of the organic system.... Now, if a farmer wants to produce food that is nutritionally superior, he can use all varieties of methods and do that.... And organic farmers are encouraged to use as many of these methods to improve nutritional value as they can practically, and it is absolutely incorrect as some people have said here this morning that there is no difference in the nutritional value."

[4] Conversely, conventional foods are sometimes said to be lacking in nutritional value because the fertilizers added to soils to aid in plant production do not contain all the nutrients plants need. This allegation similarly has yet to be sustained by experimental evidence. It is true that commercial fertilizers do not contain a complete assortment of nutrients, although they could and, in fact, they do when plants are grown hydroponically. It is equally true that "natural mineral fertilizers" favored by organic farmers do not contain a complete assortment of nutrients. When both conventional and organic farmers add nutrients to soil, the objective is to supply the plants with the nutrients that are deficient in the soil, as indicated by increases in yield associated with application of the nutrients. As deficiencies of more nutrients develop, a wider assortment of nutrients is required.

[5] Appledorf et al. (1974) purchased 25 pairs of standard food items in "health" food stores that sold their foods as "natural" or "organic" (personal communication) or in supermarkets and had them evaluated by sensory perception. The panel ranked about half of the supermarket items significantly above their natural or organic counterparts in overall acceptance. None of the natural or organic food items was found superior to the supermarket items in overall acceptance.

The Howard-Rodale philosophy seems to equate soil fertility maintenance with the return to the soil of organic matter produced by plant growth on the soil. There is much truth in this philosophy for natural conditions in which crops are not removed, but it is fallacious where agriculture is concerned.

Under natural, nonagricultural conditions, the nutrients that are removed from the soil by plants are returned to the soil along with the organic matter produced by the plants, and there is generally an effective recycling process so that losses of nutrients by leaching and soil erosion are relatively small. Soil fertility is then maintained with but slow change at whatever level is characteristic of the soil in question.

Crop production in both conventional and organic farming brings about a much more rapid depletion of nutrients because parts of the crop are removed and used for animal feed or human food. Although organic farmers and most conventional farmers return to the soil the portions of the crop that are not harvested and the manure from any livestock, thereby returning both organic matter and nutrients, much of the quantity of nutrients removed in the harvested portion of crops is not returned to the soil from which the nutrients were removed. If importation of organic matter and nutrients from other areas is to be looked upon as robbery, a practice in which one should not ethically engage, the fertility of soils used for crop production then declines. How soon the depletion of nutrients is reflected in decreased crop yields will depend on the circumstances.

The organic matter returned to the soil in both conventional and organic farming will maintain the content of organic matter in the soil at a level that in most instances is much lower than that which existed under the uncultivated, uncropped condition. In comparing the impacts of conventional and organic farming on soil organic matter, therefore, an important question is the relative amounts added in the two systems.

Surprisingly, decomposition of the unharvested portions of the crops in a conventional farmer's wheat-corn-soybean rotation results in about the same addition of humus (1433 pounds per acre) as do the crops in an organic farmer's rotation of corn-wheat-alfalfa hay (1533 pounds per acre) if the yields of corn and wheat are the same in the two rotations. See Table 1. A crop of oats returns slightly less humus than wheat. And corn harvested for grain contributes more to the soil humus supply than does corn harvested for silage, even taking into account the manure returned to the soil.

News stories describing large increases in soil organic matter due to adoption of organic farming suggest deficiencies in sampling, testing and understanding. For example, an Iowa report (Yacknin, 1978) stated that the soil humus content on one organic farm had been raised from 1.8 percent in 1967 to 6.7 percent in 1977. That corresponds to a net gain of about 13,000 pounds of humus per acre per year to a depth of 8 inches (see Table 1 for more realistic values for humus additions). Information supplied, however, indicates that the additions of organic matter from

Table 1. Estimated additions of humus to the soil by several crops (Lucas et al., 1977)

Crop and yield of harvested portion[a]	Estimated humus additions from indicated portion of plants, lb/acre[b]		
	Above ground	Below ground	Total
Corn (only grain removed)			
100 bu/acre	1240	670	1910
Soybeans (only grain removed)			
32 bu/acre	660	310	970
Wheat (only grain removed)			
45 bu/acre	930	520	1450
Field beans (only seed removed)			
15 cwt/acre	410	150	560
Alfalfa (first year, only hay removed)			
3 T/acre	230	1010	1240

[a] Values in this column are yields of the portion of the crop harvested and not returned to the soil, expressed with the standard moisture content for the air-dry product.

[b] Values in these columns are based on the assumptions that 30 percent of the carbon in the plant residues added to the soil becomes humus and that humus contains 58 percent carbon.

crops grown and from animal manures would be sufficient only to offset approximately the losses of soil humus due to decay and soil erosion.

Probably due in large part to the use of conventional farming methods, the present trend in terms of plant and animal residue additions to the soil is upward rather than downward, even in the Corn Belt. In Illinois, for instance, the amount of residue added in all forms, including green manure crops and animal manures (not including weeds) today is an estimated 60 million short tons, compared with 31 million tons in 1950 and 30 million in 1920,[6] when the practices then used by many of the farmers would be considered to be organic farming in current terminology. Furthermore, the additional fertilizer nitrogen (approximately 900,000 tons in 1978) helps convert the highly carbonaceous residues into humus.

On the other hand, one might expect that the increase in row crop acreage associated with conventional farming would lead to greater loss of humus through erosion. Stall and Lee (1978) found that soil losses from the more rolling watersheds in Illinois were indeed increasing, whereas the losses from the more level, most intensively cropped watersheds, though serious, were on a downward trend.

The evidence in the preceding paragraphs does not support the view that conventional farming and organic farming differ greatly in their effects on soil organic matter. In general, conventional farming probably adds more organic matter than organic farming because crop production is greater. And, in general, the loss of organic matter by soil erosion is probably greater with conventional farming than with organic farming.

Tillage, practiced in both conventional and organic farming (more in the former than in the latter), generally increases soil erosion and microbial decomposition of humus in the soil. Today, however, farming systems involving reduced tillage, even no tillage, are gaining favor with many farmers because these systems reduce soil erosion, save labor and energy, conserve moisture and improve soil tilth. These improvements in practice are most acceptable to conventional farmers because less tillage and more crop residues on the surface of the soil often require the use of additional pesticides to control weeds, diseases, nematodes and insects--a tradeoff not considered appropriate by organic farmers.

ISSUE NO. 2: SAFETY OF CHEMICALS

Many proponents of organic farming are concerned about possible adverse effects of "synthetic" or "non-organic" (man-made) pesticides and fertilizers. "Natural" or "organic" substances are considered safe, whereas those synthesized or processed by humans are viewed as harmful. In some instances, this distinction may be related to a fear of chemicals without due appreciation of the fact that all substances are made up of chemicals.

The argument is expressed in various ways by various persons. In the words of Barry Commoner (1979), for example, "Every compound that's made in living things has to be compatible with life."

The fact is that some chemicals synthesized by living things are produced in sufficient quantities to harm the organisms that produce them. Alcohol is an example. If enough fermentable material is present, the yeasts that form alcohol are eventually killed by the alcohol they produce.

And some chemicals produced by certain living things are toxic to other living things. Antibiotics are an example. These are chemicals produced by certain microorganisms (some are now produced synthetically) that limit the growth of other microorganisms or actually kill them. We use the ones that are sufficiently compatible with human and animal life to produce more benefit than harm. Mycotoxins are another example. These chemicals produced by fungi (molds) sometimes result in illness and death of animals and humans. Mycotoxins may produce birth defects, spontaneous abortions, tremors, cancers and other effects. One of these substances, aflatoxin B_1, is the most potent, naturally occurring, cancer-producing substance known (Diener et al., 1979).

Poisonous plants are common, and they are frequent causes of abortion, sickness, and death of livestock, particularly those that graze on natural range vegetation. Humans also may be affected. Even plants that are commonly eaten as human food, and are not regarded as poisonous, contain many chemicals, each of which would have detrimental effects in excess, and some of which would be poisonous in only small quantities. The Irish potato is an example. The potato contains compounds known collectively as solanum alkaloids (or solanine) that are toxic to humans if ingested in quantities considerably greater than those we normally get in potatoes. In earlier years, when people ate more potatoes and when some of the varieties used contained more of these alkaloids than the modern varieties, there were occasional solanum-alkaloid poisonings. If even low-solanine potatoes are exposed to light and turn green, the green portion may develop enough toxic material to cause illness if eaten in sufficient quantity (Zettel, 1937).

The view that "natural" or "organic" substances are safe applies to the ones humans have learned through experience are safe for almost all persons, as commonly used. But the examples given show that it does not apply to all natural substances or to all the components of the natural substances we use as food. Moreover, the view does not apply to all people. Some persons are allergic to foods that can be eaten safely by others.

One more important point that must be clarified is the fact that where or how a specific chemical compound is formed is irrelevant as far as the properties and effects of the compound are concerned. Today, many of the simpler organic substances produced by living organisms can be synthesized in the laboratory by chemists. When the synthetic version of a naturally occurring organic chemical is produced in a laboratory or factory, the resulting chemical is identical to the one produced naturally by plants or animals. Thus, for example, vitamins are the same organic chemicals and have the same effects whether synthesized in a laboratory or by living organisms.

Chemicals in general, and organic chemicals in particular, cannot be classified as safe or unsafe on

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[6] Estimations by S. R. Aldrich based upon crop acreages, yields and livestock numbers.

the basis of their origin. Some organic chemicals that are synthesized by living organisms are extremely toxic to humans (e.g., botulinum toxin and aflatoxin B_1), and some are essentially inert in the human body (e.g., cellulose). Some organic chemicals that are synthesized in the laboratory (e.g., TCDD or dioxin[7]) are extremely toxic to humans, and some are essentially inert in the human body (e.g., plastics).

A chemical becomes hazardous only when the degree of exposure is sufficient to cause toxic effects. Even the most highly toxic chemicals present no known hazard if the exposure is low enough. For example, parathion and carbofuran are highly toxic manmade chemicals not known to be synthesized in nature, but they may be used with little hazard if they are properly handled. Probably everyone is exposed to minute quantities of naturally occurring aflatoxin B_1 and TCDD, but recognizable toxic effects appear only with far greater exposures. The thousands of chemicals that constitute the food supply are collectively beneficial in the quantities normally ingested, but all would have detrimental effects if ingested individually in excessive quantities. For example, seven infants died in a Binghamton, New York, hospital when common table salt was added to their formula under the impression that it was sugar (Anonymous 1962, 1962a).

When highly toxic chemicals are used because of their useful properties, precautions must be taken to assure that human exposure does not exceed a safe level. For example, the pesticides known as parathion and Furadan are highly toxic substances not known to occur in nature, but they may be used safely if handled according to the directions on the label.

An unreasonable fear of chemicals has developed in recent years, and public alarm is now easily generated at the mention of compounds that are unfamiliar or bear exotic names. To illustrate, if it were proposed that acetone, acetaldehyde, methylpropyl ketone, methyl isovalerianate, isoamyl isovalerianate, methanol, o-methylpropylbenzene or β-phenylethylcaproate be added to fruit as a preservative or to enhance the flavor or aroma, a measure of public opposition could be expected, when in fact, all of these chemicals and many more occur naturally in ripe strawberries (Vereschagin, 1974). Of course, all could be harmful if ingested in excessive amounts. Acetone is sometimes used to remove varnish from furniture, and methanol is better known as wood alcohol, which, in sufficient dosages, produces blindness.

ISSUE NO. 3: SOURCES OF PLANT NUTRIENTS

The plant nutrients most often deficient in soils, and most often supplied in fertilizers, are nitrogen, phosphorus and potassium. One of the major differences between organic and conventional farming is the source of the nutrients used for crop growth. Most conventional farmers use commercial fertilizers that have been chemically processed, whereas organic farmers prefer to use "natural mineral fertilizers." Where nitrogen is concerned, organic farmers prefer to use leguminous crops to fix atmospheric nitrogen and to preserve this nitrogen for use by crops by recycling it in crop residues and animal manures.

Phosphorus

The natural mineral phosphorus fertilizer is phosphate rock (commonly called rock phosphate in agriculture), which is finely ground and mixed with the soil. Much rock phosphate was used as a fertilizer by conventional farmers in the United States at one time, but little is used at present.

Most of the rock phosphate that occurs in the United States has low solubility and low effectiveness as a source of phosphorus for plants. When rock phosphate is added to the soil, years are required for it to dissolve so the availability of the phosphorus can increase. For most rapid dissolution of rock phosphate, the soil must be strongly acid, a condition not conducive to good growth of the leguminous crops that are an integral part of organic farming.

In some parts of the world, the rock phosphate deposits are much more soluble than those in the United States. Efforts are now being made through the International Fertilizer Development Center at Muscle Shoals, Alabama, to develop the use of these deposits for direct application to soils as a source of phosphorus for plants.

Most of the fertilizer phosphorus used by conventional farmers is chemically processed in one way or another. An increasing proportion of the phosphorus used in fertilizers is present as highly soluble compounds such as ammonium phosphates that contain nutrient elements other than phosphorus, are more concentrated and more economical to ship than is rock phosphate, and are immediately available to plants. The phosphorus in such fertilizers quickly reacts with the soil to form compounds of lower solubility, but the substances of intermediate solubility persist for more than a year as a source of phosphorus of gradually decreasing solubility and availability.

The original treatment used to increase the solubility of the phosphorus in rock phosphate for use by plants was addition of fairly concentrated sulfuric acid. The added sulfuric acid disappeared, being neutralized by the phosphate rock, and the product was a solid consisting mostly of monobasic calcium phosphate and calcium sulfate. The product was often called acid phosphate in the early years, but later the name superphosphate was adopted because of the unfavorable connotation of "acid."

The use of sulfuric acid in making superphosphate sometimes leads those opposed to use of commercial fertilizers to suggest that the sulfuric acid makes the soil acid when superphosphate is used as a fertilizer. There is some indirect truth in this allegation. For example, agricultural soils would be acidified by adding superphosphate in large enough quantities to react with all the reactive substances in the soil, but this is not a realistic situation, and the reaction would be due to the monobasic calcium phosphate, not the sulfuric acid that was responsible for its formation. In practice, where superphosphate is added in small quantities, the monobasic calcium phosphate it contains interacts in different ways with different kinds of soils. If superphosphate is added to an alkaline soil that contains free calcium carbonate, the monobasic calcium phosphate acts as an acid and interacts with calcium carbonate, decomposing it and releasing carbon dioxide gas. The usual amounts

[7] TCDD is produced also when natural substances including wood and coal are burned, and it is of widespread occurrence in barely detectable traces in the environment (Chlorinated Dioxin Task Force, 1978).

of superphosphate added, however, would have no appreciable effect on the acidity of such a soil. On the other hand, if the usual amounts of superphosphate are added to a strongly acid soil, the monobasic calcium phosphate interacts as an alkali with clays and hydrous iron and aluminum oxides with the result that acidity is decreased. In most soils, addition of the usual amounts of superphosphate has no appreciable effect on the acidity one way or the other.

Potassium

The potassium used as a fertilizer in the United States is derived almost exclusively from salt beds produced from evaporation of bodies of water, mostly in earlier geologic time. The potassium salts in such deposits are soluble in water, and thus no special treatment is needed to make the potassium available to plants.

The potassium salts found in the salt beds are not pure, however, and it is uneconomic to transport the impurities along with the potassium salts for the long distances that separate the mines and most of the soils on which potassium is needed for crop production. For this reason, the potassium salts are usually purified at the site of mining by using water to remove the constituents not wanted.

Conventional farmers use the purified potassium salts, but organic farmers tend to prefer the potassium salts as mined if they are available. The sodium salts that usually constitute most of the impurities are useful for certain crops such as beets if adequate potassium is not present, but if applied in large quantities they may have unfavorable effects on some soils and crops. There may also be problems due to minor impurities that are toxic. For example, some of the first potassium fertilizer produced from deposits in the United States had disastrous effects on crops because of boron toxicity. The purification had not been conducted in such a way as to reduce the borate content to harmless or beneficial levels.

Nitrogen

Until the early 1900s, nearly all the nitrogen present in harvested crops in the United States was derived from that released upon decomposition of the soil humus, either directly or after recycling through previous crops or animal manures. Small quantities of atmospheric nitrogen were converted to plant-available forms by lightning and certain soil microorganisms.

Later, inoculated leguminous crops (alfalfa, clover, lespedeza and others) were introduced specifically to replenish nitrogen supplies for succeeding crops. The bacteria in the root nodules on leguminous crops convert atmospheric nitrogen into organic forms, and much of this nitrogen passes from the nodules into the main part of the plant, where it supplies the nitrogen needs of the plant. When leguminous plants are plowed under, they enrich the soil with nitrogen, and the microorganisms that decompose the residues then convert the nitrogen in the organic substances supplied by the leguminous plants to ammonium and thence to nitrate, which may be used as inorganic nitrogen sources by the crop that follows.

A system of "rotation" farming, in which crops were grown in a sequence with the crop demanding the most nitrogen following the legume, developed to take advantage of the nitrogen fixed by the legume. Crop rotations including legumes to supply nitrogen to the succeeding nonleguminous crops prevailed throughout much of the United States until the late 1940s and are still common on many livestock farms.

The primary schism between organic and conventional farmers, as far as nitrogen sources is concerned, developed following World War II, when synthetic nitrogen fertilizers first became available at relatively low prices. Conventional farmers then began using nitrogen fertilizers in increasing quantities. The results were profound changes in crop and livestock specialization by farms and by regions. For instance, farmers increased the acreage of corn and soybeans (high-return crops) and reduced the acreages of small grains, legume hay and green manure, making up the nitrogen deficiencies with synthetic nitrogen fertilizer. They also modified other production practices and greatly increased the yields of nearly all crops in all regions. This, in turn, increased the amount of nitrogen that was needed and could be efficiently utilized by crops.

In the following paragraphs, we shall assess the advantages and limitations of the various sources of nitrogen other than commercial fertilizers that are utilized in both conventional and organic farming. Then we shall discuss the pollution potential, which is one of the principal controversial aspects of commercial nitrogen fertilizers. The energy requirement for producing synthetic nitrogen fertilizers, another controversial issue, will be discussed with other energy-related matters under "Issue No. 5, Energy Requirements."

Nitrogen From Soil Organic Matter (Humus)

Humus contains nitrogen, phosphorus and sulfur in organic forms that are not available to plants. When the humus is decomposed by soil microorganisms, these nutrients are changed to inorganic forms that plants can absorb. Of these nutrients, nitrogen is first in quantity and generally first in importance to nonleguminous plants grown in soil that does not receive commercial fertilizer.

Under natural conditions before cropping began, the content of humus in most soils was relatively high, and annual additions of nitrogen in humus about equalled losses. When the pioneers cleared the land of its native vegetation and tilled the soil to grow food or feed crops, they upset this natural equilibrium. The humus then decomposed more rapidly than it was formed. The humus nitrogen was released in forms available to plants, and this nitrogen was the principal source used by crops.

Part of the nitrogen from crops fed to livestock was returned to the land through the manure. Return of manure provided a valuable means for reducing the rate of loss of humus from soil and for reducing the rate of depletion of nitrogen and other nutrients (Salter and Green, 1933; Salter and Schollenberger, 1939). Livestock farming was recognized as a soil-fertility-conserving system in comparison with systems in which the crops were sold as such. But since manure recycles only a portion of the nitrogen and other nutrients previously removed from the soil, soil fertility generally declined. Of course, large increases could occur on farms that imported large quantities of feed from other areas for livestock and poultry feeding operations.

Today most soils farmed in the United States have less than 50 percent of their native humus content. A new, much lower equilibrium content of humus has been established in many soils. The main cause of the decrease in soil humus content has been tillage, which accelerates the loss of humus by both microbial decomposition and soil erosion. Removal of crops is another factor. Crop yields would have been decreasing

with the level of humus, had it been necessary to depend on humus decomposition to meet crop needs for nitrogen. As a result of development of alternative sources of nitrogen, however, the proportion of the nitrogen needs of crops met by decomposition of native soil humus has been decreasing.

Nitrogen From Animal Manure

Animal manure is an excellent source of nutrients for crops, but it must be carefully preserved and applied to realize its maximum benefits. It is a highly perishable commodity. The nitrogen and potassium are readily lost by leaching, and nitrogen is lost also by ammonia volatilization.

An estimated 175 million tons of animal manure (dry weight basis) are produced annually in the United States, 107 million tons of which are dropped on the land by grazing animals. The remaining 68 million tons are produced by animals in confinement, and about 73 percent of that (50 million tons) is returned to the land (Miller et al., 1978). The potential nutrient value of the 50 million tons produced in confinement and applied back on the land is equivalent to that of about one-twelfth of the nitrogen, one-fifth of the phosphorus and one-fifth of the potassium currently applied in commercial fertilizers in the United States.

The chances of increasing markedly the quantities of nitrogen supplied to crops in animal manures appear slim. According to a 1978 USDA report (Miller et al., 1978), the 63 percent loss of manure nitrogen through volatilization and leaching in storage, handling and after application could be reduced only to 45 percent. If achieved, this reduction in loss would raise the amount of nitrogen from collectible manure from about 9 to 12 percent of the amount currently supplied by fertilizer.

Animal wastes as voided contain 75 to 90 percent water. The energy and labor required to transport this dilute source of plant nutrients limits the distance to which the wastes can be economically hauled for application. The energy required to manufacture, transport and apply plant nutrients in synthetic fertilizer is equivalent to that required to haul and spread an equal amount of plant nutrients in manure to a distance of about one mile (Heichel, 1976). Drying manure with supplemental heat or by exposure to air (suited only to arid regions unless large losses of nutrients due to leaching by rainfall in humid regions are accepted) is economically feasible mainly for specialty products for gardens, lawns, bedding plant and pot culture.

Livestock manure can lead to some environmental problems not likely to be experienced with commercial fertilizer. Surface waters near large livestock operations may absorb considerable amounts of ammonia that volatilize from the manure (Hutchinson and Viets, 1966). If manure is spread on frozen ground for disposal when feedlots or buildings are cleaned during the winter, surface runoff may be a source of water pollution.[8] Manure runoff contains organic matter that causes oxygen depletion in receiving waters. Pollution of shallow wells may result when manure accumulates in feedlots or when it is applied to soil in excessive quantities to avoid the cost and inconvenience of transporting it to more distant areas where it could be used more effectively for crop production. The accumulation of salts may have detrimental effects on plants, particularly in dry regions where the soils already contain considerable amounts of soluble salts. Moreover, a greater proportion of the nitrogen in manure than in commercial fertilizer remains in the soil after crops are harvested and is subject to change to nitrate and loss in surface and groundwater during the winter and spring when no actively growing crop is present. And, of course, many people find the odor of freshly-spread manure objectionable. Most nuisance complaints about odor occur when manure is spread in warm weather.

Although manure does have some disadvantages, it is a valuable asset for soil improvement in both organic and conventional farming, not only as a source of nitrogen and other plant nutrients but also as an amendment to improve the tilth and water relations of the soil. The potential benefits justify continuing attention to practices that will conserve manure and utilize it effectively (Salter and Schollenberger, 1939; Hinish and Jordan, 1972; Pratt, 1971; Jordan, 1974, 1976).

Nitrogen From Leguminous Crops

Nitrogen is most commonly the limiting nutrient of first importance in cropped soils. Prior to the availability of large amounts of fertilizer nitrogen at decreasing costs following World War II, most of the net input of nitrogen to soils in conventional farming resulted from growing leguminous crops. At that time, cropping patterns in nitrogen-deficient regions and, in fact, whole farming systems were built around legumes as the principal nitrogen input to farms. A mixed livestock, grain-farming system, typical in many regions, utilized the legumes as feed and returned part of the nitrogen to the soil in manure for use by other crops. Cash-crop farmers often grew a legume green-manure crop in small grains and plowed it under to supply nitrogen for the following crop. The same is true today in organic farming.

When synthetic nitrogen fertilizers became generally available at a low price, many conventional farmers found it profitable to use them rather than legumes to supply needed nitrogen. This substitution capability gave them more options in selecting cropping patterns and farming systems. The result was an increase in the number of cash-grain farms and the disappearance of livestock from many farms. Although livestock are still widely distributed, an increasing proportion is produced on fewer but larger farms.

For many farmers, a change in cropping patterns to increase the amount of farm-grown nitrogen results in fewer acres of the highest yielding or highest value crops. The loss in aggregate production because of a different mix of crop acreages is in addition to somewhat lower yields of each crop per acre.

Increasing farm-grown nitrogen under dryland and irrigation farming systems is of limited feasibility, as explained in a succeeding section on economic impacts of organic farming.

To utilize the additional legume forage most efficiently, the logical step is to increase livestock. Increasing the acreage of legume forage would of course reduce the amount of vegetables and/or cash grains on individual farms and also the aggregate production of these crops on present cropland acreage. A small shift would have a small impact; but a large shift would have a great impact. For example, a large shift to less grain and more livestock in the Corn

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[8] Significant loss of nutrients can occur by surface runoff when commercial fertilizers are applied to frozen ground, but they are not often so applied.

Belt would mean less grain for transport to grain-deficient areas in the northeastern and Atlantic Coast states and less for world trade.

A further deterrent to substituting nitrogen-producing legumes for higher value nonleguminous crops is the fact that land prices have risen seven-fold over the same period in which nitrogen costs have only doubled; hence, land productivity has become increasingly important. The short-run prediction is that the price of nitrogen fertilizer will remain relatively more favorable than the price of land. The longer term outlook cannot now be reliably forecast.

Nitrogen From Sewage Sludge

The total amount of nitrogen contained in municipal sludge produced in the United States is about one-seventh that in animal manure (Miller et al., 1978). At present, approximately 23 percent of the municipal sewage sludge produced is applied to land, but very little to crop-producing land.

According to data published by Miller et al. (1978), available sludge could replace an estimated 69,000 tons of fertilizer nitrogen annually if an adjustment is made for losses and if 40 percent of the nitrogen is available the first year. Since this amount is equivalent to less than one percent of the nitrogen presently supplied in commercial fertilizers, it is of little consequence to U.S. agriculture as a whole.

Using sewage sludge for producing food and feed raises some unresolved questions about the presence of heavy metals (cadmium, lead, copper, nickel) and other toxic substances and, hence, possible hazards for the food supply. Availability and transportation also must be considered (Walsh et al., 1976).

Nitrogen Source And Water Pollution

The nitrogen in some fertilizers is present partly or entirely as nitrate, but most of the fertilizer nitrogen applied in the United States is in other forms. Nitrate is an inorganic form of nitrogen that is a normal end-product of microbiological transformation of nitrogen added to soil in fertilizers and in nitrogen-containing organic substances, including plant materials, animal manures and sewage sludge. In both conventional and organic farming, plants absorb nitrate from soils and use it as a source of nitrogen for synthesizing proteins and other nitrogenous compounds. Soil microorganisms also absorb nitrate and change it to organic nitrogenous substances if their numbers are increasing in response to addition of plant residues low in nitrogen.

Nitrate is soluble in water and is not adsorbed by soils. Consequently, it is readily removed from soils by water and may be moved downward into ground water or laterally into surface water. Excessive nitrate in ground waters may present a hazard of methemoglobinemia to infants whose formula is prepared using high-nitrate well water. Occasional problems have been reported with shallow farm wells that appear to have been contaminated by nitrate from adjacent feed lots. Nitrate-contaminated water can easily be purified by distillation or passage through an anion-exchange resin column to prepare the small amounts of water used by infants.

The marked increase in usage of nitrogen fertilizer in the United States through the years (from 1.0 million tons of nitrogen in 1950 to 10.6 million tons in 1979) has nonetheless given rise to concern regarding the contamination of surface water and ground water with nitrate. Nitrogen fertilizer has been alleged to be the principal cause of the increase in nitrate content of some surface waters (Commoner, 1968; Kohl et al., 1971; Parker et al., 1974), the implication being that the nitrate present in these waters is the same nitrate added in the fertilizers or produced by soil microorganisms as they convert other forms of fertilizer nitrogen to nitrate.

To the extent that an increase in nitrate content of these waters has occurred in recent years, nitrogen fertilizer may indeed be largely responsible in an indirect way because the principal additional primary input of nitrogen to agricultural soils in recent years has been fertilizer nitrogen. Little of the fertilizer nitrogen is lost directly by runoff because most of the fertilizer is applied below the surface of the soil or is soon incorporated into the soil. Typically about 40 to 50 percent of the fertilizer nitrogen is taken up by the crop in the first year; the remainder is distributed among carryover of inorganic forms of nitrogen, incorporation into soil organic matter, loss by leaching, and loss by change to gaseous forms. Fertilizer nitrogen increases the productivity of soils for crops and livestock by increasing the quantities of nitrogen and other nutrients being cycled through them. Soil nitrate is a normal stage in the cycle, and an increase in loss of nitrogen from the system as nitrate may occur whenever the supply of nitrogen is increased as a result of prior addition of fertilizer. These same statements could be made if the additional nitrogen were added in animal manures produced from feed grown off the farm, in sewage sludge or in legumes that fix nitrogen from the atmosphere. In other words, the additional nitrate in water is a result of a greater total supply of nitrogen and is largely independent of the source of nitrogen (Aldrich, 1972).

Nonetheless, some differences in loss of nitrate derived from the nitrogen in different sources may be anticipated, especially in the first year. According to Allison (1965), "Past research has shown that the highest nitrogen recoveries are almost invariably observed following the addition of a readily available form of nitrogen to a crop that can utilize it quickly. The portion of the nitrogen that is applied in slowly available form, and not used the first year, is subject to leaching during the colder months, if any is made available." Thus, the proportion of the added nitrogen that is lost as nitrate is likely to be less with commercial nitrogen fertilizer than with crop residues, legumes, manures and sewage sludge that supply an equivalent amount of nitrate because much of the nitrogen in the latter materials is slowly converted to nitrate and may be subject to loss during late fall, winter and early spring when no crop is present or when the crop is absorbing little nitrate.

Nitrogen applied to the soil as fertilizers up to the point of maximum net economic return results in only small to moderate increases in nitrate levels in the subsoil (Bomke and Welch, 1972; Hensler and Attoe, 1970; Smith, 1968; Broadbent and Carlton, 1978; Olson et al., 1970). With greater applications, however, nitrate increases rapidly in soil below the root zone. Therefore, both from an economic standpoint and to avoid excessive nitrate in ground water or surface water, additions of fertilizer nitrogen should be tailored as nearly as feasible to the quantities that will produce the economic optimum yield.

The optimum amounts of nitrogen for individual fields in individual years, however, unfortunately cannot be predicted accurately at application time. It is impossible to know how much nitrogen will be

lost through leaching and transformation to gaseous forms because these processes are affected by rainfall, which cannot be accurately predicted. Moreover, the potential yield is unknown early in the season, and this is another important factor in determining the optimum application of fertilizer nitrogen.

In view of the uncertainty, the farmer is faced with the fact that he cannot recover his loss in potential yield if he applies too little nitrogen to permit his crops to take full advantage of a favorable growing season. If he applies too much nitrogen, he takes advantage of the potential yield in the year of fertilization, and he may also recoup part of his nitrogen investment that was not productive in the year of overfertilization through carryover of some of the nitrogen in the soil for the succeeding crop. Thus, if nitrogen fertilizer is relatively expensive in terms of the increases in production it generates, the uncertainty encourages the farmer to fertilize for the less favorable years and to underfertilize for the good years. If nitrogen fertilizer is inexpensive, he is encouraged to fertilize for the good years and to overfertilize for the years that turn out to be less favorable. Although the price of nitrogen fertilizer is now increasing, the price in recent years has been low enough that the traditional economic restraints to fertilization have decreased, and evidence of overuse of nitrogen fertilizer in certain instances has developed (Pratt et al., 1972; Adriano et al., 1972; Carter et al., 1976; Ludwick et al., 1976), as might be expected.

Despite the imponderables, improvements in practice can be made that will alleviate what to some is "the nitrate problem," but to the farmer is a matter of the logistics of increasing the efficiency of the nitrogen he applies as fertilizer. Methods have already been developed for assessing the use of nitrogen relative to crop needs (Pierre et al., 1977; Stanford, 1973), and researchers in several states west of the Mississippi River (where loss of nitrogen by leaching is of less importance than it is in high-rainfall areas) are starting work to improve their recommendations by measuring the nitrate carried over in the soil from the previous crop (Dahnke and Vasey, 1973). Additional information is available on the importance of timing nitrogen applications (Olson et al., 1964). Further development and implementation of improvements in practice will be encouraged if, in the years ahead, the relative increase in cost of nitrogen fertilizer exceeds the relative increase in the returns farmers receive from their crops.

ISSUE NO. 4: CHEMICAL VS. NONCHEMICAL MEANS OF PEST CONTROL

Many of the cultural and management practices used today in food production stem from attempts to reduce crop losses from weeds, insects, nematodes and diseases. Tillage, crop rotation, selection of resistant crop varieties and hand labor are employed by both organic and conventional farmers to control or avoid pests. The two groups differ, however, in the use of synthetic pesticides.

This section briefly surveys the development of present pest control methods, the importance of pest control in producing fruit, vegetable and field crops, the comparative effectiveness of chemical vs. nonchemical control methods, and the potential of "integrated pest management."

Pesticide Development And Use

Prior to the 1900s, crops were largely produced without use of synthetic chemicals for pest control. During these early days, weed control, based on human and animal toil, was sometimes so inadequate that the crop was lost. Growers had little means to prevent crop losses to pests other than weeds, and losses were extensive in many years. A dramatic example was the potato late blight disease outbreak of 1843 and 1844 in Ireland which destroyed the potato crop and caused widespread famine.

Probably the first synthetic "pesticide" was a combination of two inorganic compounds, copper sulfate and calcium hydroxide, called Bordeaux mixture. It was widely used as a fungicide before 1880 and is still used today.

Awareness of the great potential for reducing losses to pests with pesticides developed in the early 1900s, and many chemicals were tried by agricultural scientists and innovative farmers. A few came into commercial use. However, the major stimulus to pesticide development and use came with the discovery of DDT for insect control and 2,4-D for weed control. Farmers recognized the great value of these chemicals for controlling pests, and within a few years millions of acres of cropland were being treated. Concurrently, the chemical industry started an intensive search for pest control chemicals, and this resulted in numerous discoveries and the widespread use of pest control chemicals by farmers and others throughout the United States.

Chemical applications, both in the field and on harvested crops prior to shipping or storing, allow large quantities of fresh fruits and vegetables to be made available for purchase throughout the United States most months of the year. Pesticide use on field crops (corn, soybean, small grains, cotton, etc.) similarly has provided effective, low-cost pest control.

Today, the American consumer expects plentiful supplies of unblemished, insect- and disease-free agricultural products. In fact, there are government regulations that prohibit pest-infested or blemished products in market channels and retail outlets. One example is the U.S. Food and Drug Administration's "defect action levels," which limit the amount of insect parts in processed foods (Pimentel et al., 1977).

Weed Control

The importance of weed control for successful fruit, vegetable and field crop production is undisputed. Weeds compete with crops for water, plant nutrients, and light; often interfere with harvesting; and increase labor and equipment costs. They may create a favorable environment for insects and diseases. If not controlled, they lower crop yield and, in some cases, crop quality (e.g., wild onion in wheat). Organic farmers affirm that weed control is their most serious problem (Lukens, 1978; Wernick and Lockeretz, 1977; Goldstein, 1978), as indeed it is for most conventional farmers.

On a world-wide basis, weed control, mainly without the use of herbicides, requires more time than any other single human task (Holm, 1975). For example, Nigerian village farmers spend 56 to 74 percent of their working hours weeding their crops. Where subsistence farming is practiced, farm size is often limited to the area on which the farm family is able to control weeds by hand or with animal-drawn tools.

Attempts to develop biological controls for weeds have met with limited success. Of a total of 52 controls reported in 14 countries for individual species of weeds by insects, control of the weed was complete in 9 instances, substantial in 17 and partial in 26 (Wiese and Chandler, 1979). Most water weeds can be controlled by the grass carp, but there is some concern that this fish would so denude waters of vegetation that the habitat for waterfowl and native fish would be impaired (Shireman, 1979).

In U.S. agriculture, both organic and conventional farmers use management practices other than herbicide application to control weeds. The practices usually include preparation of a seedbed free of growing weeds; fertilization and liming to give the crop a competitive advantage; use of high quality seed of an adapted variety; use of optimum planting date, seeding rate and plant spacing; and tillage or cultivation after planting when feasible.

Conventional farmers make extensive use of herbicides for weed control. Use of appropriate herbicides results in substantial yield increases because: (1) they control weeds within the row where they would otherwise escape cultivation; (2) they kill weeds early in the season when crop plants are too small to be competitive and when soils are sometimes too wet for cultivation; (3) used judiciously, they may gradually reduce the number of weed seeds in the soil so that less labor, energy and herbicides are needed in the future; and (4) they reduce the number of tillage and cultivation operations needed, which lessens the degree of soil compaction and leaves more crop residue on the soil surface to control loss of soil and water. In fact, some forms of "conservation tillage," with its goal of reduced erosion and sediment pollution, would not be feasible without herbicides.

Infestations by certain weed species, however, can increase from long-term use of a single herbicide to which the weeds are resistant. For example, continual use of a herbicide that controls broadleaf weeds leads to a buildup of grasses and vice versa. Therefore, conventional farmers must carefully select the herbicide or combination of herbicides that will provide the most help in controlling their specific weed problems.

On the whole, increased production costs and reduced yield and quality of produce result when fruits and vegetables are produced without use of herbicides. In the production of small fruit, intensive weed control prior to planting is a necessity if perennial weeds are present. Conventional farmers generally control these weeds quickly with herbicides, whereas organic farmers must use repeated clean tillage, which prevents crop production on the land for one or two seasons prior to planting the small fruit. Once these weeds are controlled, a good mulching system plus limited tillage may provide adequate weed control in brambles and blueberries. The organic mulches needed to protect strawberry crowns from heaving injury (due to freezing and thawing of the soil), however, may hinder weed control or bring in new weed seeds.

For small-seeded vegetables, such as carrots, lettuce and onions, adequate weed control is usually not possible by mechanical cultivation alone. Without herbicides, intensive hand weeding within the row is a necessity. Often an hour or more is required to weed 100 to 200 feet of row. The excessive time requirement makes hand weeding economically prohibitive. Hand weeding often results in crop damage. In growing these crops, therefore, the conventional farmer who uses herbicides has a great advantage over the organic farmer who does not.

For large-seeded and transplanted vegetables, manual, mechanical and mulch systems for weed control are possible alternatives to herbicides, but these methods are significantly more expensive (e.g., $30 to $150 per acre for hand weeding vs. $5 to $35 per acre when herbicides are used).

Imaginative research in the areas of weed physiology and weed ecosystems may produce future alternatives to annual applications of herbicides. For example, if growth regulators could be developed that would cause all weed seeds in the top 4 to 6 inches of soil to germinate, crops could then be kept free of weeds with only a little tillage or with a small amount of herbicide. This principle is already being utilized in witchweed control (Langston et al., 1979).

Insect Control

Insecticides are usually used to control insect infestations that have already developed, although they are sometimes applied as a preventive measure because an insect is present or because an infestation is likely to occur. The desirable practice is to make applications only when the infestations are sufficient to cause significant economic loss if they are not checked.

It is sometimes argued that, if the use of insecticides were prohibited, the populations of beneficial and pestiferous insects would come into balance within the agro-ecosystem, thus negating the need for insecticides to protect crops from insect pests. This argument is refuted by the fact that insect problems were prevalent long before the advent of modern insecticides. In some instances, however, insecticide use has destroyed natural enemies, with the result that the severity of infestations by previously minor pests such as spider mites has increased.

Insect problems occur today in natural ecosystems; hence, they are not unique to agriculture. Nonetheless, the problems are intensified in agriculture. One reason is that the large areas devoted to a single crop in agriculture provide a concentrated source of food for insect pests specific to that crop, with decreased possibility of control by insects that might be associated with the other species that usually occur in a natural ecological setting. Another reason is that the genetic qualities that produce desirable agricultural plants may not carry with them desirable resistance to insects. The problems are further intensified if a susceptible crop is grown frequently or continuously on the same land.

The potential for biological control of insect pests varies. Some insect pests have several potent natural enemies, others very few. Many insects such as the European corn borer that became serious pests were introduced into the United States and thrived here where their natural enemies were not present. Most predators and parasites are found in the native area of the host where they have coexisted with the host population for a long time before an important regulating relationship developed (U.S. Department of

Agriculture, 1978). Even when predators and parasites are present, natural pest regulation is often erratic. When heavy infestations develop rapidly, insect pests can cause extensive damage before predator or parasite populations increase to levels adequate for control.

Mass propagation and release of natural enemies to control insect pests has sometimes been successful, and appropriate management of crop ecosystems also has been successful in controlling insect problems in some crops (e.g., crop rotation to reduce corn rootworms). The greatest success with biological control, however, has been achieved through research to incorporate genetic resistance in crops to certain insects.

There has been much publicity in the popular press suggesting that continued use of insecticides will result in development of "superpests" resistant to all insecticides. This notion indicates a misunderstanding of the nature of resistance and how it comes about. The individuals within the population of a given insect will differ in susceptibility to a given insecticide, and a few may be resistant to the dosages applied. When competition from the susceptible individuals is eliminated, the few resistant individuals may multiply and fill the ecological niche occupied by the original strain that may have consisted mostly of susceptible individuals. However, this "new" strain, while resistant to the previous specific chemical or mode of action, is likely to be as susceptible as the original population to other kinds of insecticides or other methods of control (Benson, 1971). (There is some disagreement over the extent to which the development of resistance to one insecticide carries resistance to another.)

Disease Control

One of the crowning accomplishments of plant breeders and plant pathologists has been the control of many plant diseases through breeding for genetic resistance. Commercial varieties of nearly all important fruit, vegetable and field crops are now resistant to some diseases, thus greatly reducing the need for chemical control. Many opportunities exist for further improvement in plant disease control through breeding for genetic resistance. This biological approach is immediately useful in all systems of food production.

Foliar sprays are seldom used for disease control in major field crops like corn, soybeans, wheat, oats, barley, sorghum, alfalfa and cotton. Unfortunately, some fruit and vegetable crops (e.g., peaches, pears, apples, grapes, brambles, strawberries, potatoes, onions, tomatoes, muskmelons, eggplant, celery and squash) are subject to diseases for which there is no feasible control except foliar fungicidal sprays. In some cases (especially muskmelon, squash and cucumber), insecticides are needed to control disease-carrying insects. Organic farmers thus find it difficult to obtain high yields of these species where the diseases are a problem.

The economic threshold concept that has been found useful with insect control is not generally applicable to plant diseases. As a specific example, with the late blight disease of potatoes, caused by *Phytophthora infestans*, the spray program must be applied before any late blight appears because the fungus reproduces rapidly, and the disease is so devastating that available fungicides are not capable of arresting it, once infection has occurred.

Conventional farmers treat seed with a small amount of an appropriate fungicide, which improves seedling establishment, especially in years when the soil is cool and wet at planting time. Presently, there is no effective substitute for seed treatment. The compounds now used for seed treatment in the United States have relatively low toxicity to humans and other animals and are considered safe when used according to the label directions.

Nematode Control

Nematodes are now recognized as pests of major importance in reducing crop yields, but the magnitude of the problem they create is not yet well defined in some instances. Monetary loss per acre due to nematodes is probably greater on vegetables and citrus than on field crops like corn, wheat and soybeans. But because of larger acreages, total monetary losses may be greater in field crops.

Crop rotation, plant varietal resistance (tomato and sweet potato), and suitable tillage have greatly reduced the need for commercial nematicides in some instances, but not in others. Thus, in the short run at least, nematicides will continue to be valuable, even essential, on some commercial farms.

Organic matter additions to the soil may effect nematode problems in one of two ways. (1) Adding nematode-infested plant residues will worsen the problem. (2) Adding noninfested residues, such as hay, bark, cottonseed meal and animal manure, will likely favor the growth of organisms antagonistic to nematodes, thus reducing the problem.

In North America, to date, most experiments on the effect of additions of organic materials on nematodes have been conducted in greenhouses, laboratories or small field plots. Generally, the work has been encouraging enough to continue, and it has reached the point at which more field scale studies are needed. One practical problem with this approach to nematode control, however, is that the quantity of organic amendments that would be required for effective nematode control often exceeds the supply.

Many nematicides are halogenated hydrocarbons, carbamates and organic phosphates. Their misuse can be detrimental to humans, wildlife and the environment in general. But their proper use has often resulted in increased yields that could not have been achieved by any alternative method.

Current Role Of Chemicals In Harvesting, Storing And Marketing

Use Of Desiccants And Defoliants

Chemical sprays are sometimes used in commercial agriculture to hasten the dropping of leaves from the crops to be harvested or from weeds that interfere with harvesting. For example, in areas with a growing season longer than 230 freeze-free days, the practice of using desiccants and defoliants provides three benefits in cotton harvesting: (1) it allows harvest at the optimal time for yield and quality, rather than being delayed until the first freeze defoliates the plants; (2) it is a basic component of integrated pest management, in that early harvesting reduces habitat for overwintering boll weevils and other cotton pests; and (3) it allows machine stripping, which is much less expensive than machine picking. Use of desiccants and defoliants is of less value in the High Plains area of Texas, which now grows nearly one-third of the cotton, because this area has no major insect problem and normally has natural defoliation.

Effects Of Pesticide Use On Produce Availability And Marketing

Once damaged by pests, many fruits and vegetables soon decay, and the rots quickly spread to sound produce. Even slightly damaged fruits and vegetables have a short storage life. Thus, without effective pest control chemicals, not only would present quantities and quality of produce be reduced, but also shipment from one section of the country to another and year-around availability would be unfeasible. Produce that has not been treated for insects and diseases is not acceptable for import in some countries.

A reduction in the use of pesticides that assure storage quality would lead to greater reliance on locally grown fruits and vegetables available only seasonally, and on canned and frozen products, which have relatively high energy costs.

To some extent, conventional growers must meet different standards for product appearance in the marketplace than do organic growers. The supermarket shopper desires--and gets--fruits and vegetables that are attractive and free from blemishes. Most fresh produce is traded in the wholesale market on the basis of grades which specify size and tolerable limits of blemishes according to government standards. This promotes orderly buying and selling without the purchaser having to inspect each lot. These standards are also enforced to prevent losses during shipping, handling and storing. (Some standards such as the color of oranges are cosmetic only and could be eliminated over time [Goldstein, 1978].)

In contrast, the produce from organic growers is often sold at relatively high prices to persons who are willing to tolerate imperfections for assurances that pesticides, additives and commercial fertilizers have not been used. Analyses of products collected in surveys, however, have not demonstrated that the faith of consumers in the claims is well placed. In a survey of ten food items in the State of Washington while DDT was still being used as an insecticide, the DDT content of the items purchased in a "health food" store was about the same as that of the comparable items purchased in a conventional store (Durham et al., 1965). In a more recent Florida survey (Appledorf et al., 1973) of 24 "health foods" and equivalent products produced by conventional methods, no pesticide residues were detected in either class of foods in excess of 0.01 part per million (the lower limit of sensitivity), but polychlorinated biphenyls were detected in seven samples of the health foods and three samples of the foods produced by conventional methods. In a New York survey (State of New York, 1972), 17 of 55 food products (31 percent) sold as having been produced by organic methods were found to contain trace quantities of pesticide residues, whereas approximately 20 percent of the 2000 samples of conventional foods analyzed per year were found to contain traces of pesticide residues. Tests on organic lettuce in California (Naman, 1979) showed traces of pesticide residues.

Although the source of the residues found in these surveys is not known, the implication is that the organic label is sometimes used as a ruse to obtain higher prices than could be obtained in the conventional market for products produced with the aid of pesticides. If the demand for organic foods increases sufficiently, regulatory controls will probably be developed to provide reasonable assurance that the foods sold under the organic label are in fact produced without use of chemical technology, and this will probably result in an increase in cost of these foods to consumers.

Tolerances for pesticide residues are established by the Environmental Protection Agency, and the Food and Drug Administration is responsible for monitoring food products for residues. According to a study published in 1975 by the National Research Council (1975), the U.S. population was consuming about 40 milligrams of pesticide residues per person per year in the food supply, more than half of the consumption being persistent chlorinated hydrocarbons that are no longer in use. The aggregate acute toxicity of these residues consumed in a year has been estimated to be about the equivalent of the acute toxicity of the aspirin in one aspirin tablet or the caffeine in a cup of coffee. Although the possibility is often voiced that the residues may have unfavorable long-term effects that are not assessed by acute toxicity, the results of long-term studies that have been made to date do not substantiate this argument. The issue of possible long-term risks versus current benefits from use of pesticides has not been satisfactorily resolved by the scientific data available.

Future Of Pesticides For Fruits And Vegetables

Each pesticide must have federal registration and approval for each crop on which it is to be used. The requirements for registering new pesticides and for reregistering old pesticides are now so extensive to fulfill, however, that most pesticides presently being developed are intended primarily for use on field crops that occupy large acreages and present a potential market great enough to permit the company to make a profit after covering the costs of discovery, development, production and regulatory clearances (Upchurch et al., 1977). In many cases, the cost to a company to acquire data necessary for government approval to sell a pesticide for use on a minor fruit or vegetable crop might never be regained through sale of the product.

Many of the fruits and vegetables consumed in American diets are grown on relatively small acreages and are heavily dependent on certain pesticides. Hence, the continuing trend toward increasing cost of pesticide registration jeopardizes the future of pesticides for minor crops, including most temperate-climate and tropical fruits and vegetables. Moreover, the smaller the number of pesticide products available for use on a given crop, the greater is the probability that the pests will develop resistance to them. Increasingly limited pesticide availability for minor crops will result in fewer and more expensive fruits and vegetables of lower quality in the marketplace.

Integrated Pest Management — A Promising Approach

The Concept And Its Application

In recent years, agricultural researchers have assigned an increasing portion of their efforts to alternative pest control practices involving reduced emphasis on pesticides. The term "integrated pest management" (IPM) (Metcalf and Luckmann, 1975; Smith, 1978; Goldstein, 1978) has been developed to describe a many-faceted approach to achieving the best combination of available methods to control the various pests under the different conditions in which the pests are of significance. The general IPM approach is to integrate proven cultural pest management principles and techniques (including genetic resistance in plants, modified cropping sequences, appropriate tillage, sanitation and field scouting to determine the magnitude of the problem) with timely use, if necessary, of an appropriate pesticide applied at the lowest feasible rate and at the weakest or most critical stage in the life of the pest. While IPM does not imply the com-

plete absence of pesticides, it does seek to employ alternative approaches, utilizing pesticides only when necessary and often at reduced rates.

The overall modification of agricultural practices thus far accomplished by introduction of IPM techniques has not been great because of limited availability. The potential for IPM lies mostly in the future. Development of IPM systems that are effective and appropriate for the multitude of combinations of crops and conditions that exist in practice will be a major research undertaking. Much additional knowledge about pest life cycles and greater understanding of the relationships of pests to other organisms including the crops they attack will be needed. Needed also is information on the economics of pest attack or pest infestation and the economics of various pest control strategies. To date, the IPM concept has been developed mainly in connection with insect pests.

The trend toward IPM for pest control reverses the trend toward use of synthetic pesticides that began with the adoption of DDT and 2,4-D. In this regard, therefore, conventional farming may be said to be retreating from the extensive use of pesticide chemicals in the direction of organic farming from which it departed in the 1940s.

In any subject with the emotional implications that pesticides have in the minds of many people, there are bound to be controversies and misunderstandings, and this is true also with IPM. One of the misunderstandings that has developed in the minds of some is that practical, cost-effective IPM techniques are already available for pests in general and that the techniques need only implementation. Another misunderstanding is that pests can be controlled by increasing crop diversity and, thereby, reducing the concentration of crops in a geographic region, on a farm or in a field. At best, this belief is only partially true (National Research Council, 1975). For example, rotating crops increases the severity of infestations with six of the ten most serious corn insects in the Corn Belt, has no effect with two and decreases the severity of infestations with two (Metcalf and Luckmann, 1975). The populations of northern and western corn rootworms, currently the most serious corn insects, are reduced by crop rotation. Although this is one of several factors that may be involved in the decision of conventional Midwest farmers to grow soybeans instead of corn on some of their fields, the organic farmers who use only this nonchemical control of rootworms do so at the expense of part of their acreage of corn, the principal income crop in the Midwest. In the case of weed problems, some are intensified by monocropping, and others by rotating crops. The best long-term weed control is obtained by combining crop rotation, tillage and use of appropriate herbicides.

Promising Additions To The IPM Approach

Alternative pest control strategies that appear to have promise and have already been developed to the point of some field use include a broad spectrum of biological approaches:

--Developing genetic strains of crops resistant to, or tolerant of, pest attacks.

--Introducing attractants such as sex hormones (pheromones) in insect traps.

--Utilizing juvenile hormones which interrupt the normal development sequence from young to mature insects.

--Developing insect sterilization strategies.

--Introducing predaceous and parasitic insects, pathogenic fungi and diseases.

--Using weed seed germination stimulants.

New technologies which increase pesticide effectiveness on target species while reducing nontarget impacts include the following:

--Using electrostatically charged sprays which increase retention of the pesticide on vegetation.

--Using soil-applied systemic chemicals in which the pesticide is taken up by plant roots and incorporated into the vegetation.

--Increasing the efficiency of granular pesticides at the action site.

--Applying pesticides directly on target weeds with roller or wiper applicators in lieu of sprays, granules or dusts.

--Reducing the proportion of very small droplets to reduce spray drift during ground or aerial application.

--Adjusting the pesticide application rate and spray volume to canopy density.

--Catching and recycling the pesticide solution that is not deposited on the target plants.

Regulatory Activity And IPM Development

Concern for public health and the environment has resulted in expanded government regulatory activity during the past decade. Regulatory agencies have greatly increased safety testing requirements in their efforts to reduce the risks in pesticide use. Each proposed use of a pesticide must now be officially approved. These requirements have increased both the costs of pesticide development and the length of time between discovery and marketing of the products. According to information supplied by the National Agricultural Chemicals Association, the average cost of bringing a pesticide to market for the years 1974 through 1978 was $25 million ($53 million in 1978), and the time from discovery to market was 7 years. The time required from submission of the data to approval of the product by the Environmental Protection Agency averaged 21 months (32 months in 1978). These regulatory inhibitions apply to "second generation" pesticides that generally provide control for only a single pest species as well as to broad-spectrum pesticides (Tucker, 1978).

The high costs have reduced the numbers of pesticides registered per year. They have encouraged manufacturers to emphasize broad-spectrum pesticides that will have a wide market and to avoid specific pesticides that would have a limited market. These trends inhibit the development of IPM programs in two important ways: (1) the adaptability to fit different circumstances is decreased, and (2) specific pesticides are not available to control specific pests without concurrently controlling other organisms, some of which might otherwise provide part of the control of these specific pests or others.

The regulatory quality standards that are considered desirable for producing fruits and vegetables that are free of pests and blemishes also inhibit the

development of IPM systems. Truck loads of apples, for example, may be rejected and returned to growers on the basis of evidence of the presence of apple maggot in only a small proportion of the apples. Under such circumstances, growers have little incentive to use reduced rates of pesticide application or to use alternative methods of pest control that would result in less certain and less complete control.

ISSUE NO. 5: ENERGY REQUIREMENTS

As energy became a national issue, so also it became a basis for debate in conventional versus organic farming. Organic farming is presented as the more energy-conservative of the two systems. As Rodale (1973) put it,

> Highly mechanized and chemicalized farming requires much larger energy inputs per calorie of yield than does primitive farming. For example, the oriental rice farmer gets 50 calories back for every calorie he expends in personal energy. (Almost everything is done by hand.) Farmers using large machines need many calories in fossil fuel for each food calorie they produce--exactly the reverse situation.... Can people be encouraged to adopt lifestyles that are not wasteful of resources and energy, and that simplify the problems of food production and distribution? Will more people be willing to accept the physically demanding (though extremely productive in an energy sense) work that small-scale farming is?

In this quotation, Rodale classes mechanization with agricultural chemicals as something to avoid. On the other hand, as an agricultural engineer (Splinter, 1979) put it,

> From a strictly engineering point, man and animal are not efficient sources of power, especially in the tropics. If a man or an animal is performing work at 0.1 or 1 hp respectively, and since muscular work is about 20% efficient, the man or the animal must dissipate 0.4 or 4 hp in heat energy respectively. Under high temperature-high humidity conditions the capability to dissipate heat is severely restricted, potentially leading to a heat stroke or forcing work at a lower rate.
>
> Even under temperate conditions muscular work is not efficient. In studies reported by F. B. Morrison in his text on "Feeds and Feeding," you will find that the field work efficiency of a horse is from 20-25%, respectably comparable to a gasoline engine. However, since one cannot turn his ignition off, the horse continues to burn hay and oats all night long, bringing his daily work efficiency to about 9% and, since he is not worked 365 days of the year, his annual work efficiency is only 2-3%.
>
> A. Makhijani, in his book "Energy and Agriculture in the Third World" found that the energy investment in producing a ton of rice in India, where 85 to 90% of the total energy input was human labor (including animal feed, human food, dung fuel, etc.) was 19×10^6 Btu while in Japan, where production is almost totally mechanized, the energy investment was 6.2×10^6 Btu/ton.
>
> Therefore, it must be forcefully argued that man and animals are inefficient sources of power and that relegating mankind to the status of a work animal is not a socially acceptable goal.

A simple and satisfactory analysis of energy utilization in conventional vs. organic farming has not yet been made, one reason being the diversity of both. Hence, in this report we shall endeavor to provide a basis for understanding by explaining initially the evolution of conventional agriculture in terms of energy utilization and economics. Next we shall review briefly the energy aspects of agricultural chemicals because the clearest distinction between conventional and organic farming can be made in use of agricultural chemicals. Then we shall review the comparisons that have been made of energy utilization in conventional and organic farming. And finally we shall consider energy for the future.

Evolution Of Energy Use In Agriculture

Solar energy makes plants grow, but humans must supply additional energy to direct the process to supply their needs for food, fiber and shelter. The capacity of humans to perform the hard physical work required in agricultural production is limited. Splinter rated it at 0.1 horsepower. Thus, the amount of food that can be produced by one person who must depend on his own energy to do it is relatively small. If most or all of the food is to be produced this way, a large proportion of the population must be engaged in food production. In years past, this is the way it was. In 1790, for example, 90 percent of the U.S. labor force was occupied in agricultural production (now the figure is less than 4 percent).

In the United States, agriculture has always been a competitive enterprise in which the generally low income (as well as the heavy, energy-demanding nature of the work) has encouraged the development of means to make human resources more productive. The first step in the process was shifting much of the burden to domestic animals. Now machines have displaced domestic animals, and other inputs including fertilizers, pesticides and feed additives are used to increase the productivity still further.

All these inputs require energy. Human and animal labor are based on energy derived from food: part of the output of the system is consumed as overhead in producing the surplus amount that can be used by persons other than the producers themselves. An appreciation for the magnitude of the overhead may be obtained from a publication by Gavett (1975). He calculated that to produce the crops grown in 1974 by the technology of 1918, before the widespread use of the tractor, would require 61 million horses and mules. To feed them would require 180 million acres of cropland (almost half of the U.S. cropland now in cultivation). Moreover, performing the additional hand labor needed would require approximately one-third of the total U.S. labor force.

The continuing pressure to develop a system of agricultural production that makes more efficient use of human resources than one based on human physical labor may be inferred from the fact that in 1976 it

cost $26.50 to employ a farm worker for a 10-hour day, whereas work equivalent to that performed by a healthy, vigorous man who applied himself continuously for 10 hours could be performed by electrical energy costing only 3 cents.

Electricity and the gasoline and other fuels used to power farm machines are derived almost entirely from petroleum, natural gas or coal--the so-called fossil fuels. The comparative cost of human energy derived from food and of electrical energy derived from fossil fuel brings to the fore the question of economics, which is of basic concern in current decision-making. As long as fossil fuels and other energy sources can be utilized more economically than human labor, individual producers will be motivated to use them. The practical issue, therefore, is not that of calories (which is the basis often argued), but of dollars to obtain the energy used in agricultural production and of dollars that can be obtained for the agricultural products produced. If costs of nonfood, nonfeed sources of energy become high enough, the economics of the situation will force conventional farming in the direction of the more primitive agriculture from which it has evolved. Much commercial organic farming will be similarly affected.

Energy For Fertilizers

Fertilizers accounted for an estimated 33 percent of the total energy input in crop production in the United States in 1974 (U.S. Department of Agriculture, 1976). Most of the energy consumed in fertilizer production is used in the manufacture of nitrogen fertilizers in which natural gas is used not for its energy but as a source of hydrogen gas for making ammonia. (The Tennessee Valley Authority is now completing a demonstration plant for producing hydrogen from coal.) Ammonia is a nitrogenous compound that is used as a fertilizer either directly or after conversion into other nitrogenous compounds.

Crops vary in nutrient requirements because of differences including yield potential and the ability of legumes to obtain nitrogen from the air. Corn is a nonlegume with a high yield potential, and it has a high fertilizer energy requirement. Legumes such as soybeans and alfalfa, however, have a much lower fertilizer energy requirement because they fix atmospheric nitrogen and do not require supplemental fertilizer nitrogen. As may be inferred from the data in Table 2, considerably less fertilizer-related energy is consumed in organic farming without nitrogen fertilizer than in conventional farming.

On the other hand, the use of nitrogen fertilizer alone is credited with providing one-third the productive capacity of crops in the United States (U.S. Department of Agriculture, 1973). And, according to estimates by Swanson, Taylor and Van Blokland (1978), limiting the application of nitrogenous fertilizer to 50 pounds of nitrogen per acre would result in a value loss to consumers (consumers' surplus) of $3.3 billion per year due to the lower crop yields and higher prices. The value gain to producers (producers' surplus) for the same reasons would be $2.0 billion.

There are evidently arguments on both sides of the controversy. The energy statistics favor organic farming. In practical agriculture, however, the decision turns on the cost of nitrogen fertilizer in relation to the selling price of the products it produces. The energy requirement is one of the factors in the cost of nitrogen fertilizer and in the cost of producing nitrogen-fertilized crops. If nitrogen fertilizer were free, the economic advantage to individual producers would be strongly in favor of using it generously. If nitrogen fertilizer were relatively expensive, as it was prior to World War II, the use would be sharply curtailed, and many conventional farmers would find it economically expedient to become "organic" in the sense of substituting legume nitrogen for fertilizer nitrogen.

Plowing a leguminous crop into the soil provides the maximum amount of nitrogen for the succeeding crops, but the nitrogen is expensive because of loss of production of other crops during the time the leguminous crop is grown. This procedure, therefore, is not often used unless the legume can be grown during the time of the year when the "cash" crops such as cotton and corn cannot be grown.

In practice, it is not always feasible to make a small shift in the balance of nitrogen supplied by nitrogen fertilizers and legumes. The basic reasons are that (1) the leguminous forage crops that are the most valuable sources of nitrogen have limited salability and (2) farmers can derive more current income from cash crops than from selling the leguminous forage crops. The economics of using legumes as a source of nitrogen would thus encourage farmers to modify their

Table 2. Energy consumed in production, transportation and application of fertilizers in amounts sufficient to maintain the fertility of the soil (Graffis et al., 1977; Davis and Blouin, 1977; Hoeft and Siemens, (1975)

	Energy required, kilocalories per acre			
Nutrient	Corn, 120 bu/acre	Wheat, 40 bu/acre	Soybeans 50 bu/acre	Alfalfa 5 tons/acre
Nitrogen	875,000	357,000	0	0
Phosphorus	77,565	34,500	60,300	86,200
Potassium	32,175	13,000	59,750	387,300
Total	984,740	405,300	120,050	373,500

farming enterprise to include livestock to consume the legume hay. Livestock farming and cash-grain farming are different ways of life, and farmers tend to choose one or the other.

Energy For Pesticides

About 5 percent of the energy used in agriculture goes into the production of pesticides. A small additional amount goes into pesticide application. The total amount of energy used in producing and applying pesticides is equivalent to less than 0.2 percent of the total energy used in the United States and to about 15 percent as much energy as is used in producing and applying fertilizers (U.S. Department of Agriculture, 1976).

The input-output energy relationships involving pesticides in crop production may be illustrated by the data in Table 3, derived from six experiments on use of herbicide for weed control in Minnesota. The data show that the energy input for controlling weeds was greatest with cultivation, less with herbicide, and least with hand labor. The net profit in energy was greatest where weeds were controlled by hand labor, less where they were controlled by a herbicide and least where they were controlled by mechanical cultivation. The net profit in terms of energy was great with all methods, however, reflecting the great importance of weed control.

The energy accounting in Table 3 is of theoretical interest, but in practice agricultural products are not bought and sold on the basis of their energy content, and decisions on agricultural inputs are not based on their relative energy consumption, although energy may be a factor in both. Economics is the deciding factor. The method of weed control that is most profitable economically thus may differ from the one that is most profitable energetically. The distinction between the two bases for calculating profitability may be illustrated by comparing the energy data in Table 3 with the economic data in Table 4. Hand labor, which was the best method of weed control from the energy standpoint, was a disaster from the economic standpoint. At 1976 prices for corn and farm labor, a farmer using hand labor to produce 92 bushels of corn per acre would have lost $65.90 per acre on the operation. He would have been better off to use no weed control at all and to accept a yield of only 54 bushels per acre.

Table 3. Energy relationships in weed control in six experiments on corn in Minnesota (Nalewaja, 1974)

Method of controlling weeds[a]	Energy input for controlling weeds, kilocalories per acre	Yield of corn grain per acre		Net profit due to weed control, kilocalories per acre
		Bushels	Kilocalories	
None	0	54	5,443,200	-
Cultivation	56,005	81	8,164,800	2,665,595
Herbicide	37,920	90	9,072,000	3,590,880
Hand labor	32,655	92	9,273,600	3,797,745

[a] The land was plowed, disked and prepared for planting of corn in the conventional manner.

Table 4. Economic relationships in weed control in six experiments on corn in Minnesota (Nalewaja, 1974)

Method of controlling weeds[a]	Costs per acre at 1976 prices			Value of crop per acre at 1976 prices	Net profit per acre due to weed control
	Fuel, machinery and herbicide	Labor	Total		
None	$0	$0	$0	$132.30	-
Cultivation	3.43	1.51	4.92	198.45	$61.23
Herbicide	9.58	0.13	9.71	220.50	78.49
Hand labor	0	159.00	159.00	225.40	-65.90

[a] To produce the data in this table, dollar values for 1976 were added by the author.

The profit derived from controlling weeds by cultivation and herbicide explains why these methods are acceptable in practice, and the loss from hand labor explains why this method is not acceptable. The author estimated that to control the weeds by hand labor in all the U.S. corn crop in a period of 6 weeks would require 17.7 million people working 40 hours per week. This is four times as many people as were employed on all U.S. farms in 1973.

Comparisons Of Energy Utilization, Crop Yields And Economics Of Conventional vs. Organic Farming

Several attempts have been made to compare energy utilization in organic and conventional farming systems. In some instances, the comparisons were based on specific field observations, in other instances not. In some of the studies, yields of crops were reported. In some, economic calculations were made. The various studies differed in the degree to which organic methods were followed. Some of the studies were on an individual crop basis, others on a whole farm basis. Farms also varied as to types of crops and livestock raised. A few had large outside sources of animal manure or municipal sludge. In some cases, the farms compared were in different geographic areas. Yields often were estimated by farmers rather than being precisely measured and thus are open to question, especially for hay and pasture. Because energy utilization, yields and economics are related and because the information reported is so heterogeneous it is all summarized in this section in preference to segregating the energy, yield and economic information for separate consideration.

Klepper et al. (1977) estimated that, averaged over 2 years, the energy required to produce a bushel of corn on 14 midwestern organic farms was only 36 percent as much as that required on conventional farms; energy for soybean production was 85 percent as much. The energy consumption per dollar of crops produced was 42 percent as great on organic farms as on conventional farms, and the energy consumption per acre of cropland was 38 percent as great on organic farms as on conventional farms. In the same study over a 3-year period (Lockeretz et al., 1978), the unadjusted per acre value of all harvested crops was reported to be 89 percent as great on the organic farms as on the conventional farms. After adjustment for differences in soils and assignment of varying credits for pasture, these values ranged from 78 to 87 percent as great on the organic farms as on the conventional farms (Table 5). Because of lower costs on organic farms, the unadjusted net returns per acre of cropland were estimated to be the same for the two farming systems. It would of course be appropriate to adjust net returns in a manner similar to that used to adjust gross values per acre of harvested cropland.

On the conventional farms in the study, one-third of the corn acreage was preceded by a sod crop, and one-half had received an average of 9.1 tons of manure per acre. In addition, the average application of commercial nitrogen fertilizer (101 pounds per acre) was approximately 30 percent above that recommended for these situations (Boone et al., 1978). Therefore, nitrogen available from sod crops, manure and fertilizer was unnecessarily high for the yields obtained, thus raising the energy input above that needed on these farms.

Berardi (1976) reported that, in wheat production, organic farms used considerably less energy and had lower yields, but obtained roughly the same per-acre net returns as their conventional counterparts.

Oelhaf (1978) found considerable variation in the economic viability of organic farming methods, but he suggests that organic production of a number of commodities can be as profitable, if not more so, than conventional production techniques. Using USDA and other data he estimated that organic farming would add an average of 9.2 percent in production costs for a wide range of feed grains, fruits and vegetables and would require an average of 16 percent more labor.

Farming systems of the Amish religious group, though different in motivation, are similar to organic farming in that no pesticides and usually little or no commercial fertilizer are used. Johnson et al. (1977) (Table 5) compared yields and energy input/output relationships for Amish and non-Amish farms in Illinois, Pennsylvania and Wisconsin. Production of grains, hay and livestock was aggregated by converting each to megacalories.

In Illinois, production per acre was 62 percent as great on Amish farms as on non-Amish farms. The ratio of energy output in agricultural products to energy input was 0.89 on the Amish farms and 0.70 on the non-Amish farms.

In Pennsylvania, production on Amish farms of the Nebraska subsect was 56 percent as great as that on the non-Amish farms, and production on Amish farms of the Old Order subsect was 103 percent as great as that on non-Amish farms. The ratio of energy output in agricultural products to energy input was 1.51 on the Amish farms of the Nebraska subsect, 1.01 on the Amish farms of the Old Order subsect and 0.55 on the non-Amish farms.

In Wisconsin, production on Amish farms was 78 percent as great as that on small (177 acres) non-Amish farms and 63 percent as great as that on larger (266 acres) non-Amish farms. The ratio of energy output in agricultural products to energy input was 1.61 on the Amish farms, 0.27 on the small non-Amish farms and 0.40 on the large non-Amish farms.

In the various comparisons of energy output per unit of energy input, the efficiency of energy use on the Amish farms ranged from 1.3 to 5.9 times greater than that on non-Amish farms. In terms of energy input per acre, the values on the Amish farms ranged from 13 to 49 percent as great as those on the non-Amish farms with which they were compared.

The Center for Agricultural and Rural Development (Olson and Heady, 1979) produced a national model for 1980 of the effects on land use, exports and income of three approaches to agricultural production--(I) conventional farming with exports projected at recent trend levels, (II) conventional farming with exports at a level that would utilize nearly all available cropland, and (III) organic farming with exports as in (II). Yields generated by application of the model range from about 30 to 50 percent for organic farming compared with conventional farming (Table 6). According to the authors, "The organic farming yields are lower, due to both no use of chemicals and the necessity of using less productive land to meet total demands."

Energy For The Future

If and when oil and natural gas must be rationed, a national decision will have to be made on agriculture's priority for these energy sources. At present, only about 3 percent of the total amount of energy used in the United States is devoted to agricultural production (mining ores, manufacturing steel, fabrica-

Table 5. Crop yields in organic and conventional systems

Organic vs. conventional farming comparison	Yields on organic farms as percentage of yields on conventional farms[a]
Amish vs. non-Amish farms in various areas, total aggregate production of crops and livestock per acre[b]	
Illinois (11 Amish vs. 5 non-Amish farms)	62
Pennsylvania	
Old Order Amish (12 Amish vs. 6 non-Amish farms)	103
Nebraska sect (5 Amish vs. 6 non-Amish farms)	56
Wisconsin	
Ten Amish vs. 14 small non-Amish farms	78
Ten Amish vs. unstated no. of large non-Amish farms	63
Wheat yields in New York and Pennsylvania[c]	
Entire sample (ten pairs of farms)	78
Six pairs of farms with comparable acreages	89
Aggregate crop value per acre of harvested cropland on 14 pairs of midwestern farms[d]	
Values unadjusted for land not cropped	89 (87)[a]
Values adjusted for land suited to cropping but not cropped	
Credit for grazing at one-half the value for rotation hay and pasture	84 (82)[a]
Credit for grazing equal to rotation hay and pasture	86 (84)[a]
No credit for grazing	80 (78)[a]
Corn yields, five farms, various locations[e]	85
Soybean yields, three farms, various locations[e]	107
Wheat yields, four farms, various locations[e]	91
Miscellaneous crop yields, 18 farms, various locations[e]	97

[a] Values in parentheses are adjusted for differences in soils.

[b] Johnson et al. (1977). Yields are farmers' estimates.

[c] Berardi (1976). Yields are farmers' estimates.

[d] Lockeretz et al. (1978). Yields are farmers' estimates.

[e] Oelhaf (1978). Some of the values are organic farmers' estimates of their yields relative to their estimates of yields obtained by their neighbors who were conventional farmers. Others are organic farmers' estimates of their own yields relative to the state average yields. In the instances documented, the state average yields were for different years than the farmers' yields.

Table 6. Estimated national average crop yields under conventional and organic farming (Olson and Heady, 1979)

Crop	Yields in bushels per acre with indicated alternatives[a]			Yields with Alternative III as a percentage of yields with Alternative II
	Conventional farming		Organic farming,	
	Alternative I	Alternative II	Alternative III	
Wheat	45.8	43.1	20.1	46.6
Corn	97.4	98.1	49.3	50.2
Other feed grains[b]	55.0	57.0	17.2	30.2
Soybeans	40.8	40.0	19.7	49.2
Cotton[c]	1.5	2.5	1.1	44.0

[a] See the text for a description of the alternatives.

[b] Other feed grains are in corn-equivalent bushels.

[c] Cotton is in 500-lb bales per acre.

ting machinery, producing fertilizers and pesticides, fueling tractors, harvesting and drying crops, operating livestock buildings, etc.) (U.S. Department of Agriculture, 1976).

The 3 percent figure given here for energy use in agricultural production is less than one-fourth of the amount of energy expended "from the farmer's gate to the dinner plate" (i.e., for transporting, processing, marketing, storing and cooking the food) (Federal Energy Administration, 1975). Thus, the energy saved by organic farming would apply only to the 3 percent used in actual production and not to the 16.5 percent estimated to be used in the total food system. A change from conventional farming to organic farming methods would have little impact on national fossil fuel consumption because its main direct effect would be on the energy used to produce and use agricultural chemicals. These require about 40 percent of the energy used in agricultural production or about 1 percent of the energy used in the United States (U.S. Department of Agriculture, 1976). The net effect would probably be less than a 1 percent reduction in national energy use because if agricultural chemicals were not used more energy would be expended in tillage and in farming additional land.

In spite of the relatively small proportion of the total U.S. energy consumption that is devoted to agricultural production, researchers are giving increasing attention to conserving energy, improving the efficiency of energy use, and developing alternative sources of energy for future use in agriculture. Progress is being made. For example, the poultry industry is reducing energy use by improving the insulation of shelters and substituting animal heat for fossil fuel energy. Use of solar and wind energy is increasing. The more expensive energy becomes, the more important it will be to obtain the maximum benefits from the amounts and forms used, whether they are employed in conventional farming, in organic farming or in other aspects of the economy.

IMPLICATIONS OF INCREASED ADOPTION OF ORGANIC FARMING METHODS[9]

This section attempts to assess the effects of substantial shifts from conventional to organic methods of farming. Considered will be the impacts on crop production, land use and livestock production as well as the possible economic implications for farmers, consumers and the nation as a whole.

Crop Yields

In the organic-conventional comparative studies reported in Table 5, yield reductions attributed to organic farming ranged from -7 to 44 percent. (Excluded are the data from organic farms on which outside sources of manure or municipal sludges were reportedly used.)

We estimate that, for farming in a mixed grain-livestock system without nitrogen fertilizers and pesticides, aggregate yield reductions would be 15 to 25 percent if there were little or no change in cropping patterns.[10] A major shift in cropping patterns on cash grain or vegetable farms to insert nitrogen-fixing legumes would lead to a much greater reduction in production of grain and vegetable crops on these farms because of the smaller acreages in these crops in any given year. The decrease in production would probably increase aggregate farm income because the percentage increase in farm prices would be expected to exceed the percentage decrease in production. On individual farms, either marketed legume hay or additional livestock products would probably partially offset the loss of potential income.

Acreage Needed

To offset a 15 percent decline in production on present land due to adoption of organic farming methods would require 18 percent more of the same kind of land to produce the output obtained by conventional methods. Because currently there is little idle land where soils and climate are favorable, the additional land would be less productive, and more of it would be needed. At least 20 to 25 percent additional less-well-suited land would be required.

To offset a 25 percent production decline would require 33 percent more of the same kind of land to produce the same output by organic farming methods; this would translate to perhaps 40 percent or more additional less-well-suited land. In Illinois, for example, it is estimated that 1.39 acres of land-use capability subclasses IIIe and IVe would be needed to replace 1 acre of average current cropland (Aldrich et al., 1971).

The same principle would apply if there were a partial shift to organic farming, as some have suggested. A partial shift would merely decrease the amount of additional less-well-suited land required.

Erosion Potential

Much of the land available for cropland expansion is on slopes and, thus, susceptible to erosion. If legumes become part of the cropping sequence on intensively cropped, nearly-level land, more row crops would have to be planted on the sloping land to maintain the output; this would mean increased erosion. Erosion from slopes of 2 to 4 percent is 2.6 times greater than that from nearly level land (0 to 2 percent slopes); and from slopes of 4 to 7 percent, it is 6.2 times greater (Lee and Stall, 1978).

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[9] In some situations organic farming is not feasible. These include (1) dry regions where growing nitrogen-fixing legumes in rotation is impractical; (2) crops for which pesticide use is essential; (3) soil which, for reasons of wetness, steepness, stoniness, etc., is not suited to crop rotations; and (4) wet seasons in which adequate weed control without herbicides is impossible.

[10] Part of this reduction is attributable to a lack of enough organic matter and farm-grown nitrogen to supply currently used quantities of plant nutrients, and part is attributable to increased pest losses for some crops in some areas.

Animal Production

Legume Nitrogen vs Fertilizer Nitrogen

Reliance on legumes instead of fertilizer to supply supplemental nitrogen for crop production would reduce the productivity of cash grain and vegetable farms for grain and vegetable crops because the proportion of the time these crops could occupy the land would be reduced. As noted previously, livestock or poultry would probably be introduced, either on the individual farms or on others to which legume hay would be sold, in an attempt to mitigate the loss of economic efficiency of the system.

A further consequence of reliance on legume nitrogen would be a reduction of grain production for the market. In regions such as the Northeast and East that are already deficient in grain and that import grain from other regions, the likely result would be an increase in local grain production on soils less well suited for the purpose and under climatic conditions less favorable than those in the Midwest.

Animal Nutrition

Increasing livestock and poultry numbers as a means of increasing the amount of available manure to replace fertilizers is sometimes cited as a goal of organic farming. Feeding crops to domestic animals conserves in the manure for return to the soil a portion of the nutrients that would otherwise be sold off the farm in the crops, but it does not result in a net addition of plant nutrients unless feed or manure is imported from off the farm, which would impoverish some other land.

In conventional farming, extensive use is made of nutritional supplements in animal feeds. The significance of chemical additions not provided for in the organic system is seen most vividly where the soil is markedly deficient in one or more nutrients. Allaway (1975) mentioned the following examples:

> The cattle of the early colonists of the Sacco Valley of New Hampshire suffered from a "wasting disease," which was attributed to a curse placed on the valley by the Indian Chief Chocorua. The "curse of Chocorua" is now known to be due to cobalt deficiency. When the Columbia Basin of Northwestern United States was first used for irrigation agriculture, zinc deficiency was so severe that corn and bean crops failed on many farms. These naturally occurring deficiencies and many similar ones have since been corrected by such measures as use of iodized salt, trace element fertilizers, and mineral supplementation of animal diets.

Animal manures, if available in adequate amounts, will often correct certain micronutrient deficiencies, but there are exceptions, as Allaway noted:

> Corrall disease is a term used to describe zinc deficiency in citrus trees growing on sites that have received heavy applications of manure. Some organic materials may tend to make copper less available to plants. Severe deficiencies of copper resulting in low crop yields and copper deficiencies in grazing animals are common problems on highly organic soils, such as peats and mucks.

Mineral and other nutritional supplements increase animal productivity, and they are of greatest importance in feeds for poultry and swine. In cattle feeding, considerable use is made of urea as an economical nonprotein source of nitrogen. The bacteria in the rumen incorporate the urea nitrogen into microbial protein, which is subsequently digested and converted in part to animal protein. Such use of urea upgrades the nutritional quality of low-nitrogen roughages such as cereal straw, corn fodder and sugar cane bagasse for cattle. It spares natural protein sources, allowing their use for feeding to nonruminant species that cannot use urea nitrogen. Approximately one-third of the dietary nitrogen for cattle can be supplied as urea without decreasing the rate of gain.

The minerals and nonprotein nitrogen used to improve the nutritional quality of animal diets in conventional farming also improve the quality of the manure as fertilizer because much of the quantity of these substances supplied in the feed is excreted in the manure. Avoiding the use of mineral and nitrogen supplements in animal nutrition would reduce the efficiency of animal production and would increase the area of land needed to produce animal products.

Use Of Hormones And Other Substances

Further increases in production efficiency are achieved in modern conventional animal agriculture by use of hormonally active substances (Butler et al., 1977). Hormonally active substances perform two important functions. The first, and potentially the more economically important, is the use of hormones to improve reproductive performance and to facilitate genetic improvement. Technology is currently available so that hormones may be used to induce parturition in swine and cattle. Induced parturition can decrease losses of offspring and decrease the time needed for animal care. Hormones can be used to induce ovulation, making artificial insemination more practical and effective; to induce twinning; and to increase the genetic contribution of superior cows by facilitating embryo transfer to, and propagation in, foster mother cows. Practical realization of the full benefits from these uses of hormones is yet to be achieved.

The second function performed by artificial administration of hormones is promotion of animal growth. The hormones used for this purpose increase the rate of gain and reduce the amount of feed required per pound of body weight gained. Increases in feed efficiency of 10 to 15 percent for growing and finishing beef cattle are common with the hormone implants available (Beeson, 1979). Use of monensin (a nonhormonal substance) in the ration of beef cattle increases the feed efficiency to about the same extent as the hormone products (Potter et al., 1976; Raun et al., 1976).

Most of the hormones and other active substances useful in conventional animal agriculture are naturally occurring organic compounds, but their purposeful use is unnatural and thus is objectionable to some persons. Their value in increasing the efficiency of resource use in animal production is lost in "organic" systems that do not use them.

Animal Health

Certain drugs are now used in conventional animal agriculture to protect animal health and, hence, to reduce morbidity and mortality and to increase production efficiency. These include antibacterials, anthelminthics, larvacides and antiprotozoals.

Drugs are useful in both conventional and organic systems of farming, but organic farmers prefer not to use them. Although the current trend toward increas-

ing numbers of animals in the same facilities increases the need for drugs to protect animal health, others factors remaining equal, many of the larger units are not farming operations in the usual sense but are separate enterprises.

Some of the drugs employed are naturally occurring organic compounds, and some are synthesized. The use of drugs for animals is controlled by the Food and Drug Administration, which has the responsibility for assuring that they are safe and effective for the intended purpose, as well as the responsibility for assuring that residues that might be hazardous to humans do not occur in the edible products.

Opportunities to reduce the degree of reliance on pharmaceuticals exist at present and can be expanded further by research. For example, in poultry production, the need for medication to reduce health problems can be reduced by controlling the temperature and humidity, by controlling the gases evolved from the manure and by supplying diets of high nutritional quality. Future opportunities exist to improve the genetic potential for resistance to diseases and parasites. Animals with suitable genetic qualities need little help from pharmaceuticals.

Economic Impacts

Assessing the economic feasibility of an organic approach to farming is appropriately left to individual farmers. Individual farmers may make different decisions because they differ in goals; in soil, labor and capital resources; in availability of fertilizer substitutes (animal manures, sewage sludge); in environmental conditions; and in access to special markets. In addition they may differ in personal preferences, value judgments about pesticide safety and relevant social issues, and in other respects that may influence their decision.

Farming organically may be a strategy chosen by certain farmers to lower production costs, adjust to higher energy prices or lessen the uncertainty of energy-intensive input supplies. In some instances, they may be able to substitute family labor for farm machinery or for herbicides to control weeds. Organic farming methods may also be attractive to some new entrants into agriculture who lack the funds for getting started.

The economic impacts of an increase in adoption of organic farming would depend largely on the degree and extent of adoption. Limited adoption, in which farmers might be able to take advantage of a special market under current economic conditions, would probably have little direct effect on consumers or the agricultural community. Widespread adoption, on the other hand, would have large impacts on both.

Farm Income And Farm Prices

Aggregate farm income would increase as a result of a substantial shift to organic farming. The principal reason is that total production from the land involved would decrease, and the percentage increase in price of agricultural products would exceed the percentage decrease in production.

Each 1 percent decrease in crop production would mean an estimated "farm-gate" price increase of 1 to 5 percent, depending on the type of crop and whether it is consumed domestically or exported.[11] The average increase would likely be 2 to 4 percent. The resulting percentage price increase for all food at the retail level would be approximately one-third of the farm-gate crop price increase--or from 0.75 to 1.50 percent for each 1 percent decrease in production. Thus, a 10 percent decrease in agricultural output would result in an estimated 20 to 40 percent increase in prices to the farmer and a 7.5 to 15 percent increase in retail prices.

The impact of a major switch to an organic system would not be evenly distributed among regions, among farmers or among consumers. Regions with serious insect, disease, nematode and weed problems that could not be adequately controlled without pesticides (e.g., the cotton, corn and soybean producing areas in the South and Southeast, and fruit and vegetable farms generally) would be negatively impacted. Regions or farming systems with less serious pest problems (e.g., the corn-soybean system in the Midwest, except for weeds, and rangeland livestock operations generally) would likely reap larger benefits. Cattle feeders would substitute legume hay for part of the feed grains now used.

Prices for crops that are intensive nitrogen fertilizer users would increase sharply, whereas prices for legume crops might decrease. Regions not having adequate sources of organic matter or where legume sources are not feasible, such as the dryland wheat producing area, would also be negatively affected. Much of irrigated agriculture in the West would be severely impacted, especially in the long term. Irrigation is expensive, and the cost of legume nitrogen would thus be higher in irrigated agriculture than in rain-fed agriculture. Moreover, where the source of water is underground reservoirs that are only slowly rechargeable, water that might otherwise be used to produce a crop of higher value than the legume would be lost from the system and would not be available for subsequent use.

At their present numbers, many organic farmers receive higher prices for their products than do conventional farmers because they supply a special market. According to *Organic Gardening* Editor Robert Rodale (1973):

> There are perhaps 10,000 organic farmers in America today, managing farms of all sizes. And they are reporting surprising business success, mainly because the fast-growing market for health foods is supplied in large part by organic farms. The yields of organic farmers may average less than those of comparable conventional farmers, yet they often receive higher prices for their crops because they sell to a specialty market.

This advantage, of course, would disappear if the number of organic farms increased sufficiently to supply more product than the market could absorb.

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[11] Following are estimates of farm-gate price flexibility coefficients:

	Domestic	Export
Feedgrains	-5.0	-1.67
Feedgrains	-4.0	-1.33
Oilmeal	-2.5	-1.00

These values define the expected percent change in farm-gate price resulting from a 1 percent change in output of the indicated group of commodities. The total market value of the crop is increased by reductions in the size of the crop if the price flexibility coefficient is absolutely greater than -1.0 (Taylor et al., 1977).

Land Prices And Farm Size

Increased net farm income would lead to higher land values throughout the United States. Thus, current landowners would benefit, but financial constraints would be imposed on the entrance of potential new farmers.

Current knowledge of the interrelationships between various factors of agricultural production suggests that an organic approach might encourage and reinforce the viability of family farms in the small- to medium-size range. It is not known to what extent this might be offset by the tendency to drive up the price of land, thus bringing more outside capital into agriculture and promoting large farms.

Labor Demand

If organic farming were increased substantially, agricultural production would decrease, prices would rise and cultivation of additional, less productive land would be encouraged. The additional labor required to farm this land, plus whatever increase in labor intensity might be needed for use of organic methods on land previously cultivated by conventional methods, would increase the demand for farm labor and would cause wages to rise.

A shift to a more labor-intensive American agriculture would entail difficult adjustments and social costs for many persons. For instance, although there are unemployed persons in the United States, most of them do not live in rural areas and are not trained for farm work. Local housing near farm employment opportunities would be inadequate. And it is doubtful, at least at present, that some of the urban unemployed would be receptive to the types of work involved on farms, especially the menial tasks.

Exports And Balance Of Payments

Exports of agricultural products would be adversely affected by large-scale adoption of organic farming. One national model indicates that, in 1980, the amount of wheat plus corn available for export would be 4.6 billion bushels under conventional farming and 900 million bushels under organic farming (Olson and Heady, 1979). Much of this difference would be due to the substantial shift from grain crops to forage legumes to supply nitrogen.

In the long run, the price increases resulting from decreased production would encourage importing countries either to increase their own production or to seek other sources, thus reducing the dollar value of U.S. agricultural exports and increasing the balance-of-trade deficit. In the short run, the dollar value of exports may be expected to decrease only moderately because of partially offsetting price increases. This initial reduction in value of exports would be substantially less than that which would occur with a long-term U.S. commitment to organic farming.

Our present capability to produce greater quantities of certain agricultural commodities than are needed for domestic consumption can also be used to support the alternative position that the loss in export capability due to a shift to organic farming would be an acceptable tradeoff for reducing the use of commercial fertilizers and pesticides in conventional agriculture. This proposition involves value judgments that must be made by members of society at large or by their elected representatives.

ORGANIC FARMING RESEARCH

Both organic farmers and conventional farmers are served by research on genetic improvement of crops, planting dates and rates, tillage, nonpesticidal means of pest control, and certain other management practices. Both organic farmers and conventional farmers are served by research on soil organic matter, soil structure and other soil properties, soil-plant relationships, energy and the environment. Research on fertilizers and pesticides benefits primarily conventional farmers.

In earlier years, much research was done on cropping sequences, nitrogen fixation by legumes, utilization of crop residues, and manure preservation and application--all matters of special interest to organic farmers. This information is recorded in the literature and is available to all, but relatively little such work is being done at present.

One area now being emphasized in fundamental nitrogen research is that of developing the capability of nitrogen fixation in nonleguminous plants. Although success in this endeavor is not soon anticipated, it would have a major impact on agriculture. Organic farmers would not need legumes to supply nitrogen, and conventional farmers would not need nitrogen fertilizers. The most visible distinction between organic and conventional farming--crop rotations including legumes--would disappear. The "nitrate problem" that is viewed by some as an indictment of conventional farming would then become an organic farming problem as well, as is explained on page 14.

Considerable research is being conducted also on "conservation tillage" methods, which involve stirring the soil less and maintaining more crop residues on the surface of the soil than is true of conventional farming. Conservation tillage aids in soil erosion control. Whether research on conservation tillage should be classified as research on organic farming or conventional farming may be debated, but its effect is to change conventional farming in the direction of organic farming as regards tillage intensity and erosion control. At present, the ultimate version is "no till," in which the crop is planted without previous plowing or disking and without subsequent tillage, the weeds being controlled by herbicides. In some variations being tested, a legume is used as an intercrop to supply nitrogen and to aid in weed control. Except for the herbicide usage, this variation of conservation tillage results in a form of agriculture more "organic" than the usual organic farming. The tillage practices used in conventional farming are more generally applicable than are many conservation tillage practices, but farmers are adopting conservation tillage wherever the combination of method and conditions proves advantageous.

ORGANIC GARDENING

This report deals primarily with organic farming because our food supply depends for the most part on farming. Many of those in the organic movement are gardeners, however, and so this section is addressed specifically to gardening. Organic gardening is not just small-scale organic farming. In comparison with production involving use of commercial fertilizers and pesticides, organic gardening is considerably more attractive than is organic farming.[12]

Applicability Of Methods

The most important distinction between organic gardening and organic farming is the ease with which the organic matter grown in the garden itself may be supplemented by organic matter derived from other sources. The extra organic matter contains plant nutrients and alleviates the need for commercial fertilizers, and it improves the physical properties of the soil.

Fallen leaves and lawn clippings from the home site need to be disposed of, and a garden is a good place for the purpose. Supplemental plant residues, animal manures and other wastes can sometimes be obtained from neighbors, nearby farms, municipal sewage treatment plants or nearby garden supply retail stores. Organic matter may be obtained free of charge from some of these sources, but where it must be purchased the cost is not such an important factor as it is likely to be in organic farming because many organic gardeners view their gardening activities as an avocation in which costs are not of primary concern.

The leaves, grass clippings, garden residues and other organic materials are most effectively handled by putting them in a compost pile and allowing them to decompose in part before adding them to the garden. Composting kills plant disease organisms if the temperatures attained in the compost pile are high enough. Although the value of the organic matter in improving the soil is greater if the organic matter is incorporated directly into the soil than if it is partially decomposed before addition, the amount of organic matter added in organic gardening is often so great that the difference in effectiveness is of little concern.

A second difference is that gardening without use of herbicides to control weeds is much easier than farming without herbicides. Hand weeding presents a real problem on organic farms because of the relatively large area concerned, but it is feasible in home gardens. Labor for hand weeding in home gardens is usually free and often is viewed as recreation. Moreover, some of the organic matter added to the soil may be applied as a mulch, which helps to control weeds.

A third distinction is the greater freedom of choice among fruits, vegetables and ornamentals that may be grown by gardeners. Because organic gardening is more often a hobby than a commercial enterprise, the gardener can often avoid species that offer pest problems without concern for the financial aspects of the production or sale of the products. Sometimes plants in home gardens escape diseases and insects because they are isolated from sources of infection or infestation.

[12]For a practical guide to organic gardening and a list of many references see Fletcher et al. (1972).

Finally, if the yield is poor or if part of the produce is destroyed by pests, the organic gardener can purchase the needed products at the supermarket without suffering a financial disaster.

Pesticides can be applied safely by the conventional home gardener if the instructions on the label are followed, but hazards of possible misuse are eliminated by organic gardeners that do not use pesticides. Commercial fertilizers may be used to advantage by conventional gardeners. Nonetheless, commercial fertilizers are relatively concentrated forms of plant nutrients and may easily damage plants if applied incorrectly or in excessive quantities. Compost and other organic soil amendments used by organic gardeners contain lower concentrations of soluble plant nutrients and are less apt to damage plants. Improperly applied fresh livestock and poultry manure, however, can cause injury to plants due to excessive salt and ammonia concentrations.

Controlling Pests

A home gardener who desires to grow a wide variety of fruits and vegetables will find that some insects and diseases cannot be effectively controlled at present without pesticides. Consequently, some fruits and vegetables simply cannot be satisfactorily grown if use of pesticides is ruled out.

Information is lacking on the value of releasing natural enemies for insect control in the wide range of vegetables and fruits usually grown in home gardens. Some predators attack only a single or closely related insect species and thus do not control all of the many types of insects found in the home garden (cabbage worm, potato beetle, squash bug, flea beetles, cutworm, aphids, corn earworm, etc.). The preying mantis, on the other hand, is not selective but feeds on beneficial insects such as ladybird beetles as well as on insect pests.

Presently, there is little evidence to indicate the effectiveness of "companion crops" in either repelling insects from the area or attracting them away from fruits and vegetables.

Nematodes present special problems for home gardeners, especially in the South. High concentrations of vegetables in small areas in which there is limited space for crop rotation increase the likelihood that such pests as root-knot nematodes will be serious. The hazard is often increased by incorporating organic residues because these may be infested with nematodes. A commercial nematicide is often the best control method at present. Breeding for nematode resistance (already achieved in some tomato and sweet potato varieties) appears to be a promising alternative for the future.

Providing Plant Nutrients

Unless provided from outside sources, the supply of available nitrogen is often marginal or deficient in organic home gardens. And unless adequate amounts of well-rotted plant residues and kitchen wastes or animal manure are used, garden yields are likely to be disappointing without commercial fertilizer.

Compost is the primary source of home-grown nitrogen. However, most instructions for preparing compost suggest that nitrogen fertilizer be added to hasten decomposition of the residues. Making compost is a technique for avoiding the tie-up of available nitrogen in the garden while the organic residues are decaying. The residues decay outside the garden soil and are incorporated after the initial period of nitrogen tieup.

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