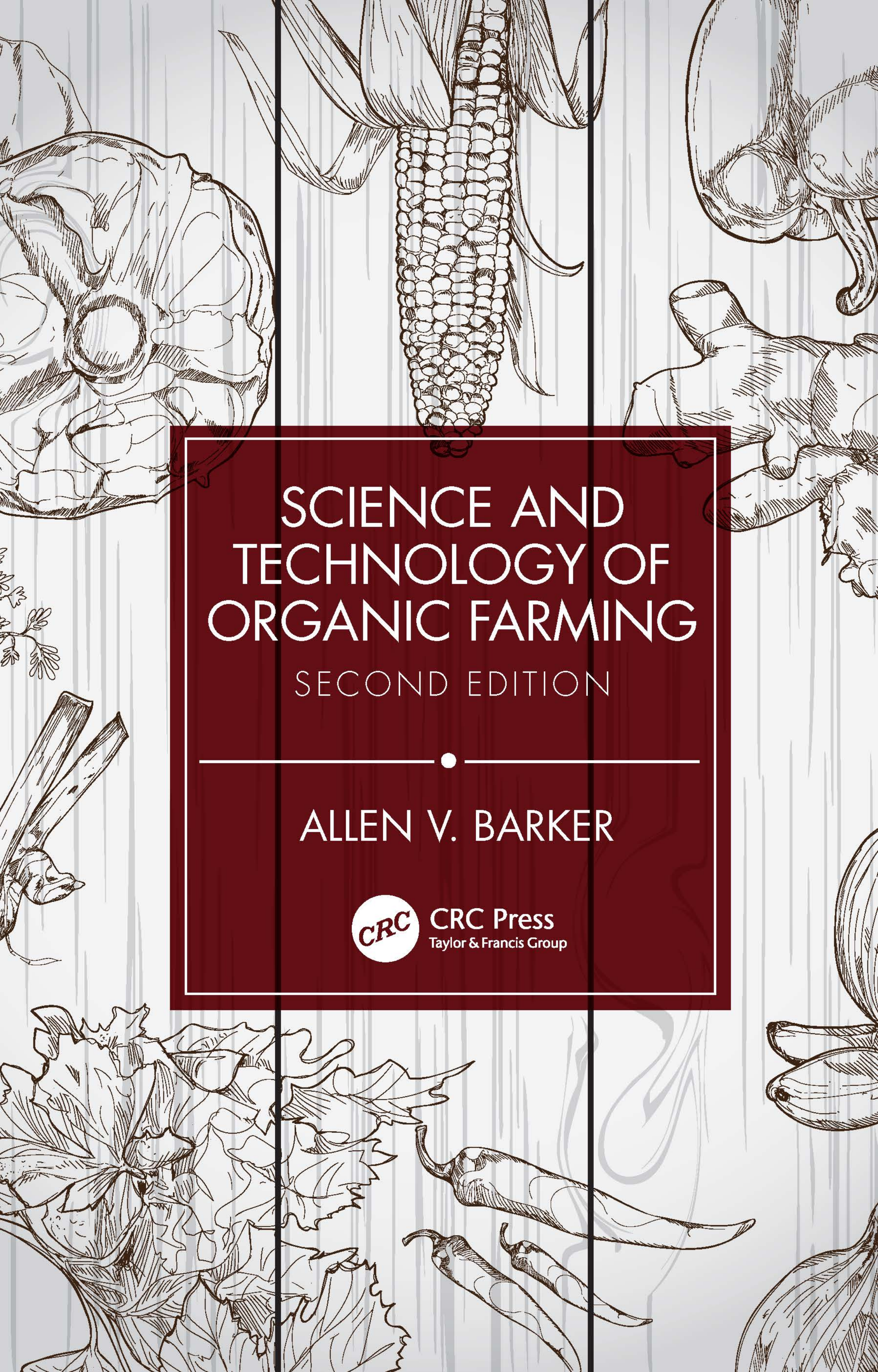

SCIENCE AND TECHNOLOGY OF ORGANIC FARMING

SECOND EDITION

ALLEN V. BARKER

CRC Press
Taylor & Francis Group

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Second Edition

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Preface

Organic farming is said to be the original, mainstream form of agriculture. Before the development of synthesized fertilizers and pesticides, practices of crop rotation and fertilization with animal manures and legumes were the options available to most farmers to maintain crop productivity. All systems of organic farming avoid the use of inputs of synthetic fertilizers and pesticides. However, the principles involved in organic farming are in common with conventional farming – a term that is used to identify agriculture that is not organic – as both systems are managed intensively. Production in the wild or in abandoned systems is not an organic practice. Crops must have nutrients, and pests must be controlled. Many conventional and organic farming systems have practices that are in common with one another. Hence, organic and conventional systems are not greatly different in technology and have the same scientific basis.

The science of organic farming has emerged as a combined study of plant and soil sciences, plant pathology, entomology, and other biological and environmental sciences. Organic farming not only is a philosophy but also is a well-researched science, for which methods of application are presented in this practical text. The purpose of second edition of *The Science and Technology of Organic Farming* is to provide a current, readily available source of information on the scientific basis for organic farming and the technology to achieve adequate yields through plant nutrition and protection. Most of the revision of the book is to improve clarity of the text, to add content, and to include metric measurements as well as units in the common system. I was advised by a reviewer, who used the metric system, "to write one for us next time". Considerable rounding is employed in the conversion of the units. A chapter on hydroponics is added. Hydroponics is known to produce high-quality plant products, and farmers are interested in adapting this method of farming into organic systems.

The Introduction of the text provides an overview of organic farming as well as the processes and results of attempts to define and regulate organic farming. Organic farming began unscientifically but has adopted traditional scientific methods in its present form. Soil fertility and plant nutrition are discussed in the subsequent chapters with emphasis on the macronutrients nitrogen, phosphorus, potassium, calcium, magnesium, and sulfur and a group of plant micronutrients. These chapters are major components of the book because failure to provide adequate nutrients to crops is a limiting factor in organic agriculture. The chemistry of the plant, the soil, and the soil solution are explained in the chapters on soil fertility and plant nutrition. Guidelines, recommendations, and procedures for determining the best fertility recommendations for individual situations are presented.

The chapter on liming has been moved to follow the chapter on plant nutrients and soil fertility. One of the major benefits of liming is improvement of the availability of plant nutrients in soils, and this placement seemed to be logical in the order of presentation of topics in the book.

The chapter on farm manures covers practices for management of farm manures for incorporating them into land. The practice of returning manures to the soil improves fertility of the soil and has been researched as a viable system of effective soil management in all forms of agriculture. A following chapter on composting discusses the purposes and the production and assessment of compost as a factor in maintaining soil fertility. A chapter on managing green manures follows and completes the discussion of organic matter in soil fertility.

Mulches and tillage are covered in detail followed by chapters on methods of organic weed, insect, and disease control. Organic pest control is a substantial component of management of soil fertility and crop productivity in organic farming. Researchers are working to advance this segment of the field, and some developments are reported. The book includes discussions of companion planting and the storage of produce.

A chapter on hydroponics is added. Hydroponics is a system of crop production that contrasts markedly with organic farming. Many people say that organic farming is conducted only in soil, and thus hydroponics, which is soilless culture, cannot be organic. The main difference, however, between organic farming and hydroponics is in the use of fertilizers to nourish crops. In hydroponics, nutrient solutions are made by dissolution of chemical salts in water. These salts can be added to supply all nutrients. The original purpose of hydroponics in about 1860 was to demonstrate the essentiality of chemical elements as plant nutrients. Organic fertilizers cannot be used directly in hydroponics since nutrients are not available from the organic fertilizers by simply suspending them in water. The unaltered organic fertilizers are usually toxic to plants; hence, methods have been developed to convert or digest organic fertilizers into chemical solutions that resemble those of made from chemical salts. Some people are satisfied that crops are grown organically if the pest control is by organic procedures even if the supply of nutrients is from chemical sources.

A glossary is included to assist readers in terminologies used in the book. A bibliography is added to acquaint readers with some of the literature that was consulted in the preparation of this book and that readers may want to read for more information. Readers may want to consult references in the bibliography to enhance their knowledge of certain subjects.

Organic farming offers a scientifically derived method of improving soil fertility and for increasing yields with limited chemical inputs. With the world population increasing rapidly, and projected to do so for some time, and with improved plant nutrition and crop protection as major factors increasing crop yields, use of the knowledge of organic farming to maximize agricultural yields and to sustain soil quality will grow in importance. Public interest in minimizing the use of chemical inputs in agriculture is increasing the demand for organically grown foods.

This text is intended to be a practical handbook of organic farming and a reference work for anyone interested in organic farming. It will also give information on how to assess and govern the nutritional status of crops and the fertility and condition of soil. It should be of use to farmers, agricultural advisers, soil scientists, and plant scientists.

The author gratefully acknowledges his daughter, Robin V. Barker, for providing the hand-drawn illustrations in the book.

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Author Biography

Allen V. Barker is Professor in The Stockbridge School of Agriculture at the University of Massachusetts, Amherst. He has over 55 years of experience in teaching and research in organic and conventional agriculture and has interests in soil fertility and plant nutrition. He was raised on a crop and livestock farm in southern Illinois, where his family has farmed since 1800. He was graduated with an Agricultural Science major at the University of Illinois, Urbana-Champaign, and received master's and doctoral degrees from Cornell University. He regularly teaches courses in organic farming, soil fertility, plant nutrition, and organic farming seminars at the University of Massachusetts. He is a retired farmer.

1 Definitions and Philosophies of Organic Farming

HISTORY AND BACKGROUND

The term "organic farming" was introduced into common usage around 1940, following farming movements that had begun in the 1920s and 1930s promoting the concept of management of a farm as a living unit or whole system. During the period of the 1920s and 1930s, Albert Howard in the United Kingdom based on his work in India laid out the social and practical groundwork for the organic gardening movement. Rudolph Steiner, through his lectures and teaching beginning in 1924, laid the foundation for biodynamic agriculture, which created the first organic-like certification and labeling system. However, biodynamic agriculture differs from organic agriculture in that the biodynamic system has spiritual, mystical, and astrological guidelines that are not part of conventional organic farming. Lord Northbourne (Walter James, 1896–1992), an agronomist in England, in reference to farming, introduced the term "organic" to the World in 1940 in his book *Look to the Land*. J.I. Rodale, introduced the organic movement to the United States about 75 years ago with publications that advocated for health through farming organically. During the 1940s, the Rodale Institute (United States), the Soil Association (United Kingdom), and Soil and Health (New Zealand) were founded as associations devoted to the study and promotion of organic farming. Similar organizations arose in Germany and Japan at about the same time or just following the establishment of the institutions in the United States, the United Kingdom, and New Zealand.

At the time of the early development of the organic movements, however, use of chemical fertilizers and pesticides was very modest compared to current practices; hence, the development of organic farming not only was related to the materials used for soil fertility and crop protection but also had a base of managing a farm as a system with integration of soils, crops, animals, and society. This concept of a systematic approach is fundamental in organic farming today and is expressed with opposition to the production of genetically engineered crops and irradiation of foods, among other practices. The association of organic agriculture with environmental sustainability arose in the 1960s and 1970s and brought about changes in the politics and social elements of organic farming. The involvement of governmental agencies in organic farming increased markedly during the 1980s and afterward.

Until recently with the applications of legal restraints to organic farming, no universally accepted definition or identification of organic farming and gardening was developed.

The difficulty of defining organic agriculture arose from multiple conceptions of the basic nature of the term "organic" among biologists, chemists, and practitioners. In some cases, terms such as "naturally grown", "wild", "biologically grown", and "ecologically grown" were used to characterize organic production. Interpretation and application of these terms are often as difficult as defining organic farming. Some people say that organic farming is agriculture that is based on the use of crop rotations, cover crops, composts, and nonchemical means of pest control and that excludes the use of manufactured fertilizers or pesticides. That concept is limited in scope and does not cover the diverse practices and restrictions of organic farming. Some people say that organic farming can occur only in soil or cropland.

In the early years, about 1940 to 1970, of organic farming, the practice was essentially local operations with much contact between consumers and farmers or retailers. With the expansion of organic production and markets in the 1970s, this association became more remote, and consumers, growers, and marketers needed means of proving that produce was organic. These needs led to the formation of certifying agencies that would vouch that the produce was grown organically and permit labeling of produce as being organically grown. By the 1980s, several private and state-run certifying agencies were operating in the United States. These agencies had variable standards for certification and charged variable fees for services. Some agencies did not recognize certifications by other agencies. Many regions of the country did not have locally accessible certifying agencies. These differences created problems of lack of certification, lack of uniform standards, unreasonable fees, and even fraud. To address these problems, the organic community sought federal legislation to enact national standards for certification of organic farming. This action led to the Organic Foods Production Act of 1990 and the establishment of the National Organic Program (NOP) of the United States Department of Agriculture. The NOP sets regulations for certification. The NOP regulations are implemented through certifying agencies that are accredited by the NOP. Accreditation ensures that the certifying agencies understand and use the regulations of the NOP and conduct business properly. Certification applies to crops and crop products and to livestock, poultry, and products of their production. The certification practices referred throughout this book are those established by the NOP for the United States. Several hundred governmental and nongovernmental organizations in the World offer certification systems. Governmental organizations have increased in prominence and importance as the volume and value of organic production has increased.

The regulations of the NOP establish transition periods for movement from conventional farming into organic agriculture. A transition period is generally 3 years following the ending of applications of nonorganic practices. Some agencies may aid growers in selection of crops to grow during the transition period. In practice, growers may certify part of a farm and leave the rest in conventional agriculture. In that case, buffer zones between the organic farm and the conventional farm operations must exist. Regulations specify what physical distance or barriers are needed to separate the organic areas from conventional areas. Produce from mixed systems must be segregated at harvest. The regulations of the NOP also establish materials that are permitted, restricted, or prohibited for use in organic agriculture.

Permitted materials can be used regularly in organic farming. Items that are restricted can be used only within the limitations set by the NOP standards. For example, farm manures need to be composted or an amount of time between application of the manure to cropland and harvest of produce must lapse to meet the organic standard. Prohibited materials cannot be used in organic production. Prohibited materials may be naturally occurring or manufactured. Consequently, definitions of organic agriculture by the NOP include listings of allowable practices in fertilization of crops, control of pests, and use of adjuvants (materials that affect the activity of other agents but that have little effect when supplied alone). Restriction of activities to those allowed in the listings and following specified practices of crop and soil management may permit a grower or the grower's produce to be certified as organic.

Organic certification is a legal process for producers of food and other agricultural products to be able to sell products as organic. Certification also can include seed suppliers, food processors, retailers, and restaurants. The organic brand provides consumers with verified choices in the marketplace. Certification is mainly by private organizations or agents that work with development and review of allowable practices for growers who want to market their produce as organic according to USDA standards. Most USDA-accredited agents are authorized to certify farms and businesses anywhere in the world. However, many countries have their own certification standards. Farmers, ranchers, and processors may choose to work with any USDA-accredited certifying agent.

Types of certification vary. Certification can be for products that are labeled as "100% organic", "organic", "made with organic ingredients", or "products with less than 70% organic ingredients". The grower or handler and certifier agree on a production or handling system that is appropriate for each classification. The certifier provides growers with definitions, guidelines, practices, and lists of materials that may be used in organic farming. A NOP of allowed and prohibited substances that can be used in organic farming is followed. This list includes natural and synthetic substances that are allowed or not allowed.

Growers that have sales of less than US$5,000, currently, do not to be certified by agencies to market produce as organically grown, but the production standards of organic farming should be followed. Certification is not covered in this book, and people interested in the details should consult the entries on certification and the NOP that are presented in the Bibliography.

ORGANIC MATERIALS REVIEW INSTITUTE (OMRI) PRODUCTS LIST

The *OMRI Products List* is a list of products that the Organic Materials Review Institute (OMRI, Eugene, Oregon) has determined are allowed for use in organic agriculture, including production, processing, and handling of farm-grown commodities. The products are reviewed for compliance with the policies of the USDA NOP, and if they pass the review, the products are included on the OMRI Products List. Products on the list can carry the OMRI-listed seal, ensuring that the product listed meet NOP standards. The OMRI review program is private, and participation by providers is voluntary and has a fee. Hence, a product may not be on the list and yet may meet NOP standards. Growers should consult the NOP list or their certifying agency for compliance of items not on OMRI Products List.

OTHER CONCEPTS AND BACKGROUND

Many people are not interested in certification for commercial organic agriculture and may want to develop their own working definitions. An understanding of “organic” as this term is defined by different scientists is helpful in definition of organic agriculture. To biologists, organic means existing in or derived from a living organism. This definition is not unambiguous, for arguments may be made about the levels of existence in an organism, about contamination, and about modifications that may occur after the death of an organism. In chemistry, organic refers to the study of carbon-containing compounds with exception of some compounds, such as carbonates, which are considered to be inorganic compounds. Combination of these two definitions into one may indicate that organic farmers and gardeners can work with carbon-containing materials obtained from organisms. Working with this combined definition, one could be a successful organic grower but would not be using the materials that would be permitted if the definitions were applied singularly. Limestone, largely calcium carbonate, is derived from living organisms and is an inorganic, carbon-containing compound. Diatomaceous earth for insect control is mostly silica, is strictly inorganic in chemistry, but is derived from unicellular algae, which are organisms. Rocks and minerals, such as granite dust and greensand, are considered to be organic fertilizers by some people, and these materials were never living and are essentially void of carbon.

Organic farming has been defined as crop or animal husbandry with *natural materials*, whether these materials are from living or nonliving matter. The weakness of this definition in certification or in practice is in the use of the words “natural materials”. Not all natural materials are considered organic materials by the National Organic Program. Potassium chloride is a naturally occurring fertilizer, but because of its high concentration of nutrients and high solubility, it does not qualify unrestricted as being organic on the lists of certifying organizations. On the other hand, potassium sulfate and potassium magnesium sulfate (langbeinite) are considered organic materials. Mined potassium chloride might be considered organic, however. Water-extracted potassium chloride might not be organic. Cottonseed meal is suspected of contamination with insecticides used in cotton growing and is restricted in use in organic farming. One might ask then if cottonseed meal should be considered organic if it is from genetically engineered cotton to which insecticide application is limited by crop improvement. Use of sewage sludge is prohibited because of the fear of contamination of land by heavy metals transmitted by the sewage sludge. However, application of sewage sludge is regulated heavily, and metal-contaminated sludge is not permitted to be applied to farmland.

Naturally occurring is a restrictive term and does not permit the use of manufactured materials, even though they may be identical to the materials produced in nature. For example, urea from the fertilizer plant is chemically equivalent to urea that is in urine. The latter source would be considered organic, whereas the former would not. Because of the potency of potassium chloride and fertilizer urea, these materials are not "organic" even though they are naturally occurring or identical to naturally occurring material. Some growers may recognize that the discrimination against these materials is due to the lack of understanding of how to use them. Growers who are educated on their use may feel that they can use potassium chloride and fertilizer urea and justify for their own interests that they are organic growers, but they cannot be certified as organic growers by the USDA.

Yet, strict definitions mandate that organic fertilizers be naturally occurring. A corollary to this definition is that the fertilizers be of low solubility or low in nutrients or have both properties. Potassium chloride does not meet the stipulations of the corollary. Rock phosphate is naturally occurring and has a high phosphorus concentration but has low solubility and is therefore organic.

Physical treatment of materials normally is permitted. Rock phosphate is ground to silt-sized particles to increase the availability of its slowly soluble nutrients. Chemical treatment of rock phosphate with acids to manufacture superphosphates is not an organic practice, unless the treatment occurs in some natural process, such as mixing rock phosphate with decaying organic matter or mixing it in acid soils. Wood ashes are organic materials, although they are not naturally occurring in the context in which they are considered organic fertilizers. Hence, it is evident that a lot of judgment goes into the definition of organic fertilizers. The NOP publishes a national list of allowed and prohibited substances for use by certifying agents, and growers who are not seeking certification may want to consult this list.

Organic control of pests involves diverse activities. Generally, sprays or dusts derived from natural sources are considered organic. In some cases, a few manufactured, extracted, or purified products are permitted, as with oils and soaps used in insect control and copper compounds used in disease control. Lack of mammalian toxicity or lack of injury to beneficial organisms is not necessarily a firm characteristic of organic pesticides. Organic sprays and dusts may be highly toxic, abrasive, or otherwise destructive to people, livestock, pets, fish, bees, and other organisms that are not targets for harm.

Organic control may involve cultural practices that limit the spread or growth of pests. These practices may include *biological control* or *natural control* of pests. Biological control involves introduction of organisms that eat, kill, or impede the growth of pests. Natural control involves taking advantage of these organisms already existing in the environment without their intentional introduction. *Integrated pest management* (IPM) is a practice that tries to use naturally occurring organisms in pest control along with the use of conventional pest-controlling chemicals and a combination of cultural practices and use of pest-resistant crop varieties. Use of barriers and traps, rotation of crops, drainage, fertilization, liming, and sanitation are cultural practices for pest control in organic agriculture. Many of these practices are in common with those used in conventional agriculture.

Many myths must be dispelled in discussions of organic agriculture. Organic agriculture is a highly managed system. Production of wild crops can be certified. An abandoned farm is not an organic farm. Failure to fertilize a crop is not an organic practice. Infestation of produce with insects is not a characteristic of organically grown material. Old or ancient practices are not necessary organic ones.

One cannot say that once upon a time, all farmers were organic farmers. Once upon a time, the most common practice was to not fertilize crops. Products such as lead or copper arsenate were used formerly for insect control. These products are not organic.

The organic farmer needs to be a scientist more than a philosopher. The organic farmer must separate fact from myth and the occasional occurrence from the rule.

PRACTICES RELATED TO ORGANIC FARMING

Biodynamic Farming and *Permaculture* are systems of agriculture that have practices and concepts contributing to or added to foundations of organic farming. Biodynamic farming in a sense was a forerunner of organic agriculture as it was first outlined in the 1920s by an Austrian philosopher, Rudolph Steiner. For a farmer to be certified as a biodynamic farmer, the farmer must be certified also as an organic farmer. The Demeter Association certifies biodynamic farmers. The system of permaculture was developed by Australians Bill Mollison and David Holmgren, in the 1970s. The word permaculture is derived from permanent agriculture and permanent culture.

BIODYNAMIC FARMING

In the 1920s, Rudolph Steiner outlined principles of biodynamic farming. A basic concept of biodynamic farming is the view of a farm as an organized, self-contained entity or as an organism with its own individuality. The farm is viewed as a closed, self-nourishing system. A biodynamic farm has an integration of crops with livestock and includes recycling of nutrients and management practices that involve environmental, social, and financial aspects of the farm. Although organic farming is basic to biodynamics, biodynamics is different in that it has an association with spiritual and astrological factors and emphasizes farming practices that have a balance between physical and higher, nonphysical realms that include the influence of cosmic and terrestrial forces on the farm. A certification system called *Demeter* was established in about 1924 for biodynamic farming.

Biodynamic farming can be divided into *biological* practices and *dynamic* practices. The biological practices are organic farming techniques that improve the quality of the soil. These practices include applications of farm manures and composts and growing of cover crops or green manures on the land. Biodynamic farming excludes the use of manufactured chemicals on soils and plants. Good tilth or physical structure of the soil is a factor that leads to the production of high-quality crops, thereby giving high-quality food for humans and high-quality feed for livestock. Biodynamic farming further involves adapting the farm to natural rhythms, such as planting of crops during lunar phases, which are specific according to the type of crop – roots, fruits, or vegetation, for example.

The biodynamic system uses specific compost preparations for land application and other materials that are applied directly to crops, biodynamic preparations made of medicinal herbs that have already undergone a fermentation process to enrich them with growth-promoting substances. These preparations are added to active compost piles to speed and direct the decomposition of plant materials in the pile and to preserve their original values. Other preparations are used as field sprays, applied directly to the soil or crops. The benefit of the soil-applied sprays is to induce humus formation in the ground and to stimulate root growth. The crop-applied spray is used to improve the green color of plants and to prevent plant diseases. These sprays are said to harness cosmic forces that improve growth of plants. Development of the preparations involves specific practices such as burying the components in animal parts, such as horns, bladders, or intestines, and leaving them in the ground over winter. Use of these preparations has been criticized as having no scientific basis, resembling alchemy, and as not contributing to the development of sustainable agricultural practices. In contrast with some applications in biodynamics, principles of organic farming generally have a scientific basis to support their use.

PERMACULTURE

Permaculture is not a production system but is a land-use and community-planning philosophy. The term originally was derived from "permanent agriculture" but has evolved to stand for permanent culture. In the 1970s, Australians Bill Mollison and David Holmgren developed ideas to create stable agricultural systems. They saw conventional, industrial agricultural methods as being harmful to soil, land, and water. Permaculture is based on creating ecological human settlements, particularly, the development of a continual agricultural system that imitates the structure and interrelationships of natural ecosystems. The intent was that by training individuals in a core set of design principles, those individuals could design their own environments and build increasingly self-sufficient human settlements that would reduce reliance on industrial systems of production and distribution. Permaculture has a large international following of people who have received training through 2-week-long courses in permaculture design.

2 Soil Fertility and Plant Nutrition

Soil fertility is a broad term that refers to the ability of soil to supply nutrients to a crop. The ability to supply nutrients is affected by their amounts in the soil and is governed also by several other chemical, physical, and biological properties. Soil fertility is sometimes referred to as *soil quality* or *soil health*. These terms have been used to direct attention that soil fertility not only is related to the chemical factors of the soil but is governed by the physical and biological factors as well. Chemical factors of soil fertility refer to the supply of plant nutrients in the soil with regards to the total supply and to the amounts of the total supply that are available for plant nutrition. Soil acidity is a chemical factor of soil fertility. Soil acidity affects the solubility or availability of plant nutrients and other chemical elements that affect the ability of plants to grow in soils.

Soil acidity has little direct effect on crop growth except in strongly acidic conditions ($pH < 4.0$) or strongly alkaline conditions ($pH > 11.0$). Physical factors of soil fertility include conditions such as soil depth, water-holding capacity, drainage, aeration, tilth, temperature, and nutrient-holding capacity. Biological factors include conditions such as the presence of harmful organisms, such as plant diseases, weeds, and insects, and the presence of beneficial organisms, such as microorganisms, that carry out mineralization of organic matter and nitrification of ammonium and that live in symbiosis with plants. Chemical, physical, and biological factors are interrelated, and sometimes it is difficult to place a soil property into one of the categories. Soil fertility is an integration of these factors.

Plant nutrition is the study of the uptake, transport, and function of nutrients in plants. Plant nutrients are known also as *essential elements*. These are chemical elements that are required for plant growth. They must be supplied whether the system is organic or otherwise. For a chemical element to be considered as a plant nutrient, several criteria must be met. These criteria are (1) *The element must be required for plants to complete their life cycles. Each element has a direct effect on plant growth or metabolism. Deficiency of an essential element will result in abnormal growth or premature death of plants;* (2) *The requirement for these elements is universal among plants, that is, all plants, not just a few require these elements. If some plants require an element and others do not, the element is not considered a nutrient but a beneficial element; and* (3) *No other element will substitute fully for an essential element. Partial substitution might occur among some elements, but each plant nutrient has a role for which no other element can substitute*. Today, 17 chemical elements (Table 2.1) are recognized as essential for plants. Of these elements, three – carbon, hydrogen, and oxygen – are obtained from the air. Fourteen are derived from the soil. The requirement for each essential

TABLE 2.1
Listing of essential elements (plant nutrients) and their approximate concentrations (dry weight basis) in plant foliage

Essential Element					
Obtained from Air		Obtained from Soil			
Nutrient	%	Macronutrients	(%)	Micronutrients (ppm)[z]	
Carbon (C)	50	Nitrogen (N)	3.0	Iron (Fe)	100
Hydrogen (H)	5	Phosphorus (P)	0.4	Zinc (Zn)	20
Oxygen (O)	40	Potassium (K)	2.0	Copper (Cu)	5
		Calcium (Ca)	1.0	Manganese (Mn)	50
		Magnesium (Mg)	0.5	Molybdenum (Mo)	0.1
		Sulfur (S)	0.3	Boron (B)	30
				Chlorine (Cl)	100
				Nickel (Ni)	1

Note:
[z] ppm = mg/kg

element is absolute, regardless of the source or amount required. Hence, no nutrient is more important than another because each one is required absolutely for plant growth and metabolism.

Ninety-two naturally occurring elements are on the periodic table. Some people believe that each of these elements is essential for plant life and state that every natural element must be supplied for plant growth. However, most naturally occurring elements have not been accepted as being plant nutrients. Even if an element promotes plant growth but the criteria for essentiality listed above are not met, the element is not essential but is a *beneficial element*. Accumulation of an element in plants is not a criterion of essentiality or benefit since plants will absorb any element that is in solution and do not make an absolute distinction between essential elements and any other element. Some people propose that rock dusts are needed in soil fertility to ensure adequacy of all of the naturally occurring elements. Rocks contain specific minerals, and the dusts do not contain all essential elements or all of the elements on the Periodic Table.

The list of essential elements is not static and may be expanded in the future as experimental techniques improve to purge elements from the environment in which plants are grown. Hydroponics was developed as a research tool in the mid-1800s to permit plants to be grown in media from which nutrients were added but from which an element under investigation was excluded. This procedure soon led to nitrogen, phosphorus, potassium, calcium, magnesium, sulfur, and iron being added to the list of essential elements. Carbon, hydrogen, and oxygen were identified earlier, before the development of hydroponics, as essential with these elements being identified as constituents of water or organic matter. The expansion of the list of plant nutrients was slow after 1860 because investigations lacked techniques of purification to eliminate certain elements from nutrient solution. An element is accepted as a plant nutrient if someone publishes an article or gives a talk that provides evidence that the element meets the criteria of being a plant nutrient. In the 1920s, techniques for research on plant nutrients improved, and many other elements were added to the list. Molybdenum was added in 1939, and chlorine was added in 1954. The last element to be accepted as an essential element is nickel in 1987. With nickel, seeds had to be depleted of the element to prove its essentiality. Perhaps, additional elements, including some of the beneficial elements, will be accepted as essential in the future. Sodium, cobalt, silicon, and selenium are among elements being considered for acceptance as plant nutrients.

One nutrient is not more essential than another, but the elements are not required in the same amounts by plants. Because of differences in amounts of requirements, elements are divided into classes of *macronutrients* and *micronutrients* (Table 2.1). On a dry weight basis, the concentrations of macronutrients in plants range from about 0.3% to 5% or higher, depending on the plant part and species under consideration.

The concentrations of nutrients listed (Table 2.1) are only guidelines, and the concentrations of nutrients in plants can vary widely from those listed depending on the plant part, plant age, soil fertility, and many other factors. Nitrogen (N) is normally the most abundant of the soil-derived elements in plants, followed by potassium (K), calcium (Ca), magnesium (Mg), phosphorus (P), and sulfur (S) in that general but not absolute order and are called macronutrients. Macronutrients are expressed as percentages of dry weight or in g/kg. Micronutrients on an analytical basis are minor constituents, ranging from one to several hundred parts per million (mg/kg) of the plant dry weight. For comparison of concentrations between macronutrients and micronutrients, 1% (g/100g) is 10,000 parts per million (mg/kg). The micronutrients are vital to plant growth and development and are just as important as the macronutrients in plant health. It is redundant and incorrect terminology to refer to plant nutrients as essential nutrients, since all nutrients are essential by definition.

Leaves are the plant organs that are used most commonly for expressing the nutrient contents of plants. The nutrient composition of leaves varies widely with differences in plant nutrition, whereas the composition of fruits and seeds is relatively constant with differences in plant nutrition. To preserve its reproductive capacity, plants maintain the nutrient concentrations in seeds at levels to maintain the reproductive capacity of the plant. The numbers and sizes of seeds will vary with plant nutrition.

The air-derived elements make up the bulk of the mass of a plant: Carbon, about 45 to 55%; oxygen, about 40%; and hydrogen, about 5% of the plant dry weight.

Some *beneficial elements* stimulate plant growth. These elements do not meet all of the requirements of essentiality – that is, they have not been shown to be required by all plants; distinct metabolic roles have not been demonstrated; or the requirement is not absolute. Sodium, silicon, selenium, and cobalt and, perhaps, aluminum, lanthanum, vanadium, and others are beneficial elements.

FERTILIZERS

Most soils do not have an unlimited capability to supply essential elements to crops. *Fertilizers* are materials that are used to carry plant nutrients to soils.