

# SOILS & ORGANIC FOOD PRODUCTION

APRIL 2013



**INSTITUTE** for  
**COMMUNITY**  
**ENGAGED**  
**SCHOLARSHIP**



The **Research** Shop



## SOILS & ORGANIC FOOD PRODUCTION

The underlying premise of this research is the hypothesis that organic farming methods can support healthy soil systems, which in turn, produce healthy food without reliance on chemical inputs. In this manner, organic agriculture practices can support soil health, enabling organic farming to continue, in situ, on an ongoing basis. The implication is that the long-term health and resilience of organically managed soils could allow these agricultural practices to continue indefinitely.

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# INTRODUCTION

## RESEARCH GOALS

The objective of the project was to identify peer-reviewed and other scientific studies linking organic agricultural practices with healthy soils. The underlying goal was to gather evidence demonstrating the benefits of organic soil management practices.

## BACKGROUND

This is the final report for a research project that took place from October 2012 to April 2013. The research was conducted on behalf of the Research Shop at the University of Guelph for the Organic Council of Ontario (OCO).

Some of the topics reviewed include: building healthy soils, how organic soil management influences long-term land use, what, if any, negative effects chemical fertilizers have on soil health, and whether or not organic soil management contributes to healthier food.

## DEFINITIONS

### Definition of Organic Agriculture in Relation to Soil Management

One cannot discuss organic agriculture without referring to soil. For instance, one definition, as stated by Gomiero, Pimentel, & Paoletti (2011), mentions soil twice:

Organic agriculture refers to a farming system that enhance **soil**\* fertility through maximizing the efficient use of local resources, while foregoing the use of agrochemicals, the use of Genetic Modified Organisms (GMO), as well as that of many synthetic compounds used as food additives. Organic agriculture relies on a number of farming practices based on ecological cycles, and aims at minimizing the environmental impact of the food industry, preserving the long term sustainability of **soil** and reducing to a minimum the use of non renewable resources. (p.96)

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\* Emphasis added by the author of this report

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The International Federation of Organic Agriculture Movements [IFOAM] defines organic agriculture to include: "a production system that sustains the health of **soils**"(IFOAMa, 2009). IFOAM also lists the intended aims of organic agriculture; those associated with soil are listed below:

- to enhance biological diversity within the whole system (including soil organisms),
- to increase soil biological activity,
- to maintain long-term soil fertility,
- to recycle plant and animal waste in order to return nutrients to the land
- to promote the healthy use of soil

It is no surprise that one of IFOAM's founders, Eve Balfour, also mentioned soil when she said, "The criteria for a sustainable agriculture can be summed up in one word— permanence, which means adopting techniques that maintain **soil**\* fertility indefinitely, that utilise, as far as possible, only renewable resources; to avoid those that grossly pollute the environment; and that foster biological activity throughout the cycles of all the involved food chains"(Gomiero et al, 2011, p.98). Stated most concisely, "Organic agriculture seeks to augment ecological processes that foster plant nutrition while conserving soil and water resources" (Pimentel, Hepperly, Hanson, Douds, & Seidel, 2005, p.575).

### **Definition of Organic Agriculture in Relation to "Conventional" Agriculture**

Organic agriculture is often described as an "alternative" agriculture; an alternative to "conventional" or industrial agriculture which has emerged over the past 100 years as the dominant agricultural system in most places across the world. Thus, the two methods are often contrasted with one another with organic agricultural operations portrayed as small-scale, mixed crop production and "conventional" agriculture portrayed as large-scale mono-cropping. However, each method encompasses a wide spectrum of practices: conventional agriculture can be small scale or involve intercropping and organic agriculture can involve mono-cropping in large fields. Therefore, care must be taken when comparing the two systems; sweeping generalizations of either should be avoided.

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For additional definitions related to organic food production and soil management a glossary is provided as an appendix at the end of this report.

## METHODS

### SOURCES

For the initial review, three websites, five books and seventeen journal articles were identified as potential sources of information pertaining to soil health and organic agriculture. These sources were located through a keyword search on the Guelph University library database; via recommended articles and links from OCO; and from works cited in the book, *The End of Food*, by Pawlick (2006).

Some of the initial searches included combinations of the following keywords “organic”, “agriculture”, “conventional”, “soil”, “management”, “soil food web”, “health”, and “biology”. The search for applicable studies progressed as new keywords presented themselves in the literature. One such term was, “cropping system”, which helped to widen the search since much of the literature referred to “cropping systems” rather than “management systems” when categorizing farming methods. Other studies and articles were identified via consulting the works cited of already reviewed literature. Consulting with two professors at the University of Guelph, one from crop science and one from soil science, led to additional resources and keywords searched, further strengthening the breadth of the research.

### LIMITATIONS OF THE METHODS

Much of the research identified was either very specific or failed to provide significant differences between organic and conventional cropping systems. Another limitation was the researcher's own lack of knowledge in the area of soil science, making some of the published research difficult to decipher and therefore, relatively inaccessible.

Additionally, not all literature identified was available to the researcher. For example, work published by the International Society for Horticultural Science (ISHS) was not available through the University of Guelph library resources and therefore left out of the study. Similarly, the only available publication by Dr. Ellen Ingham (research on the “soil food web”, as requested by OCO) was, *The Soil Biology Primer* (2000). Exploring these sources further could augment the findings of this report.

### FINDINGS

#### SUMMARY OF FINDINGS

This section outlines the need to preserve and properly manage soils and the benefits of organic agricultural practices that place an emphasis on soil-building through biological inputs and sustainable practices. These practices include increasing and protecting soil fertility, protecting soil from erosion, the importance of understanding soil biology and building soil organic matter, and using organic fertilization methods to contribute to food quality. The remainder of this report attempts to identify research that supports organic agriculture as a solution to the above concerns.

#### SOIL PRESERVATION & MANAGEMENT

Although soilless agricultural methods have been developed (for example, hydroponic growing), soil, along with water and sunlight, is generally required for most agriculture to take place. Indeed, the *quality* of the soil is considered foundational for successful crops, prompting scientists and governments to classify soil based on its fertility, texture and other significant factors. For example, the Canadian Soil Information Service (CANSIS) has the Canada Land Inventory [CLI] which uses seven classes to rate agricultural land capability in Canada. In this system, Class 1 lands have the highest capability to support agricultural land use activities and Class 7 lands have the lowest (Agriculture and Agri-Food Canada, 2008).

Since the food we eat depends on agricultural soil, it is a worrying trend that soil erosion and declining soil fertility are major problems in non-organic agriculture. According to Fookes and Dalmeny (2001), "a series of experiments comparing soil qualities under organic and non-organic management in the US led researchers to conclude that all topsoil in the non-organic managed areas would be lost in 50-100 years unless topsoil management practices were improved (p.23)." Conventional agriculture has also seen the removal of many grass strips, shelterbelts, and hedgerows that once protected soil from erosion as farm sizes more than doubled on average over the last several decades (Pimentel et al, 1995). One reason that soil erosion should be of concern to Canadians is that only 11% of land in Canada is of any agricultural use, which means that almost 90% of the land in Canada is not suitable for agriculture. A mere 0.5% of Canada's arable land is Class 1 and half of that is located in Ontario. Additionally, 95% of Canada's best climate zones for diverse farming are also in Ontario (Ontario Farmland Trust, N.D.). Thus, good soil management is one way to contribute toward retaining valuable farmland.

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In the interest of sustaining agricultural production over the long-term, erosion should be addressed, not only as an environmental concern but also an economic concern. For example, the combined off-site and on-site costs of agricultural erosion in the United States is about \$44 billion per year, which equates to approximately \$100 per hectare of cropland and pasture and increases production costs by about 25% each year (Pimentel et al, 1995).

Organic agriculture, on the other hand, offers many methods that protect farmland from soil erosion. A key aspect to this approach is built-in redundancy; many organic agriculture soil management methods serve multiple functions. For example, methods that contribute to improving soil fertility also contribute to ameliorating soil loss and erosion. Additional methods such as using cover crops and green manures (plants that help fertilize the soil) (Fookes & Dalmeny) and using conservation tillage, (any tillage sequence that reduces erosion or loss of water in relation to conventional tillage) also serve multiple purposes and according to Brady and Weil (1999), further help to minimise soil erosion.

Erosion also has detrimental effects on the diversity and abundance of soil organisms. Organic management that includes practices that maintain and build soil organic matter, such as straw-mulching, may increase soil biota as much as three times and the application of compost or manure may increase earthworm and micro-organism biomass by as much as five times (Pimentel et al, 1995, p.5).

### SOIL FERTILITY

Organic agriculture often strives to protect soil fertility which is important for growing healthy crops. Soil fertility refers to the quality of a soil that enables it to provide essential chemical elements in quantities and proportions for the growth of specific plants (Brady & Weil, 1999). Methods of protecting soil fertility include crop rotation, intercropping, polyculture, cover crops, and mulching (Gomiero et al, 2011, p.99). Although none of these activities are strictly limited to organic agriculture, they are frequently used by organic farmers. The literature suggests that crop rotation is one of the most important of these methods. According to the Soil Association (2000),

A correctly designed and implemented crop rotation is at the core of organic crop production and contains the following key elements: providing sufficient crop nutrients and minimising their losses, providing nitrogen through leguminous crops, minimising and controlling weeds, pests and disease problems, maintaining the soil organic matter and structure, and providing a profitable output of organic cash crops and/or livestock.(p.34)

In addition to contributing to soil fertility, many of these methods also contribute to reducing soil loss.

### SOIL BIOLOGY

Soil can be understood as an ecosystem, the biology of which is made up of a diverse range of organisms ranging from one-celled bacteria, algae, fungi, and protozoa, to more complex nematodes and micro-arthropods, to visible earthworms, insects, small vertebrates and plants. It is this diversity that makes up the soil food web, according to Dr. Elaine Ingham (2000). She defines the soil food web as "the community of organisms living all or part of their lives in the soil" (p. 5). All plants depend on the food web for nutrition, including trees, shrubs, grasses and agricultural crops. The food web is basically a series of conversions of energy and nutrients that occur as one organism eats another (Ingham, 2000). There are many organisms in the soil; according to Brady & Weil, a "handful of soil is likely to contain billions (1999, p.404)".

The roles that soil organisms play are varied and complex. Some decompose organic compounds, including manure, plant residue, and pesticides which prevents the compounds from entering the water table and becoming pollutants. Some organisms are able to store nitrogen and other nutrients that might otherwise enter ground water. Some fix atmospheric nitrogen and thus make it available to plants. Others enhance soil aggregation and porosity which helps to increase water infiltration and reduces surface run-off which can lead to erosion. Finally, there are soil organisms that prey on crop pests and are food for above ground animals. Thus, soil organisms support plant health through these processes that decompose organic matter, cycle nutrients, enhance soil structure, and control the population of soil organisms, including crop pests (Ingham, 2000).

Several research studies have shown that biological activity is higher in organically managed soil. For example, a 21-year-study at the Swiss Research Institute of Organic Agriculture (Fließbach, Mäder, Dubois, Gunst 2000) found that biological processes in the soil were improved under organic management and, conversely, that mineral fertilizers used in non-organic farming systems actually decrease biological activity in the soil. This evidence suggests that organic farming relies on a high level of biological activity in the soil. Mycorrhiza, a beneficial fungi, is an example of this soil biological activity. Mycorrhiza are more common and more active in organically managed soils than in soils that are non-organically managed. According to Fookes & Dalmeny (2001) some of the benefits that mycorrhizal colonies offer to plants include: improved uptake of minerals, crop vigour and higher resistance to soil-borne pests and diseases.

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Some of the problems associated with conventional agricultural practices involving fertilizer use are outlined succinctly in *The End of Food*:

On highly mechanized, industrial mono-cropping systems massive acreages are leveled and sown, year-after-year, with no or only infrequent crop rotations, to a lone, high cash-return crop such as hybrid corn, which quickly depletes soil nutrients. To make up for the lost nutrients, especially nitrogen, heavy doses of inorganic chemical fertilizers are employed, which "burn" soil organisms. (Pawlick, 2006, p. 171)

This statement demonstrates a growing concern over the damaging effects that certain farming methods may have on soils. The Soil Association describes similar concerns, stating, "pesticides, soil fumigants and inorganic fertilisers have profoundly damaging effects on microbial soil communities and, in turn, organic matter degradation (2001, p.15)."

Indeed, a high level of soil biological activity enhances the nutrient supply to crops, reduces nutrient leaching and helps to control soil pests (Soil Association, 2000, Fookes & Dalmeny, 2001). Fließbach et al (2000) found that "microbial biomass and activities were enhanced in organic systems emphasizing the important role of element cycling processes that are supported by an abundant and active soil biological community" (p. 283). Birkhofer et al (2008) conducted a long-term investigation of soil chemistry comparing two organic and two conventional wheat farming systems. With below and above-ground biological parameters, researchers found that the application of farmyard manure promoted soil quality, microbial biomass and fostered natural enemies and ecosystem engineers (an organism that creates or modifies habitats). Their findings also suggested enhanced nutrient cycling and pest resilience from the application of farmyard manure due to an increase of resources for soil biota. This study demonstrates an example in which organic farming both supports soil biology and is also dependent on it.

### ORGANIC MATTER

Increased levels of soil organic matter (SOM) is another characteristic of good soil. Soil organic matter serves several important functions. According to Pimentel, *et al.*,

It facilitates the formation of soil aggregates, increases soil porosity, and thereby improves soil structure, water infiltration, and ultimately overall productivity. In addition, organic matter increases water infiltration, facilitates cation exchange, enhances root growth, and stimulates the proliferation of important soil biota. About 95% of the nitrogen and 25 to 50% of the phosphorus is contained in organic matter. (1995, p.4)

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A Lithuanian study by Rutkoviene, Stancevicius, Rutkauskiene, & Gavenauskas (1997) found that soil humus, a component of SOM, increased 16% in soils treated organically, but declined by 7% in the conventionally treated soils. The researchers attributed this finding to correlate with improved biological activity by soil biota in the soil with the organic treatment. It was noted as an important finding because soils in Lithuania are poor in humus to begin with.

Increased SOM may also increase crop resilience. In a 1997 study Raupp found that, "in dry years or under poor growth conditions for any other reason, spring wheat yields declined more in fields relying on mineral fertilizer than on those with manure treatments. The plant-soil system with manure fertilization seems able to compensate for poor environmental conditions to stabilize yield and reduce yield decrease (p.98)." Raupp believed that the higher biological activity in the soil could have been a factor.

While biological activity may have been one factor, according to Bradly & Weil (1999), organic matter increases both water infiltration and water holding capacity (p.468). Thus, Raupp's finding may have been due to SOM as well as soil biota activity. This illustrates the interconnectivity between soil biota and SOM and the importance of fostering both as part of healthy soil management practices. Improved water holding capacity helps organically managed fields to be more resilient in periods of short term drought. Furthermore, it is SOM that fuels the "food web", described in detail below, as SOM is the main storehouse for energy and nutrients. Bacteria, fungi, and other soil dwellers release nutrients from the SOM, which can then be utilized by plants and other organisms (Ingham, 2000).

### SOIL AND FOOD QUALITY

As demonstrated by some studies, the content of certain vitamins, minerals and secondary nutrients (e.g., antioxidants) are higher in certain organically grown produce. There is also evidence that certain nutrients are more persistent; that is, some organically grown vegetables retained more of particular nutrients after a period of storage, than conventionally grown produce. Evidence suggests that these higher levels of vitamins, minerals and secondary nutrients may be a result of organic soil management practices such as the application of organic (as opposed to synthetic) fertilizer. Quayson, *et al.* (1997), researchers in Ghana, focused some of their research on soil types in Africa. They summarized the relationship between soil, food and human health by stating that, "what people and animals eat determines to a large extent their

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health status. What the soil lacks in nutrients, the crops will also lack, as will, ultimately, human beings and animals” (p.155).

A. M. Mayer (1997) suggests that the cumulative effects of ongoing synthetic fertilizer applications to the soil might affect the food grown in it:

A result of agriculture which relies on NPK fertilizers and pesticides, that adds little organic matter to the soil and that alternates between soil compaction and ploughing, could as well produce food depleted in minerals. Industrial farming practices affect the structure, chemistry and ecology of the soil in ways that could affect the availability of minerals to plants and hence the mineral content of crops. (p.208)

Agricultural approaches that focus on delivering synthetically derived nitrogen, phosphorous and potassium (NPK) are not necessarily equivalent to applying fertilizers derived through biological processes and can also result in higher levels of nitrate in produce. One example include the "heavy application of nitrogen fertilizers that have a double negative effect on the nutritional quality of fruits and vegetables since it increases the nitrate and at the same time lowers their ascorbic acid content (Mozafar, 1994, p. 172)".

Other researchers have reported similar findings, Leclerc, Miller, Joliet, & Rocquelin (1991), found organically grown celeriac to have lower nitrate contents than conventional; Kolbe, *et al.* (1995) found lower nitrate in organically grown potatoes compared to the non-organically grown potatoes and Heaton (2001), reported that "non-organic fertilisation practices result in higher levels of potentially harmful nitrate in vegetables where studies have shown lower levels in organically produced crops (p.4).

Fertilization methods have also been found to affect storage. According to Mozafar, spinach grown with organic\* fertilizer retains more (loses less) of its original vitamin C and accumulates less nitrate during storage than when grown with inorganic fertilizers. Mozafar also suggests that vegetables grown with organic\* fertilizer seem to retain more of their original ascorbic acid after a period of storage.

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\* Please note that "organic" in this sense does not necessarily refer to "certified organic" but to any by-product from the processing of animal or vegetable substances that contain sufficient

Other studies have shown higher levels of other vitamins and minerals, higher flavonoid content and higher over-all quality of organically grown produce as compared to conventional. For example, a promising study that compared analyses of archived samples from both production systems demonstrated statistically higher levels of flavonoids in organic tomatoes (Mitchell, et al., 2007, p. 6154).

In addition, a three year field trial on experimental plots conducted by Kolbe, *et al.* (1995) compared the effects of organic (compost and cattle farm yard manure) and non-organic (NPK) fertilisation practices on potatoes and found 10–20 per cent higher yields, higher Mg, K and vitamin C contents in the organically grown potatoes. Further, results from a two year farm survey involving twelve pairs of organic and non-organic farmers growing carrots and celeriac found that organically grown carrots had higher b-carotene and vitamin B1, while organically grown celeriac had higher dry matter, vitamin C and phosphorus (Leclerc, *et al.*, 1991). Finally, Reganold, *et al.* (2010) found that organic strawberry farms produced higher quality fruit.

## CONCLUSIONS

### GENERAL CONCLUSIONS

The research undertaken for this report illustrates the complexity of soil and the importance of good soil management techniques in agricultural practices. Major themes include increasing and protecting soil fertility, protecting soil from erosion, the importance of soil biology and soil organic matter, and how organic fertilization methods can contribute to food quality. The organic farming methods used to protect soil fertility and minimize soil erosion include cover cropping, mulching, crop rotation, manure and/or compost application, and conservation tillage.

Organic farming relies on a high level of biological activity in the soil and at the same time, contributes to increasing the diversity and abundance of those same soil organisms. Some of the benefits of this include: improved uptake of minerals and enhancement of the nutrient supply, improved crop vigour, reduced nutrient leaching, improved soil structure and water infiltration, and increased resistance to soil-borne pests and diseases.

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plant nutrients to be of value as fertilizers. These fertilizers would, however, likely be used in organic agriculture if they were from certified sources.

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Soil communities rely on soil organic matter (SOM), while the nutrients in SOM are made available to plants by those organisms that rely on it for food. Increased levels of soil organic matter (SOM) are also a characteristic of good soil as it serves several important functions that are especially important to organic agriculture systems. These functions include improved soil structure, aggregation, water infiltration and over-all productivity. Furthermore, organic agriculture soil management often increases SOM over time, whereas conventional agriculture generally lowers it. Therefore increasing SOM seems to be an important goal for organic farmers.

Finally, as demonstrated by some studies, the content of certain vitamins, minerals and secondary nutrients (e.g., antioxidants) are higher in certain organically grown produce. There is also evidence that some nutrients are more persistent; that is, some organically grown vegetables retained more of particular nutrients after a period of storage than conventionally grown produce. Evidence suggests that these higher levels of vitamins, minerals and secondary nutrients may be a result of organic soil management through practices such as the application of organic (as opposed to synthetic) fertilizer.

### FUTURE CONSIDERATIONS

It could be beneficial to consult farmers to understand their experience with soil improvement, especially when converting from conventional to organic. One exchange the author of this report had with a local farmer indicated that there was a very visible change in the soil when the property was converted to organic management. The farmer noticed an improvement after 1-2 years and further improvements over the subsequent 5 years. Farmers have firsthand observational knowledge of the soil, coupled with an intimate understanding of their own land. Two recommended approaches include a literature review and/or direct interviews. Identifying farmers or operations that have both conventional and organic production for interviews, or perhaps a comparative study, could also provide additional insight.

An investigation into existing research that makes links between flavour and organic agriculture, or between flavor and different types of soil, could also augment this research. Discovering if or how soil management practices contribute to taste could help to drive future agricultural practices. There is anecdotal evidence that organically produced food tastes better. Should this prove true, it could boost consumer support for organically produced food.

Finally, during the writing of this report some new resources came to light. These may also serve as areas of further study. Two recently identified resources from IFOAM are

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the book, *The world of organic agriculture: statistics and emerging trends, 2012*, available at the University of Guelph Library and via Organic Eprints, an international open access archive for papers and projects related to research in organic food and farming (<http://orgprints.org/>). Another promising publication is *Microbial ecology in sustainable agroecosystems*, 2012, edited by Cheeke, Coleman, and Wall, available at the University of Guelph Library.

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### APPENDIX

#### GLOSSARY

Definitions below selected and cited directly from *The Nature and Properties of Soils: 12th Ed* (Brady & Weil, 1999, p.p. 827-862).

**actinomycetes** A group of organisms intermediate between the bacteria and the true fungi that usually produce a characteristic branched mycelium.

**aeration, soil** The process by which air in the soil is replaced by air in the atmosphere. In a well-aerated soil, the soil air is similar in composition to the atmosphere above the soil. Poorly aerated soils usually contain more carbon dioxide and correspondingly less oxygen than the atmosphere above the soil.

**aggregate, soil** Many soil particles held in a single mass or cluster, such as a clod, crumb, block, or prism.

**biomass** The total mass of living material of a specified type (e.g., microbial biomass) in a given environment (e.g., in a cubic meter of soil)

**cation** A positively charged ion; during electrolysis it is attracted to the negatively charged cathode.

**cation exchange** The interchange between a cation in solution and another cation on the surface of any surface-active material, such as clay or organic matter.

**cover crop** A close-growing crop grown primarily for the purpose of protecting and improving soil between periods of regular crop production or between trees and vines in orchards and vineyards.

**crop rotation** A planned sequence of crops growing in a regularly recurring succession on the same area of land, as contrasted to continuous culture of one crop or growing different crops in haphazard order.

**fixation, elemental nitrogen** The process by which gaseous elemental nitrogen is chemically combined with hydrogen to form ammonia. Biological nitrogen fixation is commonly carried out by certain bacteria, algae, and actinomycetes, which may or may not be associated with higher plants (e.g. legumes).

**fertility, soil** The quality of a soil that enables it to provide essential chemical elements in quantities and proportions for the growth of specific plants.

**green manure** Plant material incorporated with the soil while green, or soon after maturity, for improving the soil.

## SOILS & ORGANIC FOOD PRODUCTION

**humus** The more or less stable fraction of the soil organic matter remaining after the major portions of added plant and animal residues have decomposed. Usually is dark in colour.

**infiltration** The downward entry of water into the soil.

**legume** A pod-bearing member of the Leguminosae family, one of the most important and widely distributed plant families. Includes many valuable food and forage species, such as peas, beans, peanuts, clovers, and alfalfas. Nearly all legumes are associated with nitrogen-fixing organisms.

**mulch** Any material such as straw, sawdust, leaves, plastic film, and loose soil that is spread upon the surface of the soil to protect the soil and plant roots from the effects of raindrops, soil crusting, freezing, evaporation, etc.

**mycelium** A string-like mass of individual fungal or actinomycetes hyphae.

**mycorrhiza** The association, usually symbiotic, of fungi with the roots of a seed plant.

**nitrogen fixation** The biological conversion of elemental nitrogen ( $N_2$ ) to organic combinations or to forms readily utilized in biological processes.

**organic fertilization** By-product from the processing of animal or vegetable substances that contain sufficient plant nutrients to be of value as fertilizers.

**soil** (1) A dynamic natural body composed of mineral and organic materials and living forms in which plants grow. (2) The collection of natural bodies occupying parts of the earth's surface that support plants and that have properties due to the integrated effect of climate and living matter acting upon parent material, as conditioned by relief, over periods of time.

**soil management** The sum total of all tillage operations, cropping practices, fertilizer, lime, and other treatments conducted on or applied to a soil for the production of plants.

**soil organic matter** The organic fraction of the soil that includes plant and animal residues at various stages of decomposition, cells and tissues of soil organisms, and substances synthesised by the soil population.

**soil quality** The capacity of a specific kind of soil to function, within natural or managed ecosystem boundaries, to sustain plant and animal productivity, maintain or enhance water and air quality, and support human health and habitation. Sometimes considered in relation to this capacity in the undisturbed, natural state.

**symbiosis** The living together in intimate association of two dissimilar organisms, the cohabitation being mutually beneficial.

**tillage** The mechanical manipulation of soil for any purpose; but in agriculture it is usually restricted to the modifying of soil conditions for crop production.

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**tilth** The physical condition of soil as related to its ease of tillage, fitness as a seedbed, and its impedance to seedling emergence and root penetration.