Sustainable Soil Management

Soil System Guide

Appropriate Technology Transfer for Rural Areas

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Abstract

Abstract: *This publication covers basic soil properties and management steps toward building and maintaining healthy soils. The publication is divided into three distinct sections, each with its own purpose. Section 1 deals with basic soil principles and provides a understanding of living soils and how they work. In section 1 you will find answers to why soil organisms and organic matter are important. Section 2 covers management steps to build soil quality on your farm. The last section covers farmer stories of people who have successfully built up their soil. A large resource section of other available information concludes the publication.*

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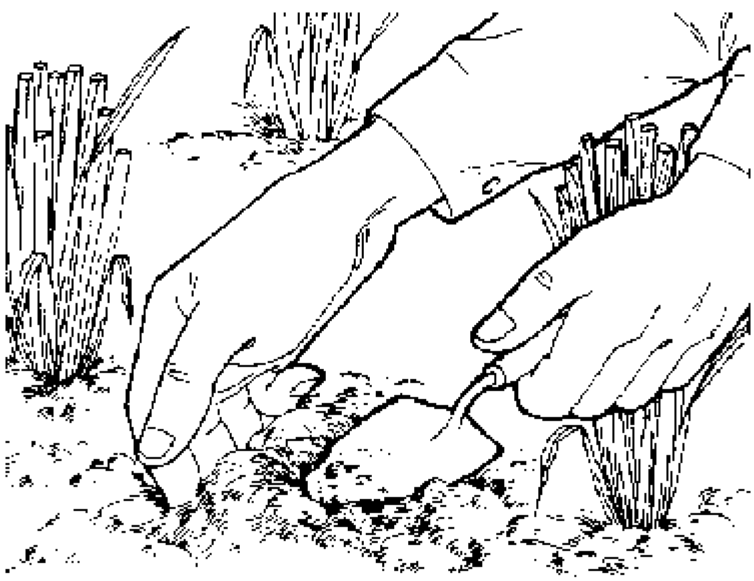

Part I. Principles and Characteristics of Sustainable Soils

Introduction

What are some features of good soil? Any farmer will tell you that a good soil:

- drains well and warms up quickly in the spring
- does not crust after planting
- soaks up heavy rains with little runoff
- stores moisture for drought periods
- has few clods and no hardpan
- resists erosion and nutrient loss
- supports high populations of soil organisms
- does not require increasing fertilizer for high yields
- has that rich, earthy smell
- produces healthy, high quality crops (1).

All these criteria indicate a soil that functions effectively today and will continue to produce long into the future. Creating soils with these characteristics can be accomplished by utilizing management practices that optimize the processes found in native soils.

Sustainable: *the ability to keep in existence; maintain or prolong; to provide sustenance for.*

How does soil in its native condition function? How do forests and native grasslands produce plants and animals in the complete absence of fertilizer and tillage? What are the principles by which these soils function? The answers to these questions assure that the soil will be productive and profitable now and for future generations. A good thing happens when the soil's natural productivity is managed in a sustainable way; the reliance on purchased inputs declines, while land value and income generation increases year by year. Some of the things we spend money on can be done by the natural process itself for little or nothing. It's an upward spiral of continued success. To understand this better, let's start with the basics.

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The Living Soil: Texture and Structure

Soils are made up of four components: minerals, air, water, and organic matter. In most soils minerals represent around 45% of the total volume, water and air about 25% each, and organic matter from 2% to 5%. The mineral portion consists of three distinct particle sizes classified as sand, silt or clay. Sand is the largest size particle that can be considered soil. Sand is largely the mineral quartz, though other minerals are also present. Since quartz contains no plant nutrients, sand is the lowest contributor to soil fertility of the three soil particle sizes. Furthermore, sand cannot hold nutrients–they leach out easily with rainfall. That is why sandy soils are not as productive as loams and need to be spoon-fed fertilizer. Silt particles are much smaller than sand but, like sand, silt is mostly quartz.

The smallest of all the soil particles is clay. Clays are quite different from sand or silt and contain appreciable amounts of plant nutrients. Clay has a large surface area resulting from the plate-like shape of the individual particles. The textural designation of a soil is derived from the relative portions of sand, silt, and clay. A sandy loam, for example, has much more sand and much less clay than does a clay loam. A loam soil is a mixture of sand, silt and clay. Most soils are some type of loam. They are more accurately described by the words the preface the word loam, such as: sandy loam or clay loam. The texture designations are found in Table 1.

Table 1. Soil textures	
	Texture Designation
Coarse Textured Fine Textured	Sand Loamy sand Sandy loam Fine sandy loam Loam Silty loam Silt Silty clay loam Clay loam Clay

Another soil characteristic–soil structure–is different from soil texture. Structure refers to the combination or "aggregation" of sand, silt and clay particles into larger secondary clusters. If you grab a handful of soil, good structure is apparent when the sand, silt, and clay particles are aggregated into granules or crumbs. Both texture and structure determine pore space for air and water circulation, erosion resistance, looseness, ease of tillage, and root penetration. However, while texture is an innate property of the native soil and does not change with agricultural activities, structure can be improved or destroyed readily through our choice and timing of farm practices.

The organic soil component contains all the living creatures in the soil and the dead ones in various stages of decomposition. An acre of living soil can contain 900 pounds of earthworms, 2400 pounds of fungi, 1500 pounds of bacteria, 133 pounds of protozoa, 890 pounds of arthropods and algae, and even small mammals in some cases (2). In fact, the soil could be viewed as a living entity, rather than an inert body.

The soil's organic matter also contains dead organisms, plant matter and other organic materials in various phases of decomposition. Humus, the dark-colored organic material in the final stages of decomposition, is relatively stable. Both organic matter and humus serve as a reservoir of plant nutrients; they also help to build soil structure and provide other benefits.

The type of healthy living soil required to support humans now and far into the future will be balanced in nutrients and high in humus with a high diversity of soil organisms. It will produce healthy plants with minimal weed, disease and insect pressure. To accomplish this we work with the natural processes and optimize their functions to sustain our farms.

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The Living Soil: Importance of Soil Organisms

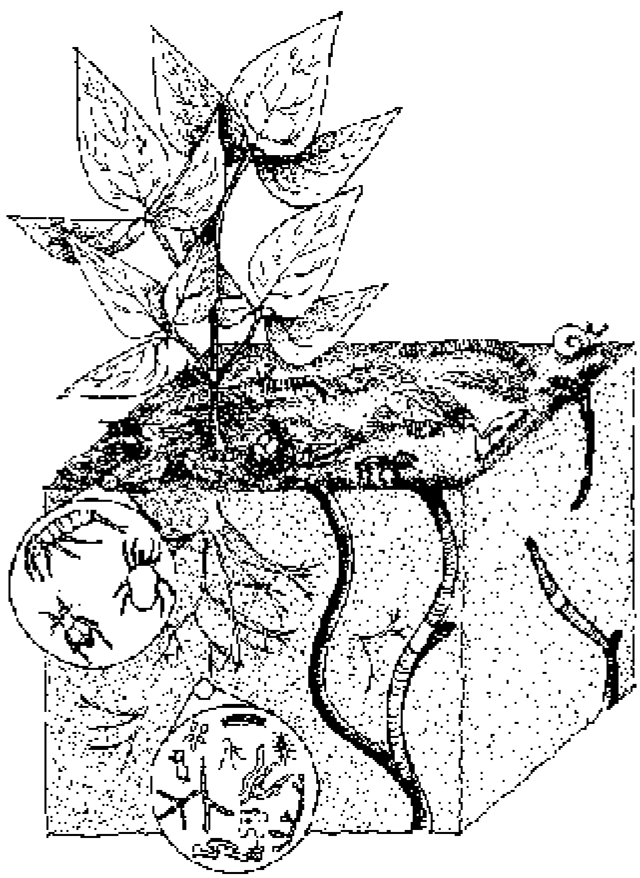

Figure 1 The soil is teaming with organisms which cycle nutrients from soil to plant and back again

If you look out at a landscape you might wonder how native prairies and forests function in the complete absence of tillage and fertilizers? These soils are tilled by soil organisms, not by machinery. They are fertilized too, but the fertility is used again and again and never leaves the site. Native soils are covered with a layer of plant litter and/or growing plants throughout the year. Beneath the surface litter layer, a rich complexity of soil organisms decompose plant residue and dead roots, then release their stored nutrients slowly over time. In fact, topsoil is the most biologically diverse part of the earth (3). Soil-dwelling organisms release bound-up minerals converting them into plant-available forms that are then taken up by the plants growing on the site. The organisms recycle nutrients again and again from the death and decay of each new generation of plants growing on the site.

There are many different types of creatures that live on or in the soil. Each has a role to play. These organisms will work for the farmer's benefit if we simply manage for their survival. Consequently we may refer to them as soil livestock. While there is a great variety of organisms that contribute to soil fertility, earthworms, arthropods, and the various microorganisms merit particular attention.

Earthworms: Earthworm burrows enhance water infiltration and soil aeration. Earthworm tunneling can increase the rate of water entry into the ground 4 to 10 times higher than fields that lack worm tunnels (4). This reduces water runoff, recharges groundwater, and helps store more soil water for dry spells. Vertical earthworm burrows pipe air deeper into the soil, stimulating microbial nutrient cycling at those deeper levels. Tillage done by earthworms can replace some expensive tillage work done by machinery.

Worms eat dead plant material left on top of the soil and redistribute the organic matter and nutrients throughout the topsoil layer. Nutrient-rich organic compounds line the tunnels that may remain in place for years if not disturbed. During droughts these tunnels allow for deep plant root penetration into subsoil regions of higher moisture content. In addition to organic matter, worms also consume soil and soil microbes as they move through the soil. The soil clusters they expel from their digestive tracts is known as a worm cast or casting. Each worm cast is separate from other casts and ranges in size from that of a mustard seed to a sorghum seed depending on the size of the worm. The soluble nutrient content of worm casts is considerably higher than those of the original soil (see Table 2). A good population of earthworms can process 20,000 pounds of topsoil per year, with turnover rates as high as 200 tons per acre having been reported in some exceptional cases (5).

Earthworms also secrete a plant growth stimulant. Reported increases in plant growth due to earthworm activity may be attributed to this substance, not just to improved soil quality.

Table 2. Nutrients in worm casts compared to the surrounding soil from which they came.		
Nutrient	Worm casts	Soil
	Lbs/ac	Lbs/ac
Carbon	171,000	78,500
Nitrogen	10,720	7000
Phosphorus	280	40
Potassium	900	140
From Graff, O. 1971. (6) Soil had 4% organic matter.		

Earthworms thrive where there is no-tillage–generally, the less tillage, the better, and the shallower the tillage, the better. Worm numbers can be reduced by as much as 90% by deep and frequent tillage (7). Tillage reduces earthworm populations by drying the soil, burying the plant residue they feed on, and making the soil easier to freeze. Tillage also destroys their vertical burrows and can kill and cut up the worms themselves. Emergence times for young worms are spring and fall–their most active periods just when most farmers are interested in tillage. Worms are dormant in the hot part of the summer and the cold of winter. Table 3 shows the effect of tillage and cropping practices on earthworm numbers.

Table 3. Effect of crop management on earthworm populations.		
Crop	Management	Worms/foot2
Corn	Plow	1
Corn	No-till	2
Soybean	Plow	6
Soybean	No-till	14
Bluegrass/clover	---	39
Dairy pasture	---	33
From Kladivko, 1995. (8)		

As a rule, earthworm numbers can be increased by reducing or eliminating tillage (especially fall tillage), never using the moldboard plow, reducing residue particle size (using a straw chopper on the combine), adding animal manure, and growing green manure crops. It is beneficial to leave as much surface residue as possible year round. Cropping systems that typically have the most earthworms are in descending order: perennial cool-season grass grazed rotationally, then warm-season perennial grass grazed rotationally, then annual croplands using no-till. Ridge-till and strip tillage will generally have more earthworms than clean tillage involving plowing and disking.

Earthworms prefer a near neutral soil pH, moist soil conditions, and plenty of plant residue on the soil surface. They are sensitive to certain pesticides and some incorporated fertilizers. Carbamate insecticides including Furadan, Sevin, and Temik, are harmful to earthworms, notes worm biologist Clive Edwards of Ohio State University (4). Some insecticides in the organophosphate family are mildly toxic to earthworms while synthetic pyrethroids are harmless to them (4). Most herbicides have little effect on worms except for the triazines, such as Atrazine, which are moderately toxic. Also, anhydrous ammonia kills earthworms in the injection zone.

As a rule, earthworm numbers can be increased by reducing or eliminating tillage.

For more information on managing earthworms, order *The Farmer's Earthworm Handbook: Managing Your Underground Moneymakers,* by David Ernst. Ernst's book contains details on what earthworms need to live, increasing worm numbers, the effects of tillage, manure and livestock management effects on earthworms, how 193 chemicals affect earthworms, and more. See the **Additional Information Resources** section of this publication for ordering information. Also visit the earthworm websites listed under this section.

Arthropods: In addition to earthworms, there are many other species of soil organisms that can be seen by the naked eye. Among them are sowbugs, millipedes, centipedes, slugs, snails and springtails. These are the primary decomposers. Their role is to eat and shred the large particles of plant and animal residues. Some bury residue, bringing it into contact with other soil organisms that further decompose it. Some members of this group prey on smaller soil organisms. The springtails are a small insect, which eat mostly fungi. Their waste is rich in plant nutrients that are released after other fungi and bacteria decompose it. Also of interest are dung beetles, which play a valuable role in recycling manure and reducing livestock intestinal parasites and flies.

Bacteria: Most numerous among soil organisms are the bacteria; every gram of soil contains at least a million of these tiny one-celled organisms. There are many different species of bacteria, each with its own role in the soil environment. One of the major benefits bacteria provide for plants is in helping them take up nutrients. Some species release nitrogen, sulfur, phosphorus, and trace elements from organic matter. Others break down soil minerals and release potassium, phosphorus, magnesium, calcium and iron. Still other species make and release natural plant growth hormones, which stimulate root growth.

A few species of bacteria fix nitrogen in the roots of legumes while others fix nitrogen independently of plant association. Bacteria are responsible for converting nitrogen from ammonium to nitrate and back again depending on certain soil conditions. Other benefits to plants provided by various species of bacteria include increasing the solubility of nutrients, improving soil structure, fighting root diseases, and detoxifying soil.

Fungi: Fungi come in many different species, sizes and shapes in soil. Some species appear as thread-like colonies, while others are one-celled yeasts. Slime molds and mushrooms are also fungi. Many fungi aid plants by breaking down organic matter or by releasing nutrients from soil minerals. Fungi are generally early to colonize larger pieces of organic matter and begin the decomposition process. Some fungi produce plant hormones, while others produce antibiotics including penicillin. There are even species of fungi that trap harmful plant-parasitic nematodes.

The mycorrhizae (my-cor-ry-'zee) group of fungi lives either on or in plant roots and act to extend the reach of root hairs into the soil. Mycorrhizae increase the uptake of water and nutrients especially in less fertile soils. Roots colonized by mycorrihizae are less likely to be penetrated by root-feeding nematodes since the pest cannot pierce the thick fungal network. Mycorrhizae also produce hormones and antibiotics, which enhance root growth and provide disease suppression. The fungi benefit from plant association by taking nutrients and carbohydrates from the plant roots they live in.

Actinomycetes: Actinomycetes (ac"-ti-no-my'-cetes) are thread-like bacteria that look like fungi. While not as numerous as bacteria, they also perform vital roles in the soil. Like the bacteria, they help decompose organic matter into humus, releasing nutrients. They also produce antibiotics to fight diseases of roots. These same antibiotics are used to treat human diseases. Actinomycetes are responsible for the sweet, earthy smell of biologically active soil noticed whenever a field is tilled.

Algae: Many different species of algae also live in the upper half-inch of the soil. Unlike most other soil organisms, algae actually produce their own food through photosynthesis. They appear as a greenish film on the soil surface following a good rain. Algae improve soil structure by producing slimy substances that glue soil together into water-stable aggregates. Some species of algae (the blue-greens) can fix their own nitrogen, some of which is later released to plant roots.

Protozoa: Protozoa are free-living microorganisms that crawl or swim in the water between soil particles. Many soil protozoa are predatory, eating other microbes. One of the most common is an amoeba that eats bacteria. By eating and digesting bacteria, protozoa speed up the cycling of nitrogen from the bacteria, making it more available to plants.

Nematodes: While nematodes are abundant in most soils, only a few species are harmful to plants. The harmless species eat decaying plant litter, bacteria, fungi, algae, protozoa and other nematodes. Like other soil predators, nematodes speed the rate of nutrient cycling.

All these organisms–from the tiny bacteria up to the large earthworms and insects–interact with one another in a multitude of ways in a whole soil ecosystem. Organisms not directly involved in decomposing plant wastes may feed on each other or each other's waste products or the other substances they release. Among the other substances released by the various microbes are vitamins, amino acids, sugars, antibiotics, gums, and waxes.

Roots can also release various substances into the soil that stimulate soil microbes. These substances serve as food for select organisms. Some scientists and practitioners theorize that plants use this means to stimulate the specific population of microorganisms capable of releasing or otherwise producing the kind of nutrition needed by the plants.

> *Research on biological life in the soil has determined that there are ideal ratios for certain key soil organisms in productive soils.*

Research on biological life in the soil has determined that there are ideal ratios for certain key soil organisms in highly productive soils (soil foodweb). The Soil Foodweb lab, located in Oregon, tests soils and makes fertility recommendations that are based on this understanding. Their goal is to alter the makeup of the soil microbial community so it resembles that of a highly fertile and productive soil. There are several different ways to accomplish this goal, depending on the situation. For more on the Soil Foodweb Lab see the **Additional Information Resources** Section of this publication. Because we cannot see most of the creatures living in the soil and may not take time to observe the ones we can see, it is easy to forget about them. See Table 4 for estimates of typical amounts of various organisms found in fertile soil. There are many websites that provide in-depth information on soil organisms. Look for a list of these web sites in the **Additional Information Resources** section of this publication. Many of these web sites have color photographs of soil organisms and describe their benefits.

Table 4. Weights of soil organisms in the top 7 inches of fertile soil.

Organism	**Pounds of liveweight/acre**
Bacteria	1000
Actinomycetes	1000
Molds	2000
Algae	100
Protozoa	200
Nematodes	50
Insects	100
Worms	1000
Plant roots	2000

From: Bollen, 1959. (10)

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Organic Matter, Humus and the Soil Foodweb

Critical to any model for sustainable soil management, is understanding the role that soil organisms play, and that farmers focus on strategies that build both their numbers and their diversity. As with cattle and other farm animals, soil livestock require proper feed. That feed comes in the form of organic matter.

Organic matter and humus are terms that describe somewhat different but related things. Organic matter refers to the organic fraction of the soil that is composed of both living organisms and once-living residues in various stages of decomposition. Humus is only a small portion of the organic matter. It is the end product of organic matter decomposition and is relatively stable. Further decomposition of humus occurs very slowly in both agricultural and natural settings. In natural systems, a balance is reached between the amount of humus formation and the amount of humus decay (11). In most agricultural soils, this balance also occurs, but often at a much lower level of soil humus. Humus contributes to well-structured soil that, in turn, produces high quality plants. It is clear that management of organic matter and humus is essential to sustain the whole soil ecosystem.

As with cattle and other farm animals, soil livestock require proper feed.

The benefits of a soil rich in organic matter and humus are many. They include: rapid decomposition of crop residues, granulation of soil into water stable aggregates, decreased crusting and clodding, improved internal drainage, better water infiltration, and increased water and nutrient holding capacity. Improvements in the soil's physical structure facilitate easier tillage, increased soil water storage capacity, reduced erosion, better formation and harvesting of root crops, and deeper, more prolific plant root systems. Improvements in nutrient cycling also reduce the fertilizer bill.

Soil organic matter can be compared to a bank account for plant nutrients. Soil containing 4% organic matter in the top 7 inches has 80,000 pounds of organic matter per acre. That 80,000 pounds of organic matter will contain about 5.25% nitrogen, amounting to 4,200 pounds of nitrogen per acre. Assuming a 5% release rate during the growing season, the organic matter could supply 210 pounds of nitrogen to a crop. If the organic matter is allowed to degrade, purchased fertilizer will be necessary to prop up crop yields due to lost organic-matter nitrogen.

Ultimately, building organic matter and humus levels in the soil is a matter of managing the living organisms in the soil–something akin to wildlife management or animal husbandry. This entails working to maintain favorable conditions of moisture, temperature, nutrient status, pH, and aeration. It also involves providing a steady food source.

Ultimately, building organic matter and humus in the soil is a matter of managing the living organisms in the soil.

All the soil organisms mentioned previously, except algae, depend on organic matter as their food source. Therefore, to maintain their populations, organic matter must be renewed from plants growing on the soil, or from animal manure or other materials imported from off site. By feeding the soil livestock, fertility is built up in the soil and the soil will feed the plants.

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Soil Tilth and Organic Matter

A soil that drains well, does not crust, takes in water rapidly, and does not make clods is said to have good tilth. Tilth is the physical condition of the soil as it relates to tillage ease, seedbed quality, easy seedling emergence, and deep root penetration. Good tilth is dependent on aggregation–the process whereby individual soil particles are joined into clusters or "aggregates."

Aggregates form in soils when individual soil particles are oriented and brought together through wetting and drying, freezing and thawing, and by plant growth and earthworm activity. The weak electrical forces from calcium and magnesium hold the soil particles together when the soil dries. When the aggregates become wet again, however, their stability is challenged and they may break apart once again. In the case of earthworm-created aggregates, they are stable once they come out of the worm. An aggregate formed by physical forces becomes stabilized (will remain intact when wet) through microbial processes involving organic matter decomposition and its by-products–chiefly gums, waxes, and other glue-like substances. These by-products cement the soil particles together forming water-stable aggregates (Figure 2). The aggregate is then strong enough to hold together when wet–hence the name "water-stable."

USDA soil microbiologist Sara Wright named the glue that holds aggregates together "glomalin" after the Glomales group of common root dwelling fungi (12). These fungi secrete a gooey protein known as glomalin through their hair-like filaments called hyphae. When Sara Wright measured glomalin in soil aggregates she found levels as high as 2% of their total weight in eastern US soils. Soils from the west and Midwest had lower levels of glomalin. She found that tillage tends to lower glomalin levels. Higher glomalin levels and higher aggregation were found in no-till corn plots than in soil from tilled plots (12). Sara has a brochure describing glomalin and how it benefits soil entitled *Glomalin, a Manageable Soil Glue*. To order this brochure see the **Additional Information Resources** section of this publication

A well-aggregated soil has increased water entry into the soil, increased aeration, and increased water-holding capacity (13). Plant roots occupy a larger volume of well-aggregated soil that is high in organic matter as opposed to a finely pulverized and dispersed soil, low in organic matter. Roots, earthworms, and soil arthropods can pass more easily through a well-aggregated soil (14). Aggregated soils also prevent glazing or crusting of the soil surface. Finally, well-aggregated soils are more erosion resistant, because aggregates are much heavier than their particle components. For a good example of the effect of organic matter additions on aggregation and subsequent increase in water entry into the soil, see Table 5.

Table 5. Water entry into the soil after 1 hour	
Manure Rate Tons/acre	Inches of water
0	1.2
8	1.9
16	2.7
Boyle, et al. 1989. (13)	

The opposite of aggregation is dispersion. In a dispersed soil, each individual soil particle is free to blow away with the wind or wash away with over-land flow of water.

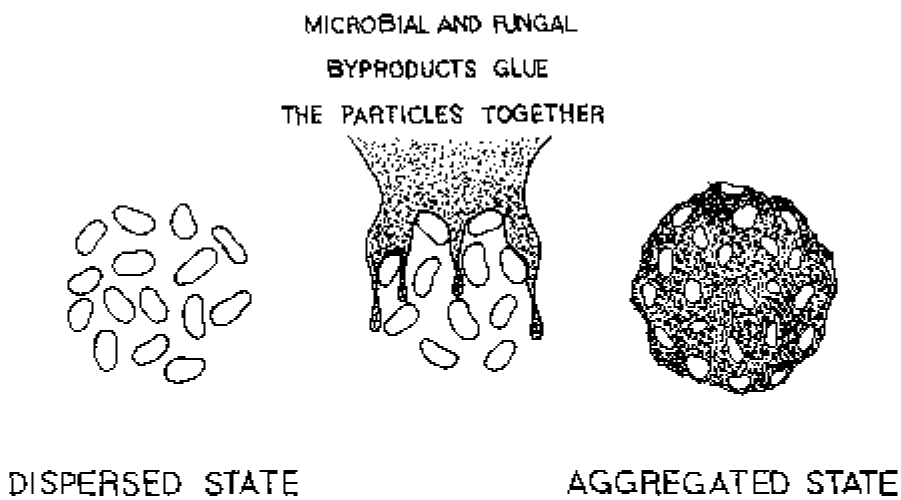

Figure 2 Microbial byproducts glue soil particles into water-stable aggregates.

Soils with poor aggregation also tend to be sticky when wet and cloddy when dry. If the clay particles in these soils can be aggregated together, better aeration and water infiltration will result. Sandy soils can benefit from aggregation by having a small amount of dispersed clay that tends to stick between the sand particles and slows the excess downward movement of water.

Crusting is a common problem on soils that are poorly aggregated. Crusting results chiefly from the impact of falling raindrops. Rainfall causes clay particles on the soil surface to disperse and clog the pores immediately beneath the surface. Following drying, a sealed soil surface results in which most of the pore space has been drastically reduced due to clogging from dispersed clay particles. Subsequent rainfall is much more likely to run off than to flow into the soil (Figure 3).

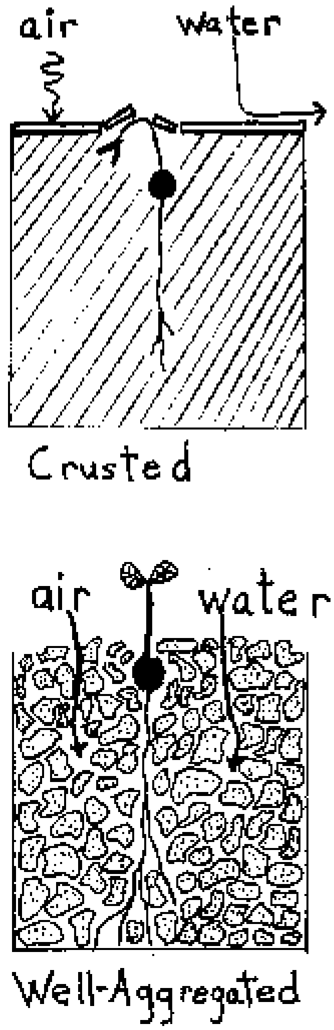

Figure 3 Effects of agggregation on water and air entry into the soil.
Derived from: Land Stewardship Project Monitoring Toolbox (15)

Since raindrops start crusting, any management practices that protect the soil from this impact will decrease crusting and increase water flow into the soil. Mulches and cover crops serve this purpose well as do no-till practices which allow the accumulation of surface residue. Also a well-aggregated soil will resist crusting because the water-stable aggregates are less likely to break apart when a raindrop hits them.

The best-aggregated soils are those that have been in long-term grass production (16). A grass sod extends a mass of fine roots throughout the topsoil, contributing to the physical processes that help form aggregates. For example, roots continually remove water from soil microsites, providing local wetting and drying effects that promote aggregation.

The best aggregated soils are those that have been in long-term grass production.

Meanwhile, the roots are also producing food for the soil microorganisms and earthworms, thus generating the compounds that bind the aggregates into water-stable units. Additionally, a perennial grass sod provides protection from raindrops and erosion while these processes are occurring. This combination of factors creates optimal conditions for the establishment of a well-aggregated soil under a perennial cover.

Conversely, cropping sequences that involve annual plants and extensive cultivation provide less vegetative cover and organic matter, and usually result in a rapid decline in soil aggregation and organic matter. For more information on aggregation, see the soil quality information sheet entitled *Aggregate Stability* at the Soil Quality Institute's homepage. From there, click on Soil Quality Information Sheets, then click on Aggregate Stability: http://www.statlab.iastate.edu/survey/SQI/sqihome.shtml

Farming practices can be geared to conserve and promote soil aggregation. Because the binding substances are themselves susceptible to microbial degradation, organic matter needs to be replenished to maintain an aggregated status. Practices should also conserve aggregates once they are formed, by minimizing factors that degrade and destroy aggregation. Some factors which destroy or degrade soil aggregates are:

- excessive tillage
- working the soil when it is too wet or too dry
- use of anhydrous ammonia that speed decomposition of organic matter
- excess nitrogen fertilization
- allowing build up of excess sodium from salty irrigation water or sodium-containing fertilizers.

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Tillage, Organic Matter, and Plant Productivity

Several factors affect the level of organic matter that can be maintained in a soil. Among these are organic matter additions, moisture, temperature, tillage, nitrogen levels, cropping, and fertilization. The level of organic matter present in the soil is a direct function of how much organic material is being produced or added to the soil versus the rate of decomposition. The objectives of this balancing act entail slowing the speed of organic matter decomposition, while increasing the supply of organic materials produced on site and/or the addition of organic matter from off site.

Moisture and temperature also profoundly affect soil organic matter level. One only has to compare organic matter present in soils of the northern states with those of the southern states to see the decline in organic matter due to higher temperature and moisture in the soil. Generally speaking, soils in the dryer western states have more organic matter than those in the eastern states receiving more rainfall. The most dramatic example of the effects of temperature and moisture may be seen by comparing the organic-matter-rich soils of the arctic region with the organic matter poor soils of the tropics. The warmer and wetter it gets, the more difficult to maintain soil organic matter.

Tillage can be beneficial or harmful to a biologically active soil depending on what type of tillage is used and when it is done. Tillage affects both erosion rate and soil organic matter decomposition rate. Croplands having organic matter levels below 1% are biologically dead. These low levels are due primarily to tillage. Clean tillage involving moldboard plowing and disking breaks down soil aggregates and leaves the soil prone to erosion from wind and water. The moldboard plow can bury crop residue and topsoil to a depth of 14 inches. At this depth, the oxygen level in the soil is so low that decomposition cannot proceed adequately.

Surface dwelling decomposer organisms suddenly find themselves suffocated and soon die. The crop residue that was originally on the surface but has now been turned under will putrefy in the oxygen-deprived zone as it rots in the absence of oxygen. This rotting activity may give a putrid smell to the soil. Furthermore, the top few inches of the field is now often covered with subsoil having very little organic matter content.

The topsoil is where the biological activity happens–that's where the oxygen is. That's why a fence post rots off at the surface. In terms of organic matter, tillage is similar to opening the air vents on a wood-burning stove; adding organic matter is like adding wood to the stove. Ideally, organic matter decomposition should proceed as an efficient burn of the "wood" to release nutrients and carbohydrates to the soil organisms and create stable humus. Shallow tillage incorporates residue and speeds the decomposition of organic matter by adding oxygen that microbes need to become more active. In cold climates with a long dormant season, light tillage of a heavy residue may be beneficial; in warmer climates it is hard enough to maintain organic matter levels even without tillage.

As indicated in Figure 4, moldboard plowing causes the fastest decline of organic matter, no-till the least. The plow lays the soil up on its side, increasing the surface area exposed to oxygen. The other three types of tillage are intermediate in their ability to foster organic matter decomposition. Oxygen is the key factor here. The moldboard plow increases the soil surface area, allowing more air into the soil and speeding the decomposition rate. The horizontal line on Figure 4 represents the replenishment of organic matter provided by wheat stubble. With the moldboard plow, more than the entire organic matter contribution from the wheat straw is gone within only 19 days following tillage. Finally, the passage of heavy equipment increases compaction in the wheel tracks, and some tillage implements themselves compact the soil further, removing oxygen and increasing the chance that deeply buried residues will putrefy.

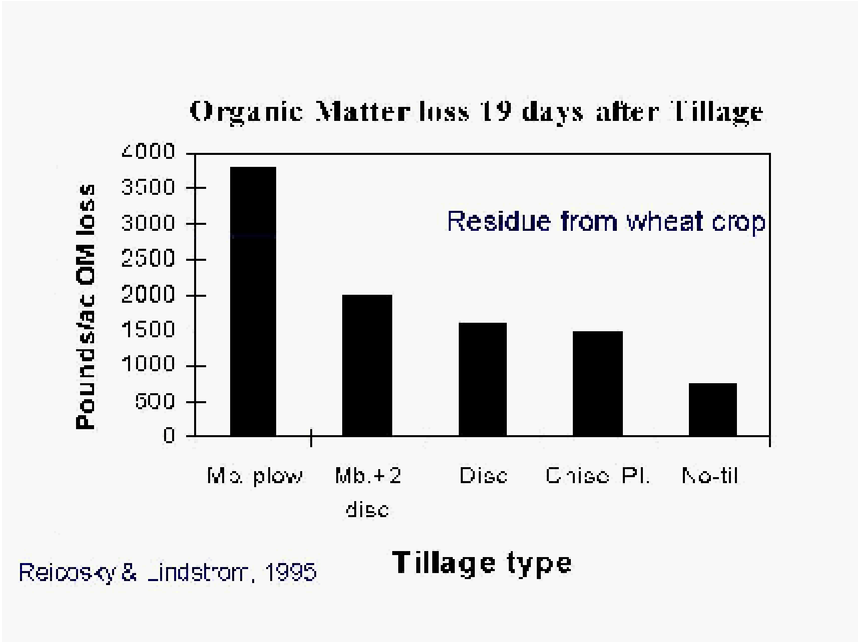

Figure 4. Organic matter losses after various tillage practices (17).

Tillage also reduces the rate of water entry into the soil by removal of ground cover and destruction of aggregates. Table 6 shows three different tillage methods and how they affect water entry into the soil. Notice the direct relationship between tillage type, ground cover, and water infiltration. No-till has more than three times the water infiltration of the moldboard-plowed soil. Additionally, the no-till field will have higher aggregation from the organic matter decomposing on-site. The surface mulch typical of no-till fields acts as a protective skin to the soil. This soil skin reduces the impact of raindrops and buffers the soil from temperature extremes as well as reducing water evaporation.

Table 6. Tillage effects on water infiltration and ground cover.

	Water Infiltration	Ground Cover
	mm/minute	Percent
No-till	2.7	48
Chisel Plow	1.3	27
Moldboard Plow	0.8	12

Boyle, et al. 1989. (13)

Both no-till and reduced tillage systems provide benefits to the soil. The advantages of a no-till system include superior soil conservation, moisture conservation, reduced water runoff, the long-term buildup of organic matter, and increased water infiltration. A soil managed without tillage relies on soil organisms to take over the job of plant residue incorporation formerly done by tillage. On the down side, no-till can foster a reliance on herbicides to control weeds and can lead to soil compaction from the traffic of heavy equipment. Pioneering development work on chemical-free no-till farming is proceeding at several research stations in the eastern US and on farms. Pennsylvania farmer Steve Groff has been farming no-till with minimal or no herbicides for several years. Steve is a 15-year no-till farmer in Lancaster County, Pennsylvania, who uses cover crops extensively in his crop fields. In the spring he rolls the cover crops down using a 10-foot rolling stalk chopper. This rolling chopper kills the rye or vetch cover crop and creates a nice no-till mulch into which he plants a variety of vegetables and grain crops.

After several years of no-till production, his soils are mellow and easy to plant into. Steve farms 175 acres of vegetables, alfalfa and grain crops on his Cedar Meadow Farm. Learn more about Steve's operation in the **Farmer Profiles** section of this publication, by visiting his website, or by ordering his video (see **Additional Information Resources** section).

Other conservation tillage systems include ridge tillage, minimum tillage, zone tillage, and reduced tillage, each possessing some of the advantages of both conventional till and no-till. These systems represent intermediate tillage systems, allowing more flexibility than a no-till or conventional till system might. They are more or less beneficial or harmful to soil organisms depending on the type and amount of tillage and when it is done.

Adding manure and composts is a recognized means for improving soil organic matter and humus levels. In their absence, perennial grass is the only crop that can regenerate and increase soil humus (18). Cool season grasses build soil organic matter faster than warm-season grasses because they are growing much longer during a given year (18).

When the soil is warm enough for soil organisms to decompose organic matter, cool-season grass is growing. While growing, it is producing organic matter and cycling minerals from the decomposing organic matter in the soil. In other words, there is a net gain of organic matter because the cool-season grass is producing organic matter faster than it is being used up.

With warm-season grasses, organic matter production during the growing season can be slowed during the long dormant season from fall through early spring. During the beginning and end of this dormant period the soil is still biologically active, yet no grass growth is proceeding (18). Some net accumulation of organic matter can occur under warm-season grasses, however. In a Texas study, switchgrass grown for 4 years increased soil carbon content from 1.1% to 1.5% in the top 12 inches of soil (19). In hot and moist regions, a cropping rotation that includes several years of pasture will be most beneficial.

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Effect of Nitrogen on Organic Matter

Excess nitrogen applications stimulate increased microbial activity that speeds organic matter decomposition. The extra nitrogen narrows the ratio of carbon to nitrogen in the soil. The native soil carbon to nitrogen ratio (C:N ratio) is around 12:1. At this ratio, populations of decay bacteria are kept at a stable level (20). When large amounts of inorganic nitrogen are added, the C:N ratio is reduced, which increases the populations of decay organisms and allows them to decompose more organic matter. While soil bacteria can efficiently use moderate applications of inorganic nitrogen accompanied by organic amendments (carbon), excess nitrogen causes bacteria populations to explode, decomposing existing organic matter at a rapid rate.

> *Excess nitrogen stimulates increased microbial activity that speeds organic matter decomposition.*

Eventually, soil carbon content may be reduced to a level where the bacterial populations are on a starvation diet. With little carbon available, bacterial populations shrink and less free soil nitrogen is absorbed. Thereafter, applied nitrogen, rather than being cycled through microbial organisms and re-released to plants slowly over time, becomes subject to leaching. This can greatly reduce the efficiency of fertilization and lead to environmental problems.

To compensate for the fast decomposition of native soil organic matter, carbon should be added with nitrogen. Typical sources–such as green manures, animal manure and compost–serve this purpose well. Amendments containing too high a carbon to nitrogen ratio (25:1 or more) can tip the balance the other way, resulting in nitrogen tied up in an unavailable form. The soil organisms consume all the nitrogen in an effort to decompose the abundant carbon. The nitrogen is unavailable because it is tied up in the soil organisms themselves. As soon as one dies and decomposes, its nitrogen is consumed by another soil organism until the balance between carbon and nitrogen is achieved again.

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Fertilizer Amendments and Biologically Active Soils

What are the soil mineral conditions that foster biologically active soils? Drawing from the work of Dr. William Albrecht (1888 to 1974), agronomist at the University of Missouri, we learn that balance is the key. Albrecht advocated bringing soil nutrients in balance so that none were in excess or deficient. Albrecht's theory (also called base-saturation theory) is used to guide lime and fertilizer application by measuring and evaluating the ratios of positively charged nutrients (bases) held in the soil. The positively charged bases include calcium, magnesium, potassium, sodium, ammonium nitrogen, and several trace minerals. When optimum ratios of bases exist, the soil is believed to support high biological activity, becomes resistant to leaching, and has optimal physical properties (water intake and aggregation). The plants growing on such a soil are also balanced in mineral levels and are nutritious to humans and animals alike.

Through extensive research, Albrecht determined the desirable percentages of base saturation in the soil. These percentages, he maintained, were optimal for the growth of most crops. These levels are:

Calcium	60-70%
Magnesium	10-20%
Potassium	2-5%
Sodium	0.5-3%
Other bases	5%

Fertilizer and lime applications should be made at rates that will bring soil mineral percentages into this ideal range. Through this approach, soil pH shifts automatically into a desirable range without creating nutrient imbalances. The base saturation theory also takes into account the effect one nutrient may have on another and avoids undesirable interactions. For example, excess phosphorus is known to tie up zinc.

The Albrecht system of soil evaluation contrasts with the approach used by many state laboratories often called the "sufficiency method." Sufficiency theory places little to no value on nutrient ratios, and lime recommendations are typically based on pH measurements alone. While in many circumstances base saturation and sufficiency methods will produce identical soil recommendations and similar results, significant differences can occur on a number of soils. For example, suppose we tested a cornfield and found a soil pH of 5.5 and base saturation for magnesium at 20% and calcium at 40%. Base saturation theory would call for liming with a high-calcium lime to raise the % base saturation of calcium; the pH would rise accordingly. Sufficiency theory would not specify high calcium lime and the grower might choose instead, a high magnesium dolomite lime that would raise the pH but worsen the balance of nutrients in the soil. Another way to look at these two theories is that the base saturation theory does not concern itself with pH to any great extent but rather with the proportional amounts of bases. The pH will be correct when the levels of bases are correct.

Albrecht's ideas have found their way onto large numbers of American farms and into the programs of several agricultural consulting companies. Neal Kinsey, a soil fertility consultant of Charleston, MO, is a major proponent of the Albrecht approach. Kinsey was a student under Albrecht and is one of the leading authorities on the base-saturation method. He teaches a short course on the Albrecht system and provides a soil analysis service (21). His book, *Hands On Agronomy*, is widely recognized as a highly practical guide to its understanding and implementation. For more information on the Albrecht theory request the ATTRA publication on Albrecht and Reams Fertility Management Systems.

Several firms–many providing backup fertilizer and amendment products–offer a biological-farming program based on the Albrecht theory. Typically these firms offer broad-based soil analysis and recommend balanced fertilizer materials considered friendly to soil organisms. They avoid the use of some common fertilizers and amendments such as dolomite lime, potassium chloride, anhydrous ammonia, and oxide forms of trace elements because they are considered harmful to soil life. The publication *How to Get Started in Biological Farming* presents such a program. See the **Additional Information Resources** section for ordering information. For more names of companies offering consulting and products order the ATTRA publications *Alternative Soil Testing Laboratories* and *Sources for Organic Fertilizers and Amendments*. Both of these are also available on the ATTRA web site located at: http://www.attra.org.

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Conventional Fertilizers

Commercial fertilizer can be a valuable resource to farmers in transition to a more sustainable system and can help meet nutrient needs during times of high crop nutrient demand, or when weather conditions result in slow nutrient release from organic resources. Commercial fertilizers have the advantage of supplying plants with immediately available forms of nutrients. They are often less expensive and less bulky to apply than processed natural fertilizers.

Not all conventional fertilizers are alike, however. Many appear harmless to soil livestock but a few are problematic. Anhydrous ammonia contains approximately 82% nitrogen and is applied subsurface as a gas. Anhydrous speeds the decomposition of organic matter in the soil, leaving a soil more compact as a result. The addition of anhydrous contributes acidity to the soil, requiring 148 pounds of lime to neutralize 100 pounds of anhydrous ammonia or 1.8 pounds of lime for every pound of nitrogen contained in the anhydrous (22, 23). Anhydrous ammonia initially kills many soil microorganisms in the application zone. Bacteria and actinomycetes recover within one to two weeks to levels higher than those prior to treatment (23). Soil fungi, however, may take seven weeks to recover. During the recovery time, the bacteria are stimulated to grow and decompose more organic matter due to the high soil nitrogen content. This is why their numbers increase after anhydrous applications. Farmers commonly report that the long-term use of synthetic fertilizers, especially anhydrous ammonia, leads to soil compaction and poor tilth (23). When bacteria increase and organic matter decreases, aggregation naturally declines because there is no more glue being produced to stick the soil particles together.

Potassium chloride (KCl) (0-0-60 and 0-0-50), also known as muriate of potash, contains approximately 50 or 60% potassium and 47.5% chloride (24). Muriate of potash is made by refining potassium chloride ore, which is a mixture of potassium and sodium salts and clay from the brines of dying lakes and seas. The potential harmful effects from KCl can be surmised from in the salt concentration of the material. Table 7 shows that, pound for pound, KCl is surpassed only by table salt on the salt index. Additionally, some plants such as tobacco, potatoes, peaches and some legumes are especially sensitive to chloride. High rates of KCl must be avoided on such crops. Potassium sulfate, potassium nitrate, sul-po-mag, or organic sources of potassium may be considered as alternatives to KCl for fertilization.

Sodium nitrate, also known as Chilean nitrate, or nitrate of soda, is another high salt fertilizer. Because of the relatively low nitrogen content of sodium nitrate, a high amount of sodium is added to the soil when normal applications of nitrogen are made with this material. The concern is that excessive sodium acts as a dispersant of soil particles, degrading aggregation. The salt index for KCl and sodium nitrate can be seen in Table 7.

Table 7. Salt index for various fertilizers.

Material	Salt Index	Salt index per unit of plant food
Sodium Chloride	153	
Potassium chloride	116	2.9
Ammonium nitrate	105	1.9
Sodium nitrate	100	3.0
Urea	75	6.1
Potassium nitrate	74	1.6
Ammonium sulfate	69	1.6
Calcium nitrate	53	3.3
Anhydrous ammonia	47	4.4
Sulfate-potash-magnesia	43	.06
Di-ammonium phosphate	34	2.0
Monammonium phosphate	30	1.6
Gypsum	8	2.5
Calcium carbonate	5	.03
		.01

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Top$oil – Your Farm'$ Capital

Topsoil is the capital reserve of every farm. Ever since mankind started agriculture, erosion has been the single largest threat to the soil's productivity and consequently, the profitability of the farm. This is still true today. In the US, the average acre of cropland is eroding at a rate of 7 tons per year (2). To sustain agriculture means to sustain the soil resource because that's where the farmer's livelihood comes from.

Protecting the soil from erosion is the first step toward a sustainable

agriculture.

The major costs to the farm associated with soil erosion come from the replacement of lost nutrients and reduced water holding ability, accounting for 50 to 75% of productivity loss (2). Eroded soil typically contains about three times more nutrients than the soil left behind and is 1.5 to 5 times richer in organic matter (2). This organic-matter loss not only results in reduced water holding capacity and degraded soil aggregation but also the loss of plant nutrients, which must then be replaced with fertilizer.

Five tons of topsoil (the so-called tolerance level) can easily contain 100 pounds of nitrogen, 60 pounds of phosphate, 45 pounds of potash, 2 pounds of calcium, 10 pounds of magnesium, and 8 pounds of sulfur. Table 8 shows the effect of slight, moderate, and severe erosion on organic matter, soil phosphorus level and plant available water on a silt loam soil in Indiana (25).

Table 8. Effect of erosion on organic matter phosphorus and plant-available water.

Erosion level	Organic matter	Phosphorus	Plant-available water
	%	Lbs./ac	%
Slight	3.0	62	7.4
Moderate	2.5	61	6.2
Severe	1.9	40	3.6

From: Schertz et al. 1984. (25)

When erosion by water and wind occurs at a rate of 7.6 tons/acre/year it costs $40 per year to replace the lost nutrients as fertilizer and around $17/acre/yr to pump well irrigation water to replace the soil water holding capacity of that lost soil (26). The total cost of soil and water lost annually from U.S. cropland amounts to an on-site productivity loss of approximately $27 billion each year (2).

Protecting the soil from erosion is the first step toward a sustainable agriculture. Erosion is initiated by raindrop impact on bare soil. Any management practice that protects the soil from raindrop impact will decrease erosion and increase water entry into the soil. Mulches, cover crops, and crop residues serve this purpose well. Additionally, well-aggregated soils resist crusting because water-stable aggregates are less likely to break apart when the raindrop hits them. Adequate organic matter with high soil biological activity leads to aggregation.

Many studies have shown that cropping systems maintaining soil-protecting plant canopy or residue cover have the least soil erosion. This is universally true. Long-term cropping studies begun in 1888 at the University of Missouri provide dramatic evidence of this concept. Gantzer and colleagues (27) examined the effects of a century of cropping on soil erosion. They compared depth of topsoil remaining after 100 years of cropping (Table 9). As the table shows, the practices that maintained the highest amount of permanent ground cover (Timothy grass) had the greatest amount of topsoil left.

The researchers commented that subsoil had been mixed with topsoil in the continuous corn plots from plowing, making the real topsoil depth less than was apparent. In reality, all the topsoil was lost from the continuous corn plots in only 100 years. The rotation lost about half the topsoil over 100 years. How can we feed future generations with this type of farming practice?

Table 9. Topsoil depth remaining after 100 years of different cropping practices.

Crop Sequence	Inches of topsoil remaining
Cont. Corn	7.7
6-year rotation*	12.2
Cont. Timothy grass	17.4

**Corn, oats, wheat, clover, Timothy, Timothy (27)*

In a study of many different soil types in each of the major climatic zones of the US, researchers showed dramatic differences in soil erosion when comparing row crops to perennial sods. Row crops consisted of cotton or corn, and sod crops were bluegrass or bermuda grass. On average the row crops eroded over 50 times more soil than did the perennial sod crops. The two primary influencing factors are ground cover and tillage. The results are shown in Table 10.

Table 10. Effect of cropping on soil erosion rates.

Soil type	Location	Slope	Row crop soil loss	Sod soil loss
	State	*%*	*Tons/ac*	*Tons/ac*
Silt loam	Iowa	9	38	.02
Loam	Missouri	8	51	.16
Silt loam	Ohio	12	99	.02
Fine sandy loam	Oklahoma	7.7	19	.02
Clay loam	N. Carolina	10	31	.31
Fine sandy loam	Texas	8.7	24	.08
Clay	Texas	4	21	.02
Silt loam	Wisconsin	16	111	.1

Average	Average	9.4	49	.09
Adapted from Shiftlet and Darby, 1985. (28)				

So, how long do fields have before the topsoil is gone? Roughly 8 tons/acre/year soil erosion loss amounts to the thickness of a dime spread over an acre. Twenty dimes stack up to 1-inch high. So a landscape with an 8-ton erosion rate would lose an inch of topsoil about every 20 years. Since this amount is barely detectable within a person's lifetime, it is not likely to be noticed.

Forward thinking researcher Wes Jackson, of the Land Institute, waxes eloquently about how tillage is engrained in human culture ever since we began farming. Beating our swords into plowshares surely embodies the triumph of good over evil. Someone who creates something new is said to have "plowed new ground." "Yet the plowshare may well have destroyed more options for future generations than the sword (29)."

Tillage, for the production of annual crops, is the major problem in agriculture due to soil erosion and the loss of soil quality. Any agricultural practice that creates and maintains bare ground is inherently less sustainable than those which keep the ground covered throughout the year.

The only exception that this writer is aware of is wetland rice, where soil can actually be gained by pumping silt-laden surface irrigation water onto the field and draining off clear water at the end of the season. Dr. Wes Jackson has spent much of his career developing perennial grain crops and cropping systems that mimic the natural prairie. Perennial grain crops do not require tillage to establish, and the ground is left covered.

Ultimately, this is the future of grain production and truly represents a new vision in how we produce food. The greatest research need in agriculture today is breeding work to develop perennial crops that will replace annual crops requiring tillage.

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Summary of Part I

Soil management involves stewardship of the soil livestock herd! The primary factors affecting organic matter content, build-up, and decomposition rate in soils are: oxygen content, nitrogen content, moisture content, temperature, and the addition and removal of organic materials. All these factors work together at any one time. Any one can limit the others. These are the factors that affect the health and reproductive rate of organic matter decomposer organisms.

Managers need to be aware of these factors when making decisions about their soils. Let's take them one at the time.

Increasing oxygen speeds decomposition of organic matter. Tillage is the primary way extra oxygen enters the soil. Texture also plays a role, with sandy soils having more aeration than heavy clay soils. Nitrogen content is influenced by fertilizer additions. Excess nitrogen without the addition of carbon speeds the decomposition of organic matter. Moisture content affects decomposition rates. Soil microbial populations are most active over cycles of wetting and drying. Their populations increase following wetting as the soil dries out. After the soil becomes dry, their activity diminishes. Just like humans, soil organisms are profoundly affected by temperature. Their activity is highest within a band of optimum temperature. Above and below optimum temperature their activity is diminished. Adding organic matter provides more food for microbes.

To achieve an increase of soil organic matter, additions must be higher than removals. Over a given year, under average conditions, 60 to 70 percent of the carbon contained in organic residues added to soil is lost as carbon dioxide (20). Five to ten percent is assimilated into the organisms that decomposed the organic residues and the rest becomes 'new' humus. It takes decades for new humus to develop into stable humus which imparts the nutrient holding characteristics humus is known for (20). The end result of adding a ton of residue would be 400 to 700 pounds of new humus. With a 7-inch depth of topsoil over an acre weighing 2 million pounds, you can see that building organic matter is a slow process. One percent organic matter weighs 20,000 pounds.

Building stable humus is a slow and long-term process. It is more feasible to stabilize and maintain the humus present before it is lost than to try to increase it. The value of humus is not fully realized until it is severely depleted (20). If your soils are high in humus now, work hard to preserve what you have. The formation of new humus is essential to maintaining old humus and the decomposition of raw organic matter has many benefits of its own. Increased aeration caused by tillage coupled with the absence of organic carbon in fertilizer materials has caused greater than 50% decline in native humus levels on many US farms (20).

Appropriate mineral nutrition needs to be present for soil organisms and plants to prosper. Adequate levels of calcium, magnesium, potassium, phosphorus, sodium and the trace elements should be present but not in excess. The cation balance theory of soil management helps guide decision making toward achieving optimum levels of these nutrients in the soil. Several books have been written on balancing soil mineral levels and several consulting firms provide soil analysis and fertility recommendation services based on that theory.

Commercial fertilizers have their place in a sustainable agriculture. Some appear harmless to soil livestock and provide nutrients at times of high nutrient demand from crops. Anhydrous ammonia and potassium chloride have limitations, however. Anhydrous kills soil organisms in the injection zone. Bacteria and actinomycetes recover within a few weeks but fungi take longer. The increase in bacteria, fed by high available nitrogen from the anhydrous speeds the decomposition of organic matter. Potassium chloride has a high salt index and some plants are particularly sensitive to chloride.

Topsoil is the farmer's capital. Sustaining agriculture means sustaining the soil resource. Maintaining ground covers like cover crops, mulch or crop residue for as much of the annual season as possible achieves the goal of sustaining the soil resource. Any time the soil is tilled and left bare it is susceptible to erosion. Even small amounts of soil erosion are harmful over time. It is not easy to "see" the effects of erosion over a human lifetime and therefore erosion may go unnoticed. Tillage for production of annual crops created most of the erosion associated with agriculture. Perennial grain crops not requiring tillage provide a promising hope for drastically improving the sustainability of future grain production.

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Sustainable Soil Management Principles Summarized:

- Soil livestock cycle nutrients and provide many other benefits.
- Organic matter is the food for the soil livestock herd.
- The soil shall be covered to protect it from erosion.
- Tillage speeds the decomposition of organic matter.
- Excess nitrogen speeds the decomposition of organic matter.
- Moldboard plowing speeds the decomposition of organic matter, destroys earthworm habitat, and increases erosion.
- To build soil organic matter, the production or addition of organic matter must exceed the decomposition of organic matter.
- Soil fertility levels need to be within acceptable ranges before starting a soil building program.

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Part II. Management Steps to Improve Soil Quality

1. Assess Soil Health and Biological Activity on Your Farm

A basic soil audit is the first and sometimes the only monitoring tool used to assess changes in the soil. Unfortunately, the standard soil test done to determine nutrient levels (P, K, Ca, Mg, etc.) provides no information on soil biology and physical properties. Yet, most of the farmer-recognized criteria listed on the first page of this publication for healthy soils include, or are created by, soil organisms and soil physical properties. A better appreciation of these biological and physical soil properties, and how they affect soil management and productivity, has resulted in the adoption of several new soil health assessment techniques which are discussed below.

The U S D A Soil Quality Test Kit
The USDA Soil Quality Institute provides a Soil Quality Test Kit Guide developed by John Doran and associates at the Agricultural Research Service's office in Lincoln, Nebraska. The kit was designed for field use. Components necessary to build a kit include many items commonly available such as pop bottles, flat bladed knives, a garden trowel, and plastic wrap. Also necessary to do the tests is some equipment usually not locally available such as hypodermic needles, latex tubing, a soil thermometer, an electrical conductivity meter, filter paper, and an EC calibration standard. The kit allows the measurement of water infiltration, water holding capacity, bulk density, pH, soil nitrate, salt concentration, aggregate stability, earthworm numbers, and respiration. The Soil Quality Test Kit Guide can be ordered from the USDA through the Soil Quality Institute's webpage:
http://www.statlab.iastate.edu/survey/SQI/sqihome.shtml

The 88-page on-line version of the guide is available in Adobe Acrobat Reader format through the above web page and may be printed out. A summary of the tests is also available from the web page. To order a paper version, see the Soil Quality Institute reference under the **Additional Information Resources** section. Section II of the test kit provides an interpretive guide for individual tests described in section I.

A greatly simplified and quick soil quality assessment is also available at the Soil Quality Institute's web page by clicking on "Getting to Know your Soil," near the bottom of the homepage. This greatly simplified method involves digging a hole and making some observations. Here are a few of the procedures shown at this website: Dig a hole 4 to 6 inches below the last tillage depth and observe how hard the digging was. Inspect plant roots for lots of branching and fine root hairs or a balled up condition. A lack of fine root hairs indicates oxygen deprivation, while sideways growth indicates a hardpan. The process goes on to tell about earthworms, smelling the soil, and assessing the aggregation. Another useful hands-on procedure for assessing pasture soils is available from the ATTRA publication entitled *Assessing the Pasture Soil Resource*.

Early Warning Monitoring for Croplands
A cropland-monitoring guide has been published by the Center for Holistic Management (30). The monitoring guide contains a set of soil health indicators that are measurable in the field. No fancy equipment is needed to make the assessments described in this monitoring guide. In fact, all the equipment is cheap and locally available on almost any farm. Simple measurements can help determine the health of croplands in terms of the effectiveness of the nutrient cycle, water cycle, and the diversity of some soil organisms. Some of the assessments you can make using this guide are living organisms, aggregation, water infiltration, ground cover, and earthworms. The monitoring guide is easy to read and understand, and comes with a field sheet to record observations. It is available for $12 from the Center for Holistic Management (See **Additional Resources**).

Direct Assessment of Soil Health
Some quick ways to identify a healthy soil include feeling it and smelling it. Grab a handful and take a whiff. Does it have an earthy smell? Is it a loose, crumbly soil with

some earthworms present? Dr. Ray Weil, soil scientist at the University of Maryland describes how he would make a quick evaluation of a soil's health in just 5 minutes (31).

Look at the surface and see if it is crusted, which tells something about tillage practices used, organic matter, and structure. Pushing a soil probe down to 12 inches, lift out some soil and feel its texture. If a plow pan were present it would have been felt with the probe. Turn over a shovelful of soil to look for earthworms and smell for actinomycetes, which are microorganisms that help compost and stabilize decaying organic matter. Their activity leaves a fresh earthy smell in the soil.

Two more easy observations are to count the number of soil organisms in a square foot of surface crop residue and to pour a pint of water on the soil and record the time it takes to sink in. Comparisons can be made using these simple observations along with Ray Weil's evaluation above to determine how farm practices affect soil quality. Some of the soil quality assessment systems discussed above utilize these and other observations and provide record keeping sheets to record your observations on.

A simple erosion test

This test demonstrates the value of ground cover. Tape a white piece of paper near the end of a 3-foot-long stick. Hold the stick in one hand so as to have the paper end within 1 inch of a bare soil surface (see Figure 5). Now pour a pint of water onto the bare soil within 2-3 inches of the white paper and observe the soil accumulation on the white paper. Tape another piece of white paper to the stick and repeat the operation, this time over soil with 100% ground cover, and observe the accumulation of soil on the paper. Compare the two pieces of paper. This simple test shows how effective ground cover can be at preventing soil particles from detaching from the soil surface.

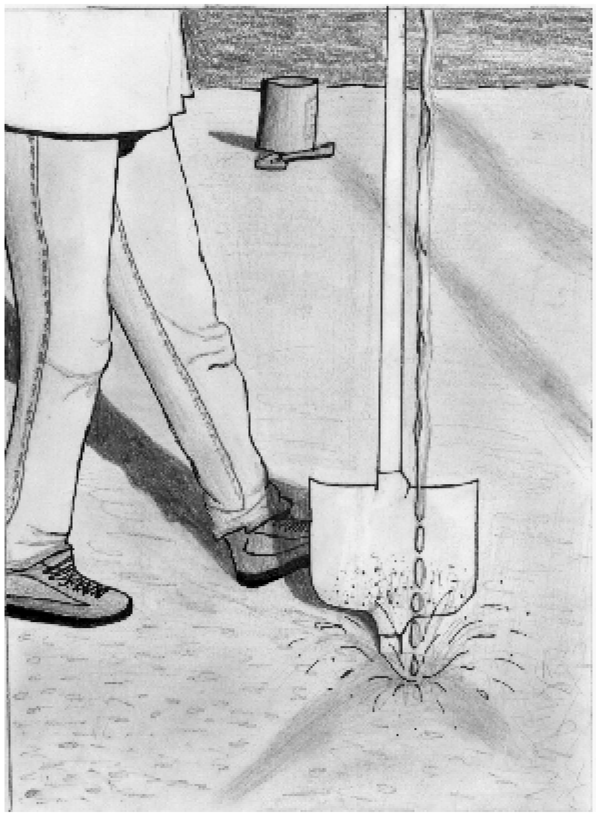

Figure 5. Simple erosion test.
Drawing from Cropland Monitoring guide (Center for Holistice Management, 98)

Detachment of soil particles occurs when falling rainwater collides with bare ground. After enough water builds up on the soil surface, following detachment, overland water flow transports suspended soil down slope (Figure 6). Suspended soil in the runoff water abrades and detaches additional soil particles as the water travels overland. Preventing detachment is the most effective point of erosion control because it keeps the soil in place. Other erosion control practices which seek to slow soil particle transport and cause soil to be deposited before it reaches the stream are less effective at preventing erosion. These latter practices are the ones typically implemented (terraces and diversions). Terraces, diversions and many other erosion "control" practices are basically unnecessary if the ground stays covered year round. For erosion prevention, a high percentage of ground cover is a good "early warning" indicator of success, while bare ground indicates a high risk of erosion (Croplands monitoring guide, 98). Muddy runoff water and gullies are "too-late" indicators. The soil has already eroded by the time it shows up as muddy water and it's too late to save soil already suspended in the water.

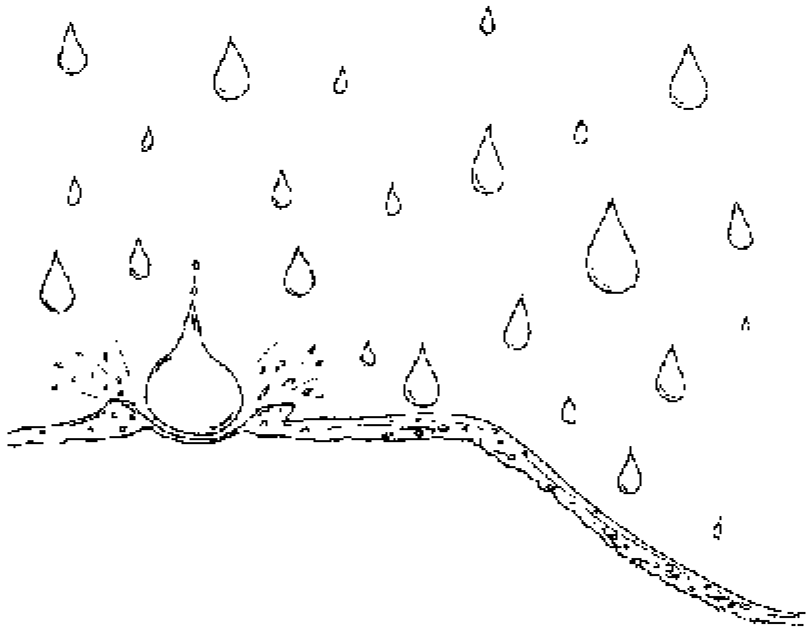

Figure 6. Raindrops falling on bare ground intitiate erosion.
Drawing from Cropland Monitoring guide, 1998, Center for Holistic Management

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2. Utilize Tools and Techniques to Build Soil

Can a cover crop be worked into your rotation? How about a high-residue crop or perennial sod? Are there economical sources of organic materials or manure in your area? Are there ways to reduce tillage and nitrogen fertilizer? Where feasible, bulky organic amendments may be added to supply both organic matter and plant nutrients. It is particularly useful to account for nutrients where organic fertilizers and amendments are utilized. Start with a soil test and a nutrient analysis of the material you are applying. Knowing the amount of nutrients needed to supply the crop to be grown guides the amount of amendment applied and can lead to significant reductions in fertilizer purchase. The nutrient composition of organic materials can be variable, which is all the more reason to determine the amount you have with appropriate testing. In addition to containing the major plant nutrients, organic fertilizers can supply many essential micronutrients. Proper calibration of the spreading equipment is also important to ensure accurate application rates.

Animal Manure

Manure is an excellent soil amendment, providing both organic matter and nutrients. Typical rates for dairy manure would be 10 to 30 tons per acre or 4,000 to 11,000 gallons of liquid for corn. At these rates the crop would get between 50 and 150 pounds of available nitrogen per acre. Additionally, lots of carbon would be added to the soil, resulting in no loss of soil organic matter. High crop residues grown from this manure application would also contribute organic matter.

A common problem with using manure as a crop nutrient source is that application rates are usually based on the nitrogen needs of the crop.

However, a common problem with using manure as a crop nutrient source is that application rates are usually based on the nitrogen needs of the crop. Because some manures often have about as much phosphorus as they do nitrogen, this often leads to buildup of soil phosphorus. A classic example is chicken litter applied to crops that require high nitrogen levels, such as pasture grasses and corn. Broiler litter, for example, contains approximately 50 pounds of nitrogen and phosphorus and about 40 pounds of potassium per ton. A common fertilizer application for established fescue pasture would be about 50 pounds of nitrogen and 30 – 40 pounds of phosphorus per acre. If a ton of poultry litter were applied to supply the nitrogen needs of the fescue, an over-application of phosphorus would result. Several years of litter application can build soil phosphorus up to excessive levels. One easy answer is to this dilemma is to adjust the manure rate to meet the phosphorus needs of the crop and to supply the additional nitrogen with fertilizer or a legume cover crop.

Compost

Composting farm manure and other organic materials is an excellent way to stabilize their nutrient content. A significant portion of raw-manure nutrients are in unstable, soluble forms. Such unstable forms are more likely to run off if surface applied, or to leach if tilled into the soil. Therefore compost is not a good source of readily available plant nutrients like manures are. Compost releases its nutrients slowly, thereby minimizing losses. Quality compost contains more humus than its raw components because primary decomposition has occurred during the composting process. It also does not contribute the sticky gums and waxes that aggregate soil particles together as much as does raw manure because these substances are also released during the primary decomposition phase. Unlike manure, compost can be used at almost any rate without burning plants. In fact some greenhouse potting mixes contain 20 to 30% compost.

Compost (like manure) should be analyzed by a laboratory to determine the nutrient value of a particular batch and insure its wise use

Composting also reduces the bulk of raw organic materials–especially manures which often have a high moisture content. However, while less bulky and easier to handle, composts can be expensive to buy. On-farm composting cuts costs dramatically compared with buying compost. For more comprehensive information on composting at the farm or municipal level, request the ATTRA publication entitled *On-Farm Composting Resource List*.

Cover Crops and Green Manures

Many types of plants can be grown as cover crops. Some of the more common ones include: rye, buckwheat, hairy vetch, crimson clover, subterranean clover, red clover, sweet clover, cowpeas, millet, and forage sorghums. Each of these plants has advantages over the others and their area of adaptability. Cover crops can maintain or increase soil organic matter if they are allowed to grow long enough to produce high herbage. All too often, people get in a hurry and take out a good cover crop just a week or two before it has reached its full potential. Hairy vetch or crimson clover can yield up to 2.5 tons per acre if allowed to go to 25% bloom stage. A mixture of rye and hairy vetch can produce even more.

In addition to the organic matter benefits, legume cover crops provide considerable nitrogen for crops that follow them. Consequently, the nitrogen rate can be reduced following a productive legume cover crop taken out at the correct time. For example, corn grown following 2 tons of hairy vetch should produce high yields of grain with only 50% of the normal nitrogen rate.

When small grains such as rye are used as cover crops and allowed to reach the flowering stage, additional nitrogen may be required to help offset the nitrogen tie-up caused from the high carbon addition of the rye residue. The same would be true of any high carbon amendment such as sawdust or wheat straw. Cover crops also suppress weeds, help break pest cycles, and through their pollen and nectar provide food sources for beneficial insects and honeybees. They can also cycle other soil nutrients making them available to subsequent crops as the green manure decomposes. For more information on cover crops request the ATTRA publication entitled *Overview of Cover Crops and Green Manure*. This publication is comprehensive and provides many references to other available resources on growing cover crops.

Humates

Humates and humic acid derivatives are a diverse family of products, generally obtained from various forms of oxidized coal. Coal-derived humus is essentially the same as humus extracts from soil but there has been a reluctance in some circles to accept it as a worthwhile soil additive. In part, this stems from a belief that only humus derived from recently decayed organic matter is beneficial. It is also true that the production and recycling of organic matter in the soil cannot be replaced by coal-derived humus.

However, while sugars, gums, waxes and similar materials derived from fresh organic-matter decay play a vital role in both soil microbiology and structure, they are not humus. Only a small portion of the organic matter added to the soil will ever be converted to humus. Most will return to the atmosphere as carbon dioxide as it decays.

Many studies have shown positive effects of humates, while other studies have shown no such effects. Generally, the consensus is that they work well in low organic matter soils. In low amounts they do not produce positive results on soils high in organic matter. At high rates they may tie up soil nutrients.

There are many humus products on the market. They are not all the same. Humate products, should be evaluated in a small test plot for cost effectiveness before using. Sales people sometimes make exaggerated claims for their products. ATTRA can provide more information on humates.

Reduce Tillage

While tillage has become common to many production systems, its effects on the soil can be counter-productive. Tillage smoothes the soil surface and reduces natural soil aggregation and earthworm channels. Porosity and water infiltration are decreased following most tillage operations. Plow pans may develop in many situations. Tilled soils have much higher erosion rates than soils left covered with crop residue.

Due to all the problems associated with conventional tillage operations, acreage under reduced tillage systems is increasing on the American landscape. Any tillage system that leaves in excess of 30% surface residue is considered a "conservation tillage" system by USDA (32). Conservation tillage includes no-till, zero till, ridge-till, zone till, and some variations of chisel plowing and disking. These conservation till strategies and techniques allow for establishing crops into the previous crop's residues, which are purposely left on the soil surface. The principal benefits of conservation tillage are the reduction of soil erosion and improved water retention in the soil, resulting in more drought resistance.

Additional benefits, which many conservation tillage systems provide, include reduced fuel consumption, flexibility in planting and harvesting, reduced labor requirements, and improved soil tilth. Two of the most common conservation tillage systems are ridge tillage and no-till.

Ridge tillage is a form of conservation tillage that uses specialized planters and cultivators to maintain permanent ridges on which row crops are grown. After harvest, crop residue is left until planting time. To plant the next crop, the planter places the seed in the top of the ridge after pushing residue out of the way and slicing off the surface of the ridge top. Ridges are re-formed during the last cultivation of the crop.

Often, a band of herbicide is applied to the ridge top during planting. With banded herbicide applications, two cultivations are generally used: one to loosen the soil and another to create the ridge later in the season. No cultivation may be necessary if the herbicide is applied broadcast rather than banded. Because ridge tillage relies on cultivation to control weeds and reform ridges, this system allows farmers to further reduce their dependence on herbicides, compared with either conventional till or strict no-till systems.

Maintenance of the ridges is key to successful ridge tillage systems. The equipment must accurately reshape the ridge, clean away crop residue, plant in the ridge center, and leave a viable seedbed. Not only does the ridge-tillage cultivator remove weeds, it also builds up the ridge. Harvesting in ridged fields may require tall, narrow dual wheels to be fitted to the combine. This modification permits the combine to straddle several rows, leaving the ridges undisturbed. Similarly, grain trucks and wagons cannot be driven randomly through the field. Maintenance of the ridge becomes a consideration for each process.

Conventional no-till methods have been criticized for a heavy reliance on chemical herbicides for weed control. Additionally, no-till farming requires careful management and expensive machinery for some applications. In many cases, the spring temperature of untilled soil is lower than that of tilled soil. This lower temperature can slow germination of early-planted corn or delay planting dates.

Also, increased insect and rodent pest problems have been reported. On the positive side, no-till methods offer excellent soil erosion prevention and decreased trips across the field. On well-drained soils that warm adequately in the spring, no-till has provided the same or better yields as conventional till.

A recent equipment introduction into the no-till arena is the so-called "no-till cultivator." These cultivators permit cultivation in heavy residue and provide a non-chemical option to post-emergent herbicide applications. Farmers have the option to band herbicide in the row and use the no-till cultivator to clean the middles as a way to reduce herbicide use. ATTRA can provide a number of resource contacts on cultural methods, equipment, and management for designing conservation till cropping system.

Minimize Synthetic Nitrogen Fertilizer Use

If at all possible, add carbon with nitrogen sources. Animal manure is a good way to add both carbon and nitrogen. When nitrogen fertilizer is used, try to do it at a time when a heavy crop residue is going onto the soil, too. For example, a rotation of corn, beans, and wheat would do well with nitrogen added after the corn residue was rolled down or lightly tilled in. Spring planted soybeans would require no nitrogen. A small amount of nitrogen could be applied in the fall for the wheat. Following the wheat crop, a legume winter-annual cover crop could be planted. In the spring, when the cover crop is taken out, nitrogen rates for the corn would be reduced to account for the nitrogen in the legume. The addition of legume residue would also be adding carbon. Avoid continual hay crops accompanied by high nitrogen fertilization. The continual removal of hay accompanied by high nitrogen speeds the decomposition of soil organic matter. Heavy fertilization of silage crops, where all the crop residue is removed (especially when accompanied by tillage), speeds soil decline and organic matter depletion.

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3. Continue to monitor for indicators of success or failure

As you experiment with new practices and amendments, continue to monitor the soil for changes using some of the tools discussed in the Assessing Soil Health and Biological Activity section. Several of these monitoring guides have data sheets you can use in the field to record data and use for future comparison after changes are made to the farming practices. Review the principles of sustainable soil management and find ways to apply them in your operation. If the thought of pulling everything together seems overwhelming, start with only one or two new practices and build on them. Seek additional motivation by reading about the people who have successfully built their soils discussed in the next section.

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Part III. Examples of Successful Soil Builders (Farmer Profiles)

Steve Groff: Steve and his family produce vegetables, alfalfa and grain crops on 175 acres in Lancaster County, Pennsylvania. When Steve took over operation of the family farm 15 years ago, his number one concern was eliminating soil erosion. Consequently, he began using cover crops extensively in his crop fields. In order to transform his green cover crop into no-till mulch, Steve uses a 10-foot Buffalo rolling stalk chopper. Under the hitch-mounted frame, the stalk chopper has two sets of rollers running in tandem. These rollers can be adjusted for light or aggressive action and set for continuous coverage. Steve says the machine can be run up to 8 miles an hour and does a good job of killing the cover crop and pushing it right down on the soil. It can also be used to flatten down other crop residues after harvest. Groff improved his chopper by adding independent linkages and springs to each roller. This modification makes each unit more flexible to allow continuous use over uneven terrain. Other farmers report similar results using a disc harrow with the gangs set to run straight or at a slight angle. Following his cover crop chopping, Groff transplants vegetable seedlings into the killed mulch; sweet corn and snap beans are direct-seeded. Since converting to a cover crop mulch system, his soils are protected from erosion and have become much mellower. For more information on his system, order Steve's videos listed under the **Additional Information Resources** section of this publication, or visit his web page: http://www.cedarmeadowfarm.com/about.html At Steve's web site you can see photos of his cover crop roller and no-till transplanter in action, and test-plot results comparing flail mowing, rolling, and herbicide killing of cover crops.

Bob Willett: Bob started no-tilling 20 years ago on his Pride, KY, corn and soybean farm. Willet not only reduced his machinery costs by switching to no-till, but also made gains in conserving topsoil. His goal is to develop a healthy level of humus in the top 2 inches, which keeps the seed zone loose. He has stopped sidewall compaction in the seed slot that still plagues his neighbors during wet springs. He attributes this to the increase in humus and organic matter. His soil surface layer is crumbly and doesn't smear when the disk openers pass through. Willett proclaims that earthworms take the place of tillage by incorporating residue and converting it to humus. Worms help aerate his soil and improve internal drainage which contributes to good rooting for his crops (33). Read more on Bob's success in "Building Soil with Residue Farming" published in the August 1998 issue of *Tennesee Farmer* (33).

David Iles: On the Iles' North Carolina dairy farm the soil has actually changed from red to a dark, almost black color since converting to no-till in 1970. David first learned about no-tillage from his college professor at North Carolina State University in 1964. Before Iles switched to no-tillage, his corn silage yielded between 12 and 15 tons per acre in years with adequate rainfall and between 4 to 5 tons in dry years indicating moisture was his major limiting factor (34). David realized that his water runoff losses and soil erosion were a direct result of tillage. Addressing the root cause of the problem, he switched to no-till and began to spread manure on 1/3 of his land annually. Since these changes, soil water is no longer limiting. If he gets adequate rainfall he makes nearly 20 tons of silage now. David says his land is vastly more productive with increased cation exchange capacity and increased phosphorus levels due to the humus present in his soil. Though his soil pH ranges in the 5.6 to 5.8 level, he applies no lime. His fields are more productive now than when he applied lime in the 70s and more productive than those of his neighbors, who currently use lime and fertilizer.

David laments that in his area, "We've lost half of our topsoil in less than 100 years. What are future generations going to do if we do not do something to save the soil?" (34). North Carolina State agronomist Bobby Brock agrees and says that for the first time in history we have the opportunity to produce food and build soil at the same time. Iles reasons that no-till is the way to improve the soil structure, increase tilth, and increase productivity while still practicing intensive agriculture. He realizes that organic matter is the engine that drives his system and provides food for earthworms and microorganisms. Iles built his soil by fallowing out 20 to 25 acres of his 380-acre farm each year . On these fallow acres he spreads manure and then sows crops that are not harvested but grown just for their organic matter.

Even weeds are not clipped but left for their organic matter. David loves his earthworms and says they are the best employees he has. "They work all the time and eat dirt for a living" (34).

His best field is one he cleared himself in the 70s. In spite of traditional native pHs in the high 4s in his area, he did not lime this new ground but instead just planted rye on it. He had a fine rye crop that year, so he applied liberal manure to it and planted rye a second time. His second rye crop was excellent as well and was followed by corn the third year.

That field yielded the highest corn on the entire farm. This field has been in continuous corn since 1981 and has never been fertilized with conventional products or tilled (34). This field has a pH of 6.1 at a 6-inch depth, an exchange capacity of 8 and an 80% base saturation. David believes this field's productivity is high because it has never been harmed by tillage. For a complete story of the Iles farm see: Dirnburger, J.M. and Johm M. Larose. 1997. No-till saves dairy farm by healing the harm that tillage has done. National Conservation Tillage Digest. Summer. p. 5-8.

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297 County Highway 357
Charleston, MO 63834
573-683-3880

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Additional Information Resources

Videos

No-till Vegetables by Steve Groff. 1997. This video leads you through selection of the proper cover crop mix to plant into to how to control cover crops with little or no herbicide as shown on Steve Groff's Pennsylvania farm. You will see mechanical cover-crop-kill methods, vegetables being planted right into this mulch using a no-till transplanter. You'll also hear comments from leading researchers in the no-till vegetable area.

Order this video for $21.95 + $3.00 shipping from:

Cedar Meadow Farm
679 Hilldale Road
Holtwood, PA 17532
717-284-5152

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Books and Periodicals

Ernst, David T. 1995. The Farmer's Earthworm Handbook: Managing Your-Underground Money Makers. Lessiter Publications, Brookfield, WI. 112 p.

To order this book send $15.95 + $4.00 shipping and handling to:

Lessiter Publications
P.O. Box 624, Brookfield, WI 53008-0624
414-782-4480

Gershuny, Grace, and Joe Smillie. 1995. The Soul of Soil: A Guide to Ecological Soil Management, 3rd edition. agAccess, Davis, CA. 158 p.

To order this book send $16.95 + $4.00 shipping and handling to:

Fertile Ground Books
P.O. Box 2008
Davis, CA 95617
800-540-0170

Kinsey, Neil. Neal Kinsey's Hands-On Agronomy. 1993. Acres, USA. Austin, TX. 340 p.
To order this book send $24.00 + $3.00 shipping and handling to:

ACRES USA
P.O. Box 91299
Austin, TX 78709
800-355-5313
512-892-4400
512-892-4448 fax.

Magdoff, Fred. 1992. Building Soils for Better Crops. University of Nebraska Press, Lincoln, NE. 176 p.

Out of print. Try to locate via interlibrary loan at your local library.

Sachs, Paul D. 1999. Edaphos: Dynamics of a Natural Soil System, 2nd edition. The Edaphic Press. Newbury, VT. 197 p.

To order this book send : $14.95 + $1.50 shipping and handling to:

North Country Organics
P.O. Box 372
Bradford, VT 05033
802-222-4277

USDA. 1998. Soil Quality Test Kit. Soil Quality Institute. 82 p.
This publication has detailed step by step instructions with accompanning color photographs on how to assess in your own fields: soil quality, soil respiration, soil water infiltration, bulk density, electrical conductivity, soil pH, soil nitrate, soil aggregate stability, slaking, and earthworms. It also covers soil physical observations and estimations, water quality tests, with background information on the tests and apendices.

To order this free test kit publication, paid for by your federal tax dollars, contact:

Cathy A. Seybold
NRCS Soil Quality Institute
Soil Science Department
Agriculture and Life Sciences Building
Room 3017
Oregon State University
Corvallis, OR 97331-7306
541-737-1786
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NRCS Soil Quality Institute
National Soil Dynamics Lab
411 S. Donahue Drive
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334-844-4741, ext 176
email: norfleet@eng.auburn.edu

Sullivan, Preston G. 1998. Early Warning Monitoring Guide for Croplands. Center for Holistic Management, Albuquerque, NM. 22 p.

To order this guide send $12.00 ppd. to:

Center for Holistic Management
1010 Tijeras, N.W.
Albuquerque, NM 87102
505-842-5252
web: http://www.holisticmanagement.org

Lamotte Company. 1994. LaMotte Soil Handbook. Chestertown, MD. 81 p.
Covers soil basics, nutrients, pH, acidity and alkalinity, and principles of the LaMotte soil testing system. Has relative nutrient and pH requirements for common crops and plants.

To order this handbook send $4.50 to:

LaMotte Company
P.O. Box 329
Chestertown, MD 21620
410-778-3100 -phone
800-344-3100
410-778-6394-FAX
email: ese@lamotte.com
web: http://www.lamotte.com

Gempler's Inc. 1998. Gempler's Soil Management Guide. Belleville, WI. 41 p.

An information source for on-site sampling and soil testing. Included in the guide is information on soil quality indicators, visual review, sampling soil, pH, conductivity, compaction, infiltration, nutrients, soil moisture and bulk density, biological activity, and organic matter. In the appendices are a number of USDA soil quality information sheets.

To order this guide send 4.95 each plus $5.90 shipping to:

Gempler's Inc.
100 Countryside Drive
P.O. Box 270
Belleville, WI 53508
800-382-8473

National Conservation Tillage Digest. The official publication for state Conservation Tillage Associations and Districts.

To order a one-year subscription to this magazine send $25 to:

National Conservation Tillage Digest
P.O. Box 468

Perryville, MO 63775
800-489-6997

Zimmer, Gary F. No date. How to get Started in Biological Farming. 11 p.

To order this publication send $3 to:

Midwestern Bio-Ag
Highway ID, Box 126
Blue Mounds, WI 53517
608-437-4994

Wright, Sara. 1999. Glomalin, a Manageable Soil Glue. 1-page brochure.

To order this free publication contact:

Sara Wright
USDA-ARS-SMSL
Bldg. 001, Room 140, BARC-W
10300 Baltimore Avenue
Beltsville, MD 20705-2350
301-504-8156
Swright@asrr.arsusda.gov

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Soil Web Sites

Life in the Soil
This is an excellent website which includes brief overviews of many subjects including: nutrient transformation, biological degradation, soil structure, crop rotation, tillage, soil testing for microbes and organic matter turnover. Color photos of many soil critters with short descriptions appear on the front webpage. Other drawings and black and white photos of soil microbes and their effects on soil are on other pages at this site.
http://www-crcslm.waite.adelaide.edu.au/soillife.html

Davy Jone's Homepage: Plant-Soil-Microbial and Rhizosphere Interactions
This webpage contains a complete course in soil microbiology, for free! Davy Jones is a soil professor who teaches at the University of Wales, Bangor. The microbiology course contains detailed notes from 24 lectures in soil microbiology. From the module D2503's homepage click lecture notes, then click lecture notes main index, then click on lecture notes to see the microbiology class. Also available are lecture notes on soil management, soil fertility and world soils, and soil plant interactions and the role of trees. You can also view microbes in action from quick animated bug movies showing dividing

bacteria, a bacteria swimming along, and root hairs. There is a lot more than I can mention here. Don't miss it at: http://www.safs.bangor.ac.uk/dj/

The Pedosphere and its Dynamics: A Systems Approach to Soil Science
A complete on-line soils textbook covering what soil is, ecological functions of soil, soil texture, structure and color, soil formation, Canadian soil classification system, mineralogy, soil reaction, soil water, soil air, soil ecology, soil organic matter and soil survey. To view this textbook click on the textbook icon at the homepage. Much more information is available from the homepage including educational resources, tutorials, workshops, publications, etc. Visit the University of Alberta's Soil Science Server at: http://www.soils.rr.ualberta.ca/

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Other Resources:

Soil Foodweb Inc.
1228 NE 2nd Street
Corvallis, OR 97330
541-752-5066
Email: info@soilfoodweb.com
http://www.soilfoodweb.com

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