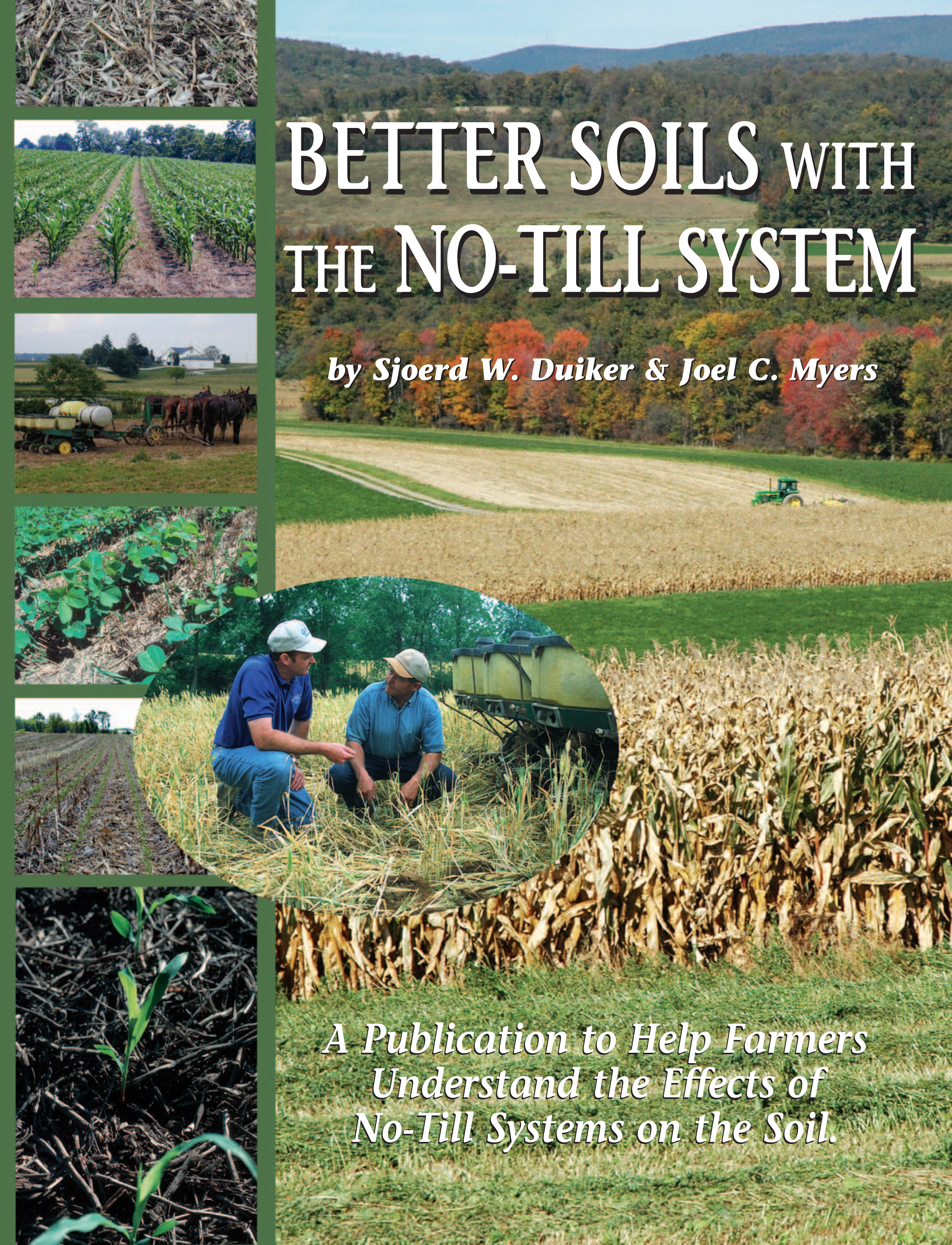

BETTER SOILS WITH THE NO-TILL SYSTEM

by Sjoerd W. Duiker & Joel C. Myers

A Publication to Help Farmers Understand the Effects of No-Till Systems on the Soil.

AUTHORS

Sjoerd Duiker and Joel Myers are known throughout the Northeastern United States as staunch supporters of no-till farming.

Sjoerd Duiker, Ph.D. is an assistant professor of soil management at the Pennsylvania State University. Sjoerd has both research and extension responsibilities in his position in the Department of Crops and Soils at Penn State University. Much of his time is devoted to the impact of no-till on soil quality management. His specialization focuses on the effects of soil management practices on soil properties and processes. He has extensive experience working in the Netherlands, Spain, Africa and the United States. Sjoerd has actively supported no-till throughout Pennsylvania and the northeast and successfully started no-till programs and field days with the Amish in Lancaster County, Pennsylvania. He has actively supported the regional no-till groups in Pennsylvania and made presentations relating to no-till systems at many producer meetings.

Joel Myers is the State Agronomist for the USDA Natural Resources Conservation Service in Pennsylvania. He has promoted no-till through his support of field days, no-till programs and other programs in Pennsylvania. He integrates the principles of no-till into numerous training sessions he conducts. His personal farm experience with complete no-till systems has enabled him to discuss the practical aspects of no-till with producers, agency personnel and others. Joel has spoken several times at the National No-Till Conference. He has been a member of the Mid Atlantic No-Till Conference for over 20 years and has supported and helped start three regional no-till groups in Pennsylvania. He has also been working with researchers and equipment representatives to address the issues of managing manure in no-till systems.

For more information on No-Till in your county contact your local conservation district, NRCS office, Extension agent or the Pennsylvania No-Till Alliance.

The Pennsylvania No-Till Alliance seeks to bring together farmers and others interested in improving soil quality and crop production through the promotion of no-till agricultural systems within the Commonwealth. The main goal of the Alliance is to serve as a network for farmers interested in no-till practices as well as to provide the most recent resources available regarding no-till research, technology and funding. The Alliance will promote the development of strong relationships between producers, private sector, agencies and research institutions in Pennsylvania.

Participation in the Alliance is open to no-till farmers and those supporting no-till agriculture in the private sector. In addition, legislative and governmental agencies provide support and technical guidance as needed.

The successful formation of the PA No-Till Alliance has been the result of a great collaborative effort, and will continue to be mainly a producer-driven organization. Partnering groups/agencies that have been providing support for the effort include:

- USDA/Natural Resources Conservation Service
- Pennsylvania Department of Agriculture
- State Conservation Commission
- Pennsylvania Department of Environmental Protection
- Penn State College of Agricultural Sciences
- Penn State Cooperative Extension
- PA Association of RC&D Councils
- Chesapeake Bay Foundation
- Pennsylvania Farm Bureau
- PennAg Industries Association

For additional information or to join the PA No-Till Alliance, contact Susan Parry at the Capital Resource Conservation and Development Area Council office at (717) 948-6633, or email susan.parry@pa.usda.gov

BETTER SOILS WITH THE NO-TILL SYSTEM

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INTRODUCTION

SOIL IS IMPORTANT

Soil is Important for Crops and Life

Most people do not recognize the important role soil plays in our lives. Soil is a very thin mantle or layer between rock or unconsolidated material in the atmosphere. Because it is such a thin layer, soil is also very fragile and can be easily damaged or even destroyed.

Soil thrives with life … if all is well. It provides many critical ecosystem functions that are necessary for life on Planet Earth. A productive agriculture depends on healthy soil. The soil guarantees that nutrients are made available in sufficient amounts during a plant's life cycle. Soil holds water and makes it available to plants so they don't wilt during dry weather. Water is filtered as it percolates or moves through soil. The soil releases water slowly to the surface and subsurface water systems and thus acts as an important flow regulator.

FIGURE 1. The top 1-2" of the soil determines many soil quality properties that impact production and the environment.

Soil is nature's recycling system, where waste products and dead bodies of organisms are decomposed and their components made available for re-use. Soil is the habitat of a myriad of living

FIGURE 2. Soil erosion, the number one cause of soil degradation.

organisms. Because soil is so important, we, as human beings, need to insure that we are good stewards of this valuable resource.

SOIL IS AT RISK

While soil is a resource that can re-create itself, it is a very slow process. Unfortunately, our nation's soils have been and continue to be degraded at an alarming rate. Soil erosion is still the number one cause of soil degradation. Other causes of soil degradation include: soil compaction, soil acidification, soil pollution, and salinization. Dramatic increases in the use of no-till systems by American farmers have led to many benefits, including reductions in erosion, and savings of time, labor, fuel, and machinery. Between 1990 and 2000, no-till farming acreage rose from 16 million acres to 52 million acres, an increase of 300 percent. Now that some fields have been under no-till production systems for many years, farmers and researchers have begun to notice additional benefits including changes in soil physical, chemical, and biological properties. The most notable of these benefits include increases in organic matter and improved water infiltration. Improved water infiltration can lead to more efficient use of rainfall, increasing yields when rainfall is in short supply.

TABLE 1. Soil loss by erosion in the U.S.

	Cultivated cropland	Uncultivated cropland	CRP land	Pasture land
	SOIL LOSS (TONS PER ACRE)			
1982	4.4	0.7	-	1.1
1987	4.0	0.7	2.0	1.0
1992	3.5	0.6	0.6	1.0
1997	3.1	0.7	0.4	0.9

USDA National Resources Inventory, 1997

Although conservation practices have brought about improvement, the average soil erosion rate on U.S. cropland is still 3.1 tons/acre (Table 1). The erosion rate is often greater than the soil formation rate. As an example, **the average soil erosion rate in Pennsylvania was 5.1 tons/acre in 1997, whereas the tolerable soil loss level is 3-4 tons /acre per year for most of the soils of this state.** With the average loss of 5.1 tons/acre, you can see that the tolerable soil loss level was far exceeded on many fields. That means that our current rate of erosion is a threat to the future productivity of the soil.

Soil erosion removes the best portion of the soil—the part that contains most of the plant nutrients and soil organic matter. In many cases, the topsoil has more favorable soil texture for crop growth than the subsoil. When the topsoil is gone, the farmer is left with less productive subsoil. In addition, eroded soil becomes an environmental threat; polluting streams, lakes, and estuaries. In Pennsylvania, sediment is still the number one pollutant of streams and other bodies of water.

TILLAGE, MAJOR CAUSE OF EROSION

The process of planting, growing and harvesting brings about a certain amount of expected erosion that is considered acceptable to bring a crop to the table. The tolerable soil loss level is called "T" by soil conservationists. The major soil management practice that causes soil erosion is tillage, the process of preparing a field for seeding. Erosion due to tillage can be kept in check through methods such as contour farming, contour stripcropping, conservation buffers, grassed waterways, terraces and diversions to meet soil loss tolerance levels.

You will find that soil can still move within a field—for example, in a strip cropping system where sediment from unprotected soil is trapped by a down-slope strip with high residue or permanent cover. In fact, average soil loss on this entire field or system may be at, or below T, where it exceeds T on the tilled strips. But, if soil can be kept covered, erosion can be stopped before it starts and T can be met on the entire field every year.

The way to dramatically reduce soil erosion is the **no-till systems approach. This method keeps the soil covered with crop residue, reduces soil disturbance to almost zero, and attempts to maximize the number of days in the year when living roots grow in the soil.**

FIGURE 3. Soil tillage is the major cause of soil erosion.

Farmers and researchers have demonstrated that there are many other benefits to the no-till system besides soil savings. For example, a farmer can save significant amounts of time not working the fields prior to planting. That can result in more timely planting as well as increased acreage that can be managed with the same equipment and labor force. The efficiency of field operations will also increase because the farmer can often meet soil conservation requirements in a no-till system without adding as many conservation practices. Finally, the costs of producing a crop are decreased by excluding tillage machinery expenses.

Soil will improve over time in a no-till system through increased organic matter. Soil structure and water infiltration will improve in a no-till system through the slow, but continuous decomposition of crop residue and roots and the high activity of living organisms creating a permanent macro-pore system in the soil. Due to this high biological activity in no-till, soil compaction can be minimized. Finally, there are other environmental benefits of a no-till system that extend beyond the farm—cleaner air and streams and increased groundwater recharge.

THE USE OF CONSERVATION TILLAGE IN THE U.S.

In the 1970s, many researchers believed that by the year 2000, most cropland in the United States would be farmed without tillage. That prediction has not come true, although there

FIGURE 4. Ten Benefits of a No-Till Systems Approach

- Erosion control
- Higher infiltration
- Lower evaporation
- Organic matter conservation
- Improved soil structure
- Higher biological activity
- More earthworms
- Reduced total phosphorus losses
- Lower labor needs per acre
- Higher efficiency of farm operations

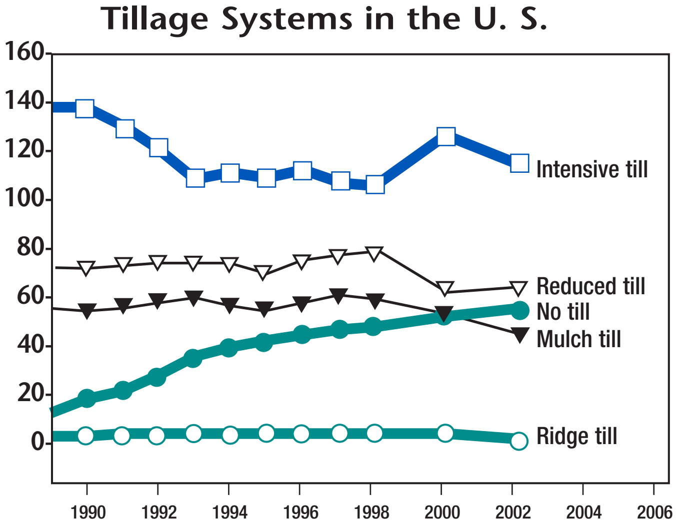

FIGURE 5. No-till is used on a growing amount of acreage in the U.S.

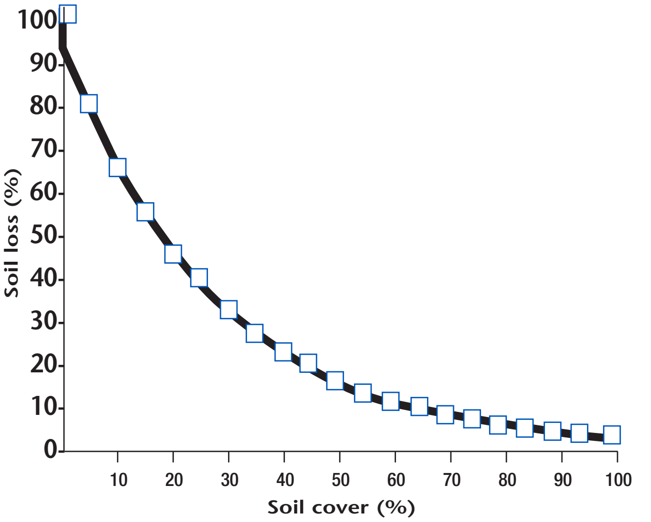

FIGURE 6. Residue cover – relative soil loss relationship. With 30% residue cover, soil loss is reduced 70%.

FIGURE 7. No-till leaves crop residue at the soil surface and reduces soil erosion dramatically.

has been a steady increase in the acreage of no-till (Figure 5). The Conservation Technology Information Center summarizes data collected by USDA-NRCS, Conservation Districts and Cooperative Extension.

Two broad categories of tillage systems are recognized: conservation tillage, which includes all tillage systems that leave more than 30% crop residue cover after planting; and conventional tillage, which leaves less than 30% crop residue cover after planting. **A 30% residue cover limit has been set because significant soil erosion reduction is achieved only when more than this amount is present (Figure 6).**

Conservation tillage includes no-till, mulch-till, and ridge-till. No-till is defined for the survey as conservation tillage acreage where no tillage is done from harvest to planting. It may include very limited in-season tillage for weed control. No-till includes in-row tillage systems such as zone- and strip-till that disturb less than 30% of the soil surface. In 2002, almost 20% of planted acres in the U.S. were no-tilled. Mulch-till includes all other tillage systems which leave more than 30% crop residue cover on the soil surface at planting. It was practiced on 16% of planted acres in 2002. Ridge-till was practiced on 1%. This brings the total percentage of conservation tillage to 36%. Reduced tillage leaves 15-30% residue after planting and was practiced on 23% of planted acres, while intensive tillage (<15% residue cover after planting) represented 41% of planted acres in 2002. Conventional tillage is still practiced on 63% of U.S. cropland.

These statistics hide many important details about changes in tillage systems in the U.S. For instance, across the U.S., more and more farmers use the chisel or disk plow for primary tillage instead of the moldboard plow. However, because they often leave less than 15% crop residue cover after planting, their tillage is still considered intensive because residue cover is the primary determinant of soil erosion. On the other hand, **the use of a continuous no-till system seems to be limited** to a fraction of the no-till acres. Instead, the rotation of no-till with tillage is more common. In the Midwest, many farmers plant soybeans without tillage but corn with tillage in their corn-soybean rotation. There is increasing recognition that many soil quality benefits are linked to the continuous use of a no-till system.

SOIL EROSION

WHEN TO BE READY

Soil erosion depends on many factors: the erosivity of rainfall (mostly related to the intensity and duration of rainstorms), the erodibility of soils, the length and steepness of slopes, and management practices. Although average annual soil loss rates are used for the design of conservation practices, it is important to remember that most erosion is caused by infrequent, heavy rainstorms. Long-term erosion data is available from a few places to verify this.

One site is the USDA-North Appalachian Experimental Watershed in Coshocton, Ohio. This station, established during the Great Depression to develop better farming methods for sloping land, provides a wealth of historical soil erosion data. Observations from 7 watersheds on the station showed that in a 25-year period, most erosion was caused by only 5 rain storms out of a total of almost 4,000. In fact, 75% of the soil erosion was caused by 0.1% of the total number of rainstorms.

To minimize soil erosion, it is necessary to be ready for the big, rare rainfall event at all times. Because of that, we **recommend maximum erosion protection at all times.** It is not

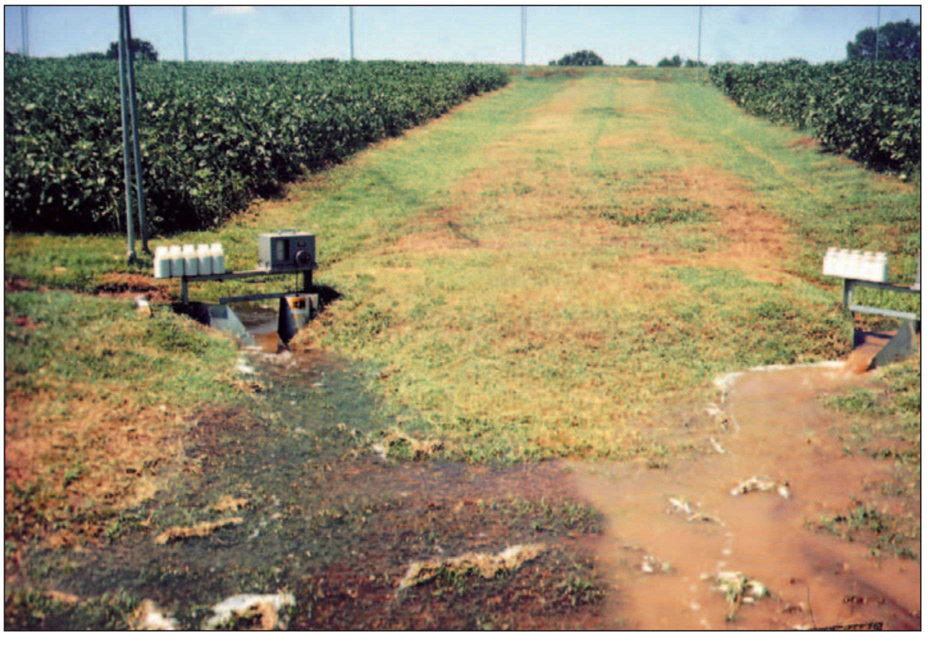

FIGURE 8. Runoff from no-till field on the left and conventional tilled field on the right from plots at Milan Experimental Station, Milan, Tennessee. The clear water from the no-till side of the field is transporting significantly less topsoil, nutrients, and pesticides.

enough to have erosion protection 95% of the time because the rainstorm that causes massive erosion might just occur in that 5% time window that the soil is not protected.

TYPES OF EROSION

There are four different kinds of erosion: sheet, rill, gully and streambank erosion. Only the first three occur on farmland. Sheet erosion is the washing of a uniform sheet of soil from the soil surface. Rill erosion occurs when small parallel rivulets start to form in the field. When these rivulets begin to concentrate, they form gullies. Most soil is lost due to sheet and rill erosion, although these are the least visible forms of soil erosion.

Sheet erosion represents the beginning of the erosion process. If sheet erosion can be stopped, the soil erosion problem is 'nipped in the bud.' Sheet erosion is primarily caused by the effect of raindrops hitting the soil surface. If soil is protected against raindrop impact by crop residue, little sheet erosion takes place. **Therefore, the key to erosion control is to keep the soil covered.**

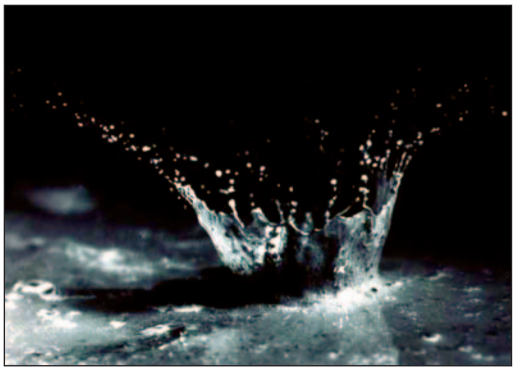

FIGURE 9. The impact of large raindrops is the major cause of sheet erosion.

It is important to remember that not all rainstorms are equally erosive. Gentle, drizzling rains cause very little erosion in contrast to heavy rainstorms. Raindrops from gentle storms are smaller and fall more slowly than raindrops from heavy storms. The energy of the raindrops is a function of their velocity and their mass, in other words, their speed and size. The kinetic energy of large raindrops is much greater that that of small drops. When those large drops hit the soil surface, they act as small bombs that dislodge soil particles from the soil matrix. **Convective rainstorms (heavy thunderstorms) are frequent in spring or summer in the U.S. These storms are the most erosive so soil cover is especially important during these periods of the year.**

Figure 10. The purpose of conservation tillage is to keep crop residue at the soil surface.

Once soil is dislodged from its matrix, it can be easily carried away. With shallow runoff, raindrops act as stirring rods that keep the eroded soil in suspension. This makes it possible for a shallow flow to transport soil that would normally settle out. More runoff occurs on bare soils than covered soils because small, dislodged soil particles settle out and form a seal that subsequently dries to become a crust. Infiltration or absorption decreases rapidly once a seal or crust is formed.

If the velocity and size of the raindrops can be reduced, sheet erosion will be minimal. This was most vividly illustrated in an experiment with two types of plots—both were cultivated and bare, but one had mosquito gauze placed above it to break up the rain drops and reduce their velocity. When a heavy rain storm hit the two plots, the erosion on the plot with the gauze was 1/100 of the other plot. Again, keeping soil covered is the secret of soil conservation. The purpose of a no-till system is to keep soil covered.

DOES IT REALLY WORK?

How do these principles work in practice? At the North Appalachian Experimental Watershed, one watershed (9% slope) was in long-term no-till corn, where another watershed (6% slope) was moldboard plowed every year prior to corn planting. Because only the grain was harvested and all crop residue was left in the field, virtually 100% of the soil of the no-till watershed was covered all the time.

The most critical period for soil protection in the Northeastern United States is from April-July when most rain falls in high-intensity thunderstorms. When crops are planted using tillage, residue levels are low and therefore susceptible to erosion, as compared to no-till planted crops where residues are present to protect the soil.

FIGURE 11. Chisel plowing is between moldboard plowing and no-till. It does less soil inversion and leaves more residue cover than the moldboard.

During a 4-year period, the annual erosion rate from the no-till watershed was only 6 lbs/A, while it was 4750 lbs/A from the conventionally-tilled watershed. **The erosion from the conventionally tilled watershed was almost 700 times greater than that from the no-till watershed!** This shows the power of maximum-residue no-till.

In a follow-up study, chisel-plowing was compared with no-till in a corn-soybean rotation. Annual soil loss in the chisel plowed watersheds was a small–1100 lbs/A; but it was twice as much as that in the no-till watershed (500 lbs/A). **Chisel plowing is an intermediate practice for soil erosion control between moldboard plowing and no-till,** primarily because soil cover is considerably reduced with chisel plowing.

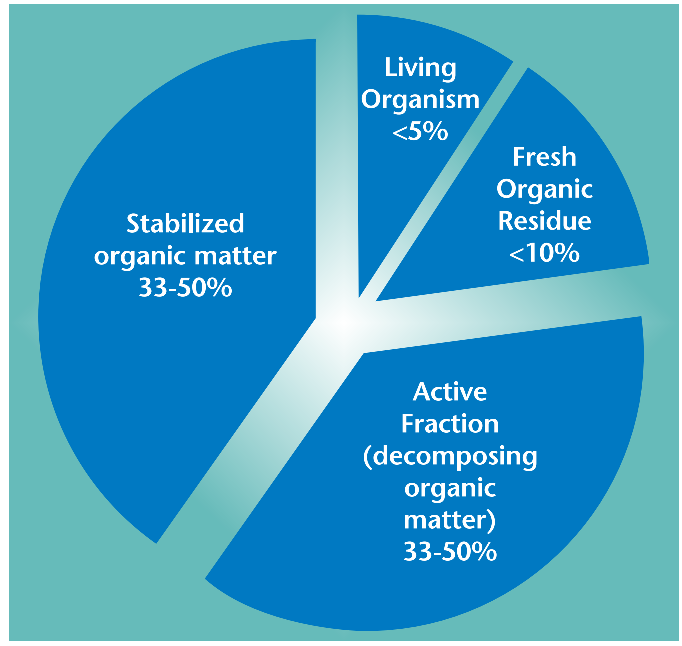

FIGURE 12. Different fractions of organic matter are: living organisms, fresh organic residue, and active and stabilized organic matter. Tillage causes young organic matter to oxidize more quickly leading to a decrease in organic matter content.

SOIL QUALITY
TILLAGE EFFECTS

The most important factor in determining soil quality is soil organic matter. The organic matter consists of living organisms, fresh organic residue, decomposing organic matter, and stabilized organic matter (Figure 12). Carbon makes up about 60% of total soil organic matter content. When the soil is opened up by tillage, large amounts of carbon dioxide are released in a matter of days (Figure 13). This results in reduced organic matter contents and explains why it is very difficult to build up organic matter contents with tillage.

Inversion tillage with the moldboard plow results in the greatest carbon dioxide losses. The deeper the depth of inversion tillage and the greater the volume of soil disturbed, the greater the losses of carbon dioxide. Long-term cropping studies have shown a steady decline in soil organic matter with conventional tillage. Lower losses have been recorded with non-inversion tillage such as chisel plowing. Because tilling a no-till field once can release much of the organic matter that has been previously preserved, **it is important to use no-till continuously within a no-till system.**

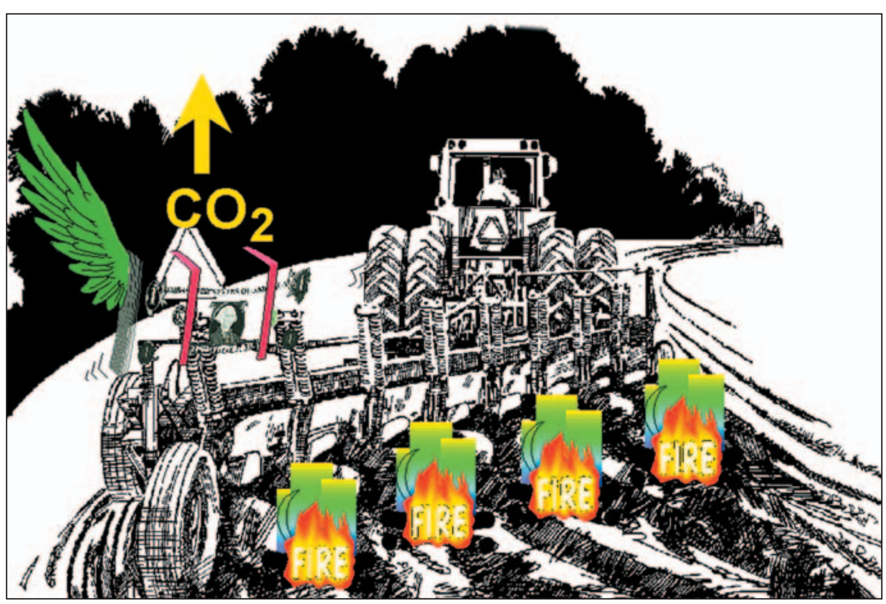

FIGURE 13. Intensive tillage results in the oxidation of organic matter and the release of massive quantities of carbon dioxide. This is like losing money out of your savings account of organic matter.

In a Minnesota study, five times more carbon was lost shortly after moldboard plowing than without tillage. The carbon lost in 19 days after plowing was more than what was present in the roots and straw of the preceding wheat crop. In a review of 20 long-term studies with moldboard plowing, the average loss of organic matter was 256 lbs/acre/yr. These studies were conducted with continuous corn or wheat and rotations of corn with soybeans and oats in Illinois, Oregon, and Missouri.

However, in 10 long-term no-till studies conducted in Ohio, Alabama, Georgia, Kentucky, Illinois, Minnesota and Nebraska, organic matter increased an average 953 lbs/acre/yr. These studies were with continuous corn or soybeans, and corn-soybean rotations. A summary of results with continuous corn or corn-soybean rotations from 4 Midwestern states (Figure 14) shows that approximately 400 lbs/acre/yr were lost with moldboard plowing, 200 lbs/acre/yr were gained with chisel plowing, and more than 1000 lbs/acre/yr were gained with continuous no-till.

WHERE YOU LIVE MATTERS

The potential for increases in soil organic matter is greater in the northern states than in the southern states. This is due to higher temperatures in the south, leading to the higher decomposition of organic matter which increases losses. In dry climates, the potential for organic matter build-up is also smaller because the crops grown produce little residue.

The amount of residue varies per crop. Corn and wheat, for example, return more residue to the soil than soybeans. This means the potential for increases in organic matter is greater with corn and wheat than with soybeans.

In a long-term study, the soil organic matter content was greatest with corn-wheat rotations, smaller with corn-wheat-soybeans-wheat, and smallest with soybeans-wheat.

COVER CROPS ARE IMPORTANT

Growing cover crops can increase organic matter beyond what is possible by simply leaving crop residue in the field. The potential and need for cover crops to build organic matter in the soil is greatest in the southern parts of the United States. Because of higher temperatures, organic matter oxidation is greater in the South. However, cover crop options as well as cover crop biomass production are also greater.

Pioneer research from the southeastern United States is showing the benefits of having actively growing crops in the field 365 days a year. The increased losses of organic matter from heat can be compensated for by combining cover crops and intensive cropping to produce increased residue. In colder regions, options are reduced due to freezing temperatures during part of the year, but there is work taking place to increase opportunities to maximize the time that crops or cover crops grow in the field.

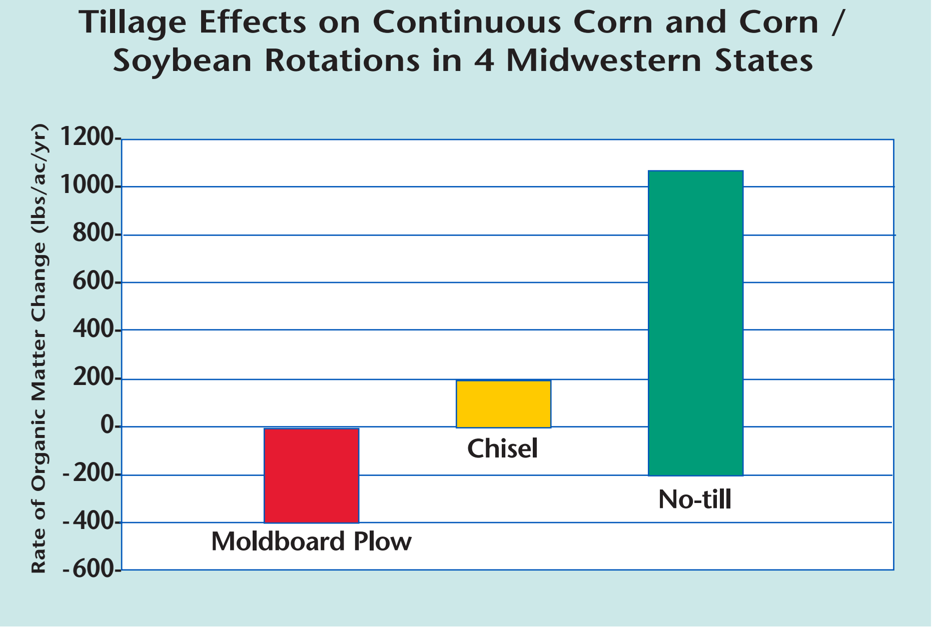

FIGURE 14. Tillage system effects on soil organic matter change recorded throughout long-term studies in 4 Midwestern States.

Nitrogen fertilization to provide optimal plant growth can also increase the rate of organic matter formation. The primary reason for this is the increased root and above-ground biomass production.

Besides increasing total soil organic matter content, no-till results in a different distribution of organic matter (Figure 16). Most organic matter is concentrated at the surface of the soil in no-till where it is mixed in the plow layer with tillage. The residue protects the soil from erosion, surface sealing and crusting. The increased surface organic matter content helps improve soil tilth and aggregate stability. In a conventional tillage situation, the reverse happens and a lack of residue cover exposes the soil to the elements. The result is sealing, crusting, and erosion. No-till has also been found to affect the stability of organic matter pools. The residence time of organic matter in no-till can increase by 10-15 years over conventional tillage.

SOIL STRUCTURE IMPROVEMENT

Over time, soil structure, also referred to as "soil tilth," will improve with no-till. One reason for this is the increased presence of fungal communities in no-till soils when compared with tilled soils (Figure 17). Tilled soils have more bacteria instead of fungi. Fungi form hair-like structures called "hyphae" which act like a net holding small aggregates together in larger units. Another reason for increased aggregation in no-till is the presence of old, partly decomposed roots from the previous

FIGURE 15. A cover crop can serve a multitude of functions, such as erosion protection, nitrogen fixation, additions of crop residue to build soil organic matter contents, and weed control.

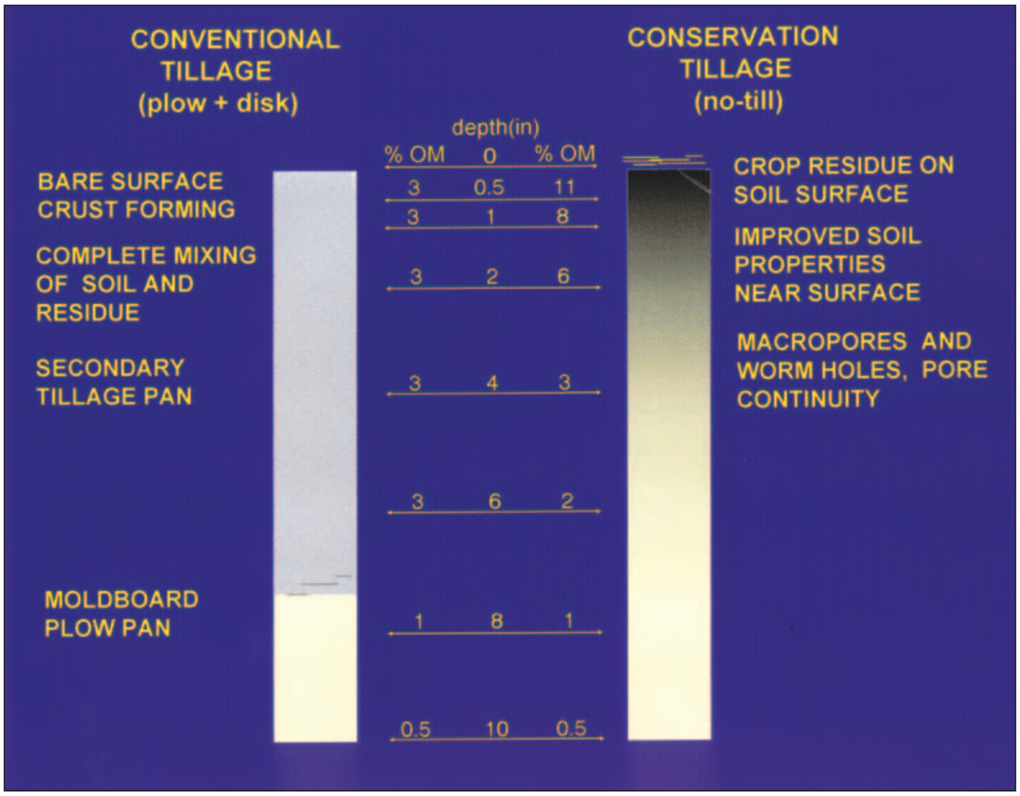

FIGURE 16. Soil organic matter will be concentrated near the surface of no-till soil where it is distributed throughout the plowed layer in moldboard plowed soil.

the appropriate depth for soil fertility sampling. If soil fertility recommendations in your state are based on a sampling depth of 6 inches, it is important to use that sampling depth. With the increased popularity of continuous no-till, future recommendations may be based on shallower sampling depths. It is important to use the same method of determination to track changes in organic matter over a period of time. Methods vary so check which method is used by your lab and stick with that method to track change.

crops. Finally, the increased organic matter in no-till helps improve soil structure. Stable aggregates in no-till soil resist the sealing of soil surfaces which can cause crusting and water runoff.

Increased aggregation in no-till helps to increase water infiltration and the resistance of the soil to erosion. (Infiltration is the movement of water into and through the soil, feeding plant roots and working its way into groundwater systems.) Additionally, the aggregates enhance conditions for a desirable mix of air and water for good plant growth. They hold more water in place for crops to use.

CHECKING YOUR SOIL CONDITIONS

If you are interested in changes in total organic matter contents, it is important to sample to the same depth over a period of time. Follow state recommendations for

Soil organic matter content as determined by a lab is on a weight basis (For example, per cent or grams of organic matter per kilogram of soil). It may be more appropriate to compare soil organic matter content on a per acre basis. **To calculate soil organic matter content per acre, you need to know the bulk density of the soil or the weight of soil per unit volume.** Bulk density is usually expressed as metric tons per cubic meter. This becomes important when determining

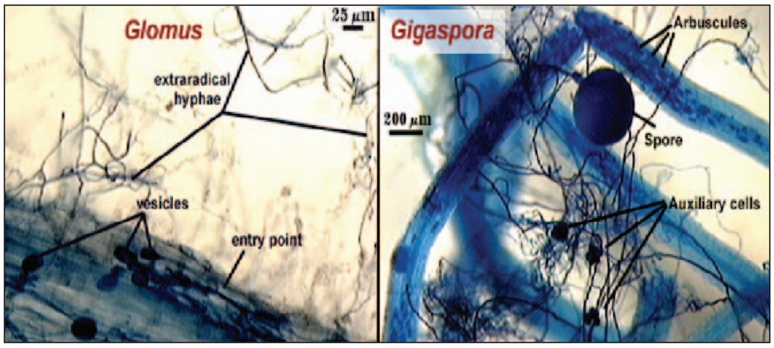

FIGURE 17. Residue is food for fungi and bacteria. The fungal hyphae and fine roots surround and stabilize soil aggregates. These aggregates don't easily fall apart with the action of rain or wind.

the effect of tillage systems on organic matter contents.

The bulk density of no-till soil is sometimes greater than that of conventionally tilled soil. In those cases, differences in organic matter content between the two systems are greater on a per-acre basis than on a weight basis. Much depends on the time of the sampling and the amount of time a soil has been in no-till. Shortly after tillage, a tilled soil is usually fluffy and has a lower bulk density than its no-till counterpart. However, at the end of the season, the difference in bulk density may be negligible because the tilled soil has settled. Increased organic matter contents in no-till may further reduce bulk density.

TABLE 2. A 4-year comparison of runoff and erosion on a no-till and moldboard plowed watershed at the North Appalachian Experimental Watershed.

YEAR	RAINFALL (inches)	RUNOFF (inches)		EROSION Lbs / A	
		NO-TILL	MOLDBOARD	NO-TILL	MOLDBOARD
1979	44	0.14	5.52	8	436
1980	46	0.19	12.47	15	8455
1981	42	0.00	5.60	1	7645
1982	35	0.00	4.46	0	2461
Average		**0.09**	**7.01**	**6**	**4748**

WATER IN THE SOIL

Many long-term no-till farmers have noted improvements in water infiltration or absorption in their fields. There are times during the same storm when no runoff occurs in no-till fields while adjacent tilled fields produce large amounts of water and sediment runoff. Similar observations have been made by researchers. At the North Appalachian Experimental Watershed, runoff from the no-till watershed was only a fraction of that of the moldboard plowed watershed (Table 2). Here we see the power of residue cover illustrated again. By breaking the impact of falling raindrops, soil sealing and crusting is reduced dramatically. Improved surface tilth also stimulates infiltration. **The channels created by soil organisms such as worms, soil insects and the decomposed plant roots that are found in the continuous no-till system increase water infiltration.** The residues on the soil surface act as small barriers, slowing runoff and giving water a greater opportunity to infiltrate.

FIGURE 18. Soil organic matter is conserved by using no-till, which results in better soil structure.

THE ROLE OF EARTHWORMS

Burrows of earthworms and soil insects have been discovered to be important in improving water infiltration. One earthworm species are nightcrawlers *(Lumbricus terrestris L)*. They are surface feeders and construct vertical burrows. **In one study, up to 10.3% of simulated rainfall infiltrated through these burrows although they only occupied 0.3% of the horizontal area of the no-till field.** Tillage not only destroys the tops of the burrows, but more importantly destroys the habitat of the nightcrawlers. These earthworms need surface residue that they pull to the mouth of their burrow. If a soil is devoid of crop residue, nightcrawlers will be scarce or absent.

There are other earthworms that live in the surface of the soil. These earthworms are not as sensitive to tillage. They fill their burrows with casts as they go. These earthworms also have a positive influence on soil structure, which helps infiltration. In a study in Indiana, the number of earthworms (nightcrawlers and other species combined) was twice as high in continuous no-till fields as in moldboard plowed fields. In Missouri, up to 8 times more earthworms were counted in continuous no-till corn than in moldboard plowed corn.

FIGURE 19. Nightcrawlers live in vertical burrows that can extend 4-6 feet deep. Water can quickly infiltrate through these burrows. Nightcrawler excrements are called casts. Deposited at the soil surface, casts contain high contents of organic matter and nutrients. They form stable aggregates when dry.

CONTRADICTORY RESULTS

In some cases, tillage temporarily increases infiltration compared to no-till. Several explanations can be offered.

- Shortly after tillage, infiltration can be high because of increased surface roughness and high porosity. This increase is usually short lived. After heavy rainstorms hit the soil, surface clods start to break down, roughness decreases, and because of sealing and crusting, infiltration decreases. Despite the fact that total porosity may be lower in continuous no-till, infiltration may still be higher because of pore continuity, soil protection against the action of raindrops, better surface tilth, and surface residue that obstructs runoff. However, if a farmer causes compaction in no-till, infiltration can be negatively affected. Judicious use of "vertical tillage" may be justified in these conditions. Vertical tillage disturbs below the soil surface without a reduction of surface residue cover. The use of vertical tillage is recommended to maintain the benefits of maximum residue cover.
- Another reason infiltration is not always higher in no-till versus full tillage may be due to the methodology used in some research studies. In one review of 45 different studies, runoff with no-till was on average reduced only 14% compared with conventional tillage. In some studies, runoff was greatly reduced due to no-till, but in other studies, there was no reduction or even increased runoff with no-till. Many of these studies were rainfall simulation studies. In these studies, it is typical to prepare a site (preferably without a growing crop) and simulate a very heavy rainfall event for half an hour to an hour. The methodology often dictates that the rainfall is applied shortly after tillage when infiltration may still be

FIGURE 20. This table top rainfall simulator shows the dramatic differences in quantity and quality of runoff associated with high residue farming versus clean tillage. All trays received the same amount of simulated rainfall.

high. Little time is available for surface roughness to disappear as happens in a field situation.

In the field, runoff usually increases with time in tilled fields and decreases with time in no-till fields. Another peculiarity of these simulation studies is that the fields may not be in no-till for a long period of time. There has not been time for the macro-pore system to develop, or for surface soil tilth to improve. It is more realistic, therefore, to determine the effects of continuous no-till on infiltration in long-term field studies subject to natural rainfall where runoff is measured continuously.

Even if the infiltration of natural rainfall is measured over the full growing season in continuous no-till, there may be no measured improvement of infiltration. Two factors may help to explain the disparity: soil type and time in no-till. If soils have restrictive subsurface layers or are poorly drained, increased crop residue and organic matter at the surface cannot overcome a profile that is already full of water or has a restricted ability to transmit water to lower layers. These soils are not a good habitat for nightcrawlers and other earthworms, and will not benefit as much from

TABLE 3. Hydrologic soil group characteristics.

SOIL GROUP	SOIL GROUP CHARACTERISTICS
A	Soils having high infiltration rates, even when thoroughly wetted and consisting chiefly of deep, well to excessively-drained sands or gravels. These soils have a high rate of water transmission.
B	Soils having moderate infiltration rates when thoroughly wetted and consisting chiefly of moderately deep to deep, moderately fine to moderately coarse textures. These soils have a moderate rate of water transmission.
C	Soils having slow infiltration rates when thoroughly wetted and consisting chiefly of soils with a layer that impedes downward movement of water, or soils with moderately fine to fine texture. These soils have a slow rate of water transmission.
D	Soils having very slow infiltration rates when thoroughly wetted and consisting chiefly of clay soils with a high swelling potential, soils with a permanent high water table, soils with a claypan or clay layer at or near the surface, and shallow soils over nearly impervious material. These soils have a very slow rate of water transmission.

TABLE 4. Summary of natural rainfall studies comparing water runoff with continuous no-till to conventional tillage (usually moldboard plow).

HYDROLOGIC SOIL GROUP	AVERAGE WATER RUNOFF IN NO-TILL AS % OF CONVENTIONAL TILL	CROPS	AVERAGE # YEARS IN NO-TILL	STATES
B	56%	Corn, soybean, cotton, rye, tobacco	5	IA, KY, MO, MD, NC, AL
C	67%	Corn, soybean, sorghum, cotton, tobacco, rye	6	OH, MS, NC
D	101%	Corn, soybean,	4	MO, MS, MD

their activity. **Soil hydrologic categorization is one way of grouping soils with respect to their potential to result in reduced runoff with no-till.** Hydrologic groups are mostly determined by soil texture and restrictive layers in the soil that slow water movement in the soil (Table 3).

Table 4 is a summary of runoff measured in various studies with natural rainfall. The studies have been grouped according to hydrologic soil group and the average number of years in no-till as indicated. The salient result of these studies is that runoff was dramatically reduced in continuous no-till fields on Group B and C but not on Group D soils. **It must be concluded that the runoff-reducing benefits of no-till will be greatest on coarse to medium textured soils that do not have an impeding layer or water table near the surface.**

Even on soils that have a moderate to fine texture or an impeding layer, no-till can still offer substantial runoff reduction as long as they are not too heavy and the impeding layer is not too close to the soil surface. Soils that are fine-textured have heavy swell/shrink clay or a restricted layer near the surface are not likely to show reduced runoff with no-till. It is interesting to note that the coarse to moderately textured soils also respond favorably to no-till crop production.

Clay soils are the most challenging for no-till. No-till crop yields are customarily higher or equal to those achieved with conventional tillage on Group A, B and C soils, but are often reduced on Group D soils. It may be necessary to make modifications to no-till equipment to improve crop yields and infiltration on Group D soils. Examples are in-row tillage techniques such as strip or zone-tillage that leave full residue cover between rows. Artificial drainage will also help to make these soils more suitable for no-till crop production. Crop rotation also becomes more important on these more challenging no-till soils.

When a farmer changes from plowing to no-tillage, the soil (and the farmer!) needs to adapt to the new management system. Organic matter content slowly increases and biological activity creates a new soil macro-pore system. This period may be associated with reduced yields in no-till until a new ecological equilibrium is achieved in the soil. There are some ways to get around this transition period.

If no-till annual crop production can be started immediately following a perennial grass or legume crop, the transition period can be reduced or eliminated. The perennial crop gives soil organisms the chance to develop a macro-pore system and improve soil tilth without tillage and with residue cover. The **extensive root systems and high root turnover of grasses will stimulate porosity and aggregate stability.** Taproots of some perennial legumes such as alfalfa will, upon death and decomposition, leave large vertical channels that help improve infiltration.

The benefits of starting no-till in a sod were illustrated in one study. Corn was established into sod with and without tillage. Water runoff occurred on the tilled plots when less than 1.5 inches of water was applied while no runoff occurred on the no-till plots even when 5.3 inches of water was applied. In another study in Kentucky, runoff was reduced 83% when planting no-till into a bluegrass sod as compared to conventional tillage, despite the fact that 5.2 inches of rain fell after tillage when infiltration is highest.

PESTICIDE EFFECTS ON WATER QUALITY

Reduced runoff with long-term, continuous no-till has many environmental advantages. However, some may comment that no-till is likely to pollute the natural environment due to a heavy reliance on chemical pesticides and a fear that those pesticides will end up in our surface and groundwater.

A decade ago, a review of the impact of conservation tillage (no-till, ridge till or mulch till) on pesticide runoff into surface water appeared in the Journal of Soil and Water Conservation. In the article, it was first concluded that total pesticide use in conservation tillage has not appreciably increased when compared with conventional tillage. Many people forget that even with conventional tillage, most farmers use herbicides for weed control and some insecticides and fungicides for insect and disease control. With the use of crop rotation, pesticide use in conventional tillage as well as no-till can be significantly reduced. **Crop rotation is an essential component of sustainable no-till systems.**

In no-till systems, a farmer will have to use a burndown herbicide application to eradicate any weeds or cover crops that are present at planting. After that, there is no need for different amounts of herbicide applied in no-tillage versus conventional tillage, although the types of herbicides may be different. Common burndown herbicides such as paraquat and glyphosate bind very tightly to soil particles and are mainly lost from fields associated with sediment.

Because erosion is dramatically reduced in no-till, and these herbicides are very quickly broken down by soil organisms into harmless compounds, the threat of surface water contamination is very small. What is more important, however, is that runoff is significantly reduced in no-till compared to conventional tillage. Because of this, the likelihood of the pesticides ending up in surface water is small (even those that do not bind to soil particles and are easily dissolved in runoff).

In a review of a large number of natural rainfall studies, the average herbicide loss in runoff from no-till and chisel plowed fields was 30% of that in moldboard plowed fields. The greatest threat of surface-applied herbicides leaving the field in runoff was if heavy rainfall occurred very soon after herbicide application. It should be noted that sometimes the concentration of herbicide in runoff was higher in no-till than conventional tillage, but because the total volume of runoff was small, total losses were significantly less with no-till. **In summary, it is justified to expect lower pesticide losses from no-till fields than from conventionally tilled fields because of smaller runoff and reduced erosion rates.**

SOIL COMPACTION

Some say soil compaction in no-till is less; some say it is more than with tillage. What to believe? It is first of all important to note that most soil compaction research has been done with conventional tillage, not with no-till. We know far less about soil compaction in no-till than in tillage systems. With increased adoption of no-till, however, more research is being initiated.

COMPACTION IS DIFFERENT IN NO-TILL

Compaction is caused by the movement or traffic of vehicles, livestock or humans over the surface of the soil. There are a few factors that change the effects of traffic in no-till fields compared to tilled fields. Over time, organic matter content in the surface soil increases with no-till. Soils with high organic matter content cannot be compressed as easily as those with low organic matter content. This means that compaction in the top 2 inches is not of great concern in long-term no-till. In addition, a firm no-till soil matrix with macropores for air and water movement can better support traffic without being compressed than a soft, tilled soil.

The higher biological activity in no-till soils also helps alleviate the effects of compaction. However, the soil under crop residue often stays wet longer than in clean tilled conditions. This makes it more likely the farmer will be in the field when soil conditions are really too wet for traffic in no-till.

In addition, no quick alleviation of compaction with tillage equipment takes place in no-till. Overall, research is suggesting that soil compaction can be a significant threat in no-till systems. In one study, extreme soil compaction of the complete soil surface to a depth of 12 inches reduced crop yields 98% compared to non-compacted long-term no-till fields. It was interesting that the following year, the yield in the compacted fields increased to 85% of that in the non-compacted plots. The recovery from soil compaction (without tillage) was attributed to high biological activity.

In another study, soil compaction due to heavy axle loads caused a 15-30% reduction in yield in a long-term no-till field. Soil compaction can increase soil density, and

FIGURE 21. Care has to be taken not to compact the soil in no-till. This can be achieved by avoiding traffic at suboptimal soil moisture conditions, using low tire pressure or tracks, and reducing axle load at least below 10 tons. Improving soil organic matter contents and stimulating soil biological activity make soil more resilient to compaction.

reduce porosity and infiltration in no-till soils. In a controlled traffic study in long-term no-till, infiltration was significantly reduced in wheel tracks compared to non-wheel tracks. In the non-trafficked area, the first inch of water took 2 min 15 sec to infiltrate and the second inch took 31 minutes. In a wheel track, the first inch took 7 minutes, whereas the second inch took more than 3 hours. This illustrates that soil compaction can significantly compromise soil quality in long-term no-till.

MINIMIZING AND ALLEVIATING COMPACTION IN NO-TILL

Farmers have some options to manage soil compaction in no-till. The very first principle is that soil compaction does not pose a significant threat if a farmer limits his traffic to dry soil conditions. It is only because field operations cannot always be tailored to soil moisture conditions that soil compaction becomes a threat. To limit soil compaction a farmer should limit his axle load to 10 tons (preferably 6 tons), and use flotation tires or tracks instead of road tires.

Another, even better solution is to use traffic lanes. By keeping all wheel traffic limited to permanent tracks, the areas between tracks will never be affected. If wide wheel spacing can be used, a limited area of the field will be impacted by traffic. The disadvantage of such an approach is that all heavy equipment has to be re-engineered to be on the same wheel spacing.

Research into using cover crops to alleviate soil compaction has not resulted in widely accepted solutions, although there are indications that cover crops with vigorous root systems or tap roots help loosen compacted soil.

A compromise of the no-till system may be to use vertical, in-row tillage techniques. There are different equipment options to alleviate soil compaction without disturbing surface residue cover. These ‘vertical tillage tools’ are consistent with the no-till system because they maintain surface residue cover. This method combines the benefits of mulch cover between rows with the compaction alleviation of tillage equipment in the row.

FIGURE 22. Manure injection limits ammonia losses and odor from liquid manure in no-till.

MANURE IN NO-TILL

PROS AND CONS OF MANURE IN NO-TILL

Many successful long-term no-tillers use surface-applied poultry and animal manure. Surface-applied manure serves:

1. as food for soil microbes, earthworms and night crawlers.
2. to enhance supplement surface residue, especially when solid manure and/or bedded pack manure is used.
3. as a source for soil organic matter.
4. to reduce the transition period for those just beginning no-till systems.

It should also be noted that surface application of manure reduces equipment costs for manure incorporation and saves time.

A disadvantage of the surface application of manure is the nitrogen loss due to ammonia volatilization that is likely to be higher compared to immediate incorporation into the soil.

It should be noted that when surface applied manure receives 0.5 inches rainfall or more, ammonia volatilization losses are the same as if manure had been incorporated. Early in the spring of the year when temperatures are generally cooler, the chances of rainfall occurring to reduce nitrogen losses is greater. Also, with cooler soil temperatures, nitrogen lost on a daily basis is reduced so rainfall several days after application will save more nitrogen than if manure is applied when temperatures are higher.

USE OF COVER CROPS

The use of cover crops becomes a very important consideration in the application of manure in terms of the uptake of nutrients, reduced runoff and increased infiltration and, in general, a reduction in soil erosion. Cover crops are essential to conserve nitrogen from fall-applied manure. The cover crop should be established using no till equipment, by airplane or helicopter, or by lightly incorporating during the process of manure handling as described earlier in this section.

EQUIPMENT BEING STUDIED

Research is currently underway to evaluate the use of minimal disturbance equipment such as rotary harrows, spiked rollers, and manure injectors to improve infiltration of liquid manure and to mix solid, semi solid or slurry manure with the upper several inches of the soil or place the manure under the soil surface. In all these instances, the key is to cause minimal impacts to the integrity of the soil in a no till system, which includes using no additional tillage equipment and retaining a high percentage of the surface residue which exists prior to the application of manure.

CONCLUSION

In a no-till systems approach, a producer aims to keep soil covered with crop residue, reduce soil disturbance to zero, and maximize the number of days with living roots in the soil. This system can lead to dramatically reduced erosion, increased soil quality, and improved water quality when compared with conventional tillage. It can help agricultural producers improve the efficiency and profitability of their operation and to improve their environmental stewardship. Society will benefit from the improved water and air quality that result from increased use of no-till systems.

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