UPPER MIDWEST

TILLAGE GUIDE

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A Brief History of Soil Tillage and Tillage Research

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A INTRODUCTION

Knowledge of "what produces a good crop" has been passed down, generation to generation, for centuries. Farmers gained this knowledge the long and hard way… by experience through trial and error. Before we dig in too deep, it is of benefit to ask the question:

Why do we till the soil?

Most farmers, and researchers alike, will answer: *to prepare a good seedbed*. However, this does not answer the question nor does it place any historical perspective. Instead, it only causes us to rephrase the question:

Why do we want a good seedbed?

Coming up with a clean, short answer is not easy. The following sections and chapters will provide information and results from local research on the various modern tillage implements available and how these implements prepare a good seedbed.

For now, addressing a slightly different question is perhaps more convenient and easier:

What happens if we do not prepare a good seedbed?

The historical answer is **Competition**. Since human's first use of "digging sticks" to grow a crop, thousands of years ago, the main objective has been to provide the crop with the best chance to compete against weeds. Disturbing the soil kills the weeds that compete for space, water, sunlight, and nutrients with our seedlings. The disturbed soil also gives the seed a safe place without being eaten by birds and rodents. As the seed sprouts and the plant grows, farmers continue to thin out the competition with cultivation, thus giving the seed the advantage.

Digging sticks used to till the soil.
Photo credit - https://www.nm.blm.gov/features/dinetah/disk_images/clothing_tools/digging_sticks_600.jpg

Over the centuries, farmers have recognized other benefits of tillage than just weed management. These include the drying and warming of soils during the wet, cool spring months, breakdown of the previous crop's residue, removing ruts and compaction, and incorporation of broadcasted manures and fertilizers. The invention of herbicides replaced tillage as the primary tool for removing the weedy competition. Therefore, these other benefits have now become what contemporary tillage implements are based on. In the last 150 years, the advancement of science and technology has moved forward our farming practices at an astounding rate, resulting in the need for up-to-date information for producers to stay informed of their management options.

To gain perspective of the current state of modern tillage technologies and the variety of implement options available, let us start with a brief history of tilling the soil.

B A GLOBAL PERSPECTIVE

In ancient times, the difference between a good and a bad crop determined if families had to rely solely on hunting and gathering to survive the upcoming months. Around the world today, many people still rely on handheld or draft-animal-pulled implements to give them the best chance for maintaining their health and nutrition and even gain some wealth. In other societies with strong economies and appropriate landscapes, farmers rely on tractor-pulled and automated implements to grow crops on thousands of acres each year. Regardless of where they live or how sophisticated their tools, the primary goal of all farmers has been to produce a plentiful crop by giving each plant a competitive advantage.

Digging Sticks and Draft-Animal-Powered Agriculture

The methods and strategies for obtaining a plentiful crop differ from farmer to farmer based on their region, soil, and crop of interest. For instance, a soil preparation strategy called "puddling" is vastly popular across the world for rice farmers. This strategy contradicts any strategy used on corn or soybean field in the Midwestern United States. To puddle the soil, farmers plow and harrow the ground while it is flooded, often with the use of draft animals. The goal of puddling is to destroy soil aggregates so that the ground becomes nearly impervious to water and can be flooded. This is the exact opposite of what is desired for corn and soybean fields in the Midwestern United States. This method would almost certainly cause failed corn and soybean stands. However, rice is a wetland plant and the puddling of soil helps to maintain and conserve water levels. This helps to drown out competing plants and makes it much easier to transplant rice seedlings by hand, giving the rice a competitive advantage.

The Ifugao people in the Philippines have puddled the famous Banaue rice terraces using handheld and then draft-animal-pulled tools for over 2,000 years. The mechanization of rice production in Banaue with large, modern equipment is nearly impossible due to the small size of the terraces and the topography. This is a similar scene across Asia and South America on terraced, steeply sloped landscapes. In other regions, the economy is the primary restriction for agricultural mechanization. However, this is changing for some areas. In Kirinyaga, Kenya, the mechanization of rice production with tractors and combines is on the rise for the Mwea Irrigation Scheme. These efforts and many others around the world are largely made possible through international aid and the generous voluntary contributions of agricultural experts from around the world.


2,000-year-old rice terraces in Banaue, Philippines
Photo credit - Dr. Jill Motschenbacher

Many grain (corn, beans, etc.) and root-crop growers in rural regions of the world rely solely on hoeing the soil by hand using digging sticks. Farmers in the high mountainous regions, such as the Himalayans and Andes, are generally inaccessible for large equipment. Their soils may also be too rocky for tools pulled by draft-animals. Whereas other farmers in sub-regions of Uganda, Sudan, and Ethiopia rely on digging stick and other hand-held tools largely due to severe poverty after years of armed conflict.


Pudding rice soils in Los Banos, Philippines
Photo credit - Dr. Jill Motschenbacher


Tillage using hand tools (digging sticks, hoes, etc.)
Photo credit - Dr. Jill Motschenbacher

Mechanization

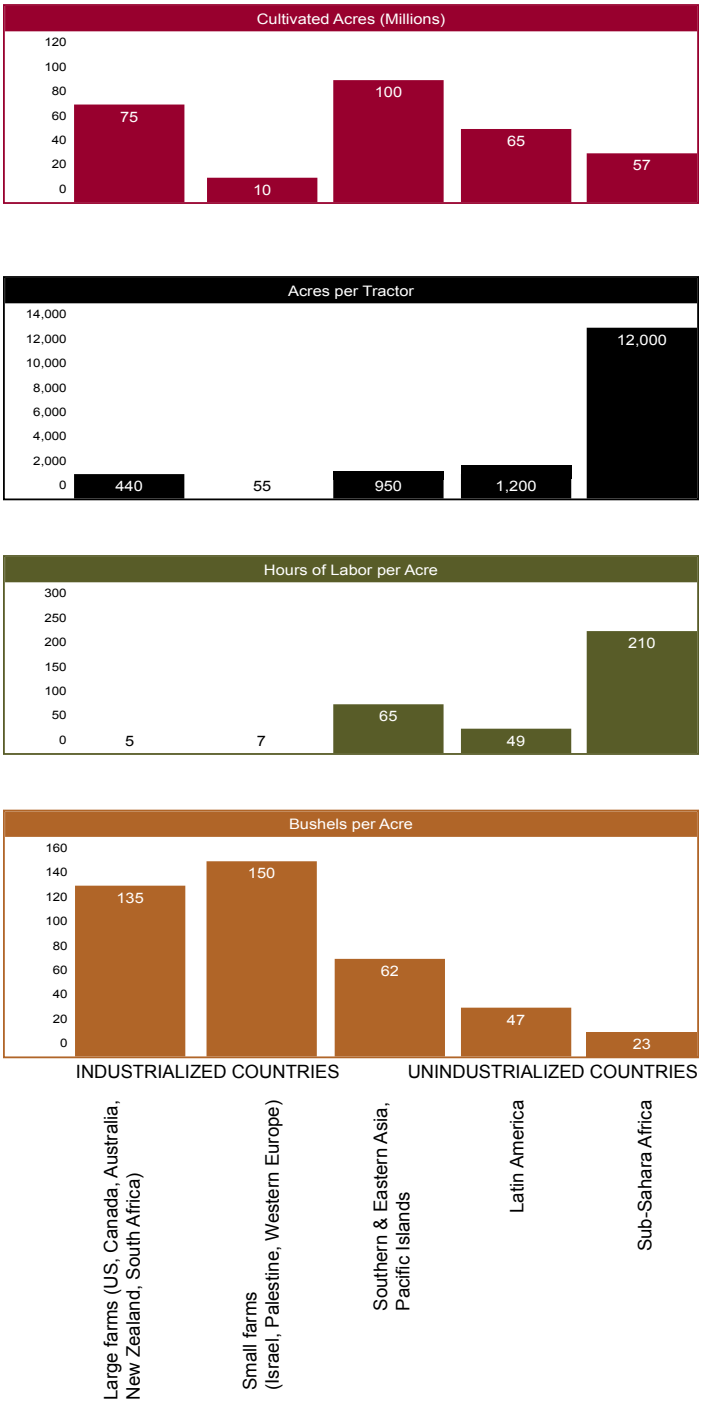
Agricultural mechanization and technology has helped to enhance farmers' productivity, particularly in industrialized countries with large farms that require timely field operations during the fall and spring season. Such countries include the United States, Canada, Australia, New Zealand, and South Africa, who all have an average farm size of over 250 acres. The arrival of mechanization in the early 1900s and its progression through the 2000s relieved the food pressures of these countries' booming populations while they also enduring a dwindling workforce of field laborers.

The trends among corn yields, number of tractors, and hours of labor per acres give evidence to the importance of mechanization (Figure 1). In general, mechanization is an important step in agricultural areas that have a dwindling workforce and require timely field operations due to weather constraints. However, many regions are not conducive to mechanization either due to the shape of the landscape, the region's economy, or tradition.

Puddling of rice soils in Wanguru, Kenya for the Mwea Irrigation Scheme
Photo credit - Dr. Jill Motschenbacher

Mechanization is also not always beneficial to a farmer's bottom line if the region's seasonal weather shifts are relatively mild and a substantial portion of the population rely directly on labor jobs in the field. In these areas, the use of digging sticks and draft-animal-pulled implements remain the best economic options.

Figure 1. Farm statistics of industrialized and unindustrialized regions as of the year 2000



Source: Pawlak, J., G. Pellizzi, and M. Fiala. 2002. On the development of agricultural mechanization to ensure a long-term world food supply. Agricultural Engineering International: The CIGR Journal of Scientific Research and Development.

C PHILOSOPHY AND KNOWLEDGE OF SOIL

In the United States, farmers, engineers, and researchers have played a vital role in shaping the history and progression of tillage implements available today. Tillage tools used here have varied as much or more than most other regions of the world. Although much of the early activities were heavily influenced by Europe, substantial breakthroughs in soil management have been the product of work here in the United States.

Pre-1850s

The European settlers brought over and deployed soil management practices from their western European homes. Until the early 1900s, after World War I, most American scientists continued to look to Europe for new philosophies and knowledge. In these early days, many American scientists traveled to Europe for their advanced education and scientific training. During this time, European scientists attempted to uncover the sole "principle" or the one, single item that plants consumed in order to grow.

In the 1500's, Bernard Palissy of France proposed that plants took up salts from the earth. Crop residues and animal excrement would then return those salts to the soil for use by the plants to follow. In general, he was somewhat correct, but not all salts are the same nor are all salts beneficial to plants. In the 1600's, Jan Baptista van Helmont of the Netherlands proposed water as the "principle" item that plants consumed after conducting his famous willow tree experiment.

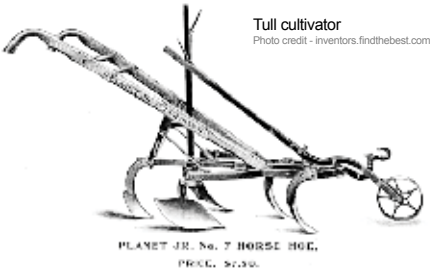
"Earth. That which nourishes and augments a plant is the true food of it. Every plant is Earth, and the growth and true increase of a plant is the addition of more Earth... Suppose water, air, and heat, could be taken away, would it not remain to be a plant, tho' a dead one? But suppose the earth of it taken away, what would then become of the plant?"

- Jethro Tull

Other scientists proposed that air or even heat was the "principle" item. Later, John Woodward of England as well as many others proposed that the pulverized earth itself (individual soil particles) or the particulate decay of plants was the "principle". In the early 1700s, Jethro Tull of England also proposed that plants consumed the small, pulverized power of the earth. In other words, he thought plants actually took in pieces of the earth such as silts and clays.

English Scientist Jethro Tull
Photo credit - Hulton Archive / Getty Images

Mr. Tull had a wide influence on agriculture across the world, since he was the inventor of the cultivator (referred to as a horse hoe in those days) and the seed drill. In his book *Horse-Hoeing Husbandry: An Essay on the Principles of Vegetation and Tillage*, first printed in 1731, Jethro Tull emphasized a need to pulverize the soil to a fine power so that plants could access the fine pieces of earth that were otherwise bound up in clods of soil.



Tull cultivator
Photo credit - inventors.findthebest.com

"The first and second plowings with common ploughs scarce deserve the name of tillage; they rather serve to prepare the land for tillage. The third, fourth, and every subsequent plowing, may be of more benefit, and less expense, then any of the preceding ones. But the last plowings will be more advantageously perform'd by way of hoeing. For the finer land is made by tillage, the richer will it become, and the more plants it will maintain."

Through the late 1700s to the mid-1800s, scientists, such as Antoine Lavoisier and J.B. Boussingault of France and Justus von Liebig of Germany, discovered that no single "principle" was the source of the plant's growth; instead many chemicals (nutrients, oxygen, water, and carbon) were responsible and required for plants to grow.

"... I am in no doubt, that any soil (be it rich or poor) can ever be made too fine by tillage." - Jethro Tull

However, the soil was still not recognized as a physical media that hosts a tremendous activity of biological life, which is responsible for cycling these nutrients. In the book *Soil: The 1957 Yearbook of Agriculture*, the famous Dr. Charles Kellogg** states in his chapter We Seek; We Learn:

"The seemingly simple reasonableness of (these) views… swept away all the alchemistic theories of plant growth. … however, was based on the assumption that soils were static, lifeless storage bins filled with pulverized rocks, which held the water and nutrients and which farmers stirred in tillage."

**Dr. Kellogg was a professor of soil science at North Dakota State University and served as Chief of the Bureau of Chemistry and Soils within the Soil Conservation Service (now the National Resource Conservation Service) implementing a vital role in the National Cooperative Soil Survey Program.

1850s to the early 1900s

Since the 1850's, scientist have made enormous advances in discovering plant nutrient requirements and in laboratory analyses for determining the amount of nutrients within soil, manures, and plant tissues. Although much of the earlier science was done in or with the heavy influence of Europe, American scientists and engineers made huge strides forward with testing management practices with practical field experiments. In the year 1919, Dr. M.C. Sewell at the Kansas Agricultural Experiment Station published Tillage: A Review of the Literature in the *Agronomy Journal.* The *Agronomy Journal* is the official journal of the American Society of Agronomy, which to this day remains the nation's strongest collection of professional agricultural researchers and scientists. Dr. Sewell's article was the journals first publication on soil tillage. In the opening sentences of Sewell's article, he stated:

"The prevailing opinions are so conflicting regarding plowing and cultivation that a review of the literature seems desirable"

Back in those days, corn yields exceeding a couple dozen bushels per acre meant you had a good year. In farmers' fields today, producers raise ten times as much grain due to advances in technology, seeds, and varieties.

Dr. Sewell's review included reference to 70 manuscripts, books, experimental station bulletins, and state board of agriculture reports from as far back as the year 1790. These documents reported on a number of field studies across the United States concerning mixed results of whether soil tillage did or did not benefit crop yields and noting the consequences of tillage to the soil. A couple noteworthy references in Dr. Sewell's paper include Dr. D. Lee's 1849 article, The Philosophy of Tillage, and Dr. H.J. Water's 1888 report, Relation of Tillage to Soil Conservation. Dr. Water's report noted observations concerning the ease of "soil washing" (water erosion in today's terminology) following tillage and the subsequent decline in crop yield. This report, and many more to follow over the next century, began the first concerns about soil and water conservation and the notion that soil lost to erosion is nonrenewable within our lifetimes. In Dr. Lee's article, he concluded:

"Crop yields decline over time due to the oxidation and loss of soil organic matter"

Producers were also observing yield declines in their fields after years of continuous tillage and cultivation. Mr. David Rankin (whose farm inventory was valued at $3.2 million in 1908; most of which was in land) wrote a marvelous short book on this farming experiences, titled *Modern Agricultural Methods Compared with Primitive Methods by the Life History of a Plain Farmer*, first printed in the year 1909. In his recommendations 'to raise a good corn crop', he advised others to invert the soil with the moldboard plow, pulverize the soil by harrowing or disking, and then cultivate as soon as possible in the year. He then went on to advise at least weekly cultivations thereafter through the crop season. However, Mr. Rankin immediately followed with this statement:

"Then when I raise four, five or more crops, just as the land will stand, I sow my corn field down to clover and timothy, and begin to pasture and feed on the land three to five years, and get good rich soil"

By putting his corn fields to pasture for several years, Mr. Rankin was unknowingly building back soil organic matter and creating soil aggregates.

"Dirty Thirties"

During the early 1900's, the "dirty thirties" or "dust bowl" emphasized the need for soil conservation and the adoption of reduced tillage strategies. Although the dust storms tended to lessen, soils continued to erode in many regions. New strategies were developed to reduce tillage even more and leave more of the soil protected from wind and water erosion. New research on the physical and biological properties of the soils emerged and the complex nature of soil began to be revealed.

Dust Bowl
Photo credit - USDA Natural Resources Conservation Service

The most profound findings have stemmed from our new understanding of the beneficial role soil aggregation and structure has on the soil environment and crop production. These findings sharply contrast with the previous eras when producers and scientists alike believed a fine, pulverized power was essential for a good seedbed. Through modern research, we now know the following benefits emerge from a well-aggregated and structured soil:

- Reduced bulk density
- Resistance to soil compaction
- Improved water infiltration and drainage
- Longer retention of plant available water
- Reduced nutrient leaching
- Less soil erosion
- Enhanced biological activity
- Increased soil organic matter

All these benefits are based on building and preserving good soil structure. Tillage breaks apart soil aggregates, damaging the existing soil structure. The deeper and more aggressive the tillage, the less structure the soil will have. In some production systems, such as in rice, this may be actually desirable. However, for nearly all other crops, a well-structured soil is essential for sustainable crop production.

Producers are still faced with the challenge of how to manage crop residues. Since the 1940's, advances in plant breeding, use of herbicides, and technology has produced large yielding crops that also leave high quantities of crop residues. These advances shifted the use of tillage from a primary means to manage weeds to now a primary means to manage crop residues. Therefore, the question of "should I till the soil and how deep or aggressive should I till" remains a vital question to most producers.

Well-structured soil in Minnesota
Photo credit - Jodi DeJong-Hughes

Monitors in tractor cab deliver precise delivery of nutrients, seed and location within the field
Photo credit - Dorian Gatchell

In the following chapters, we aim to present an overview of our current knowledge regarding the benefits, challenges, and options farmer have when reducing their tillage operations. However, before we get to these chapters, the remaining sections briefly detail the history of soil tillage tools in the United States from the Native Americans up to the new implements for reducing soil tillage.

D TILLAGE TOOLS

Before European settlement, Native Americans developed an array of handheld digging sticks using their natural resources. Later, settlers and Native Americans began to integrate the use of horse- and oxen-drawn implements made initially from wood and then iron and steel in following decades. Mechanization replaced the use of draft animals and paralleled the development of the oil and gas industry. Today, mechanized implements are becoming "wired up" with sensors, circuits, and screens coupled with hydraulics so producers can monitor progress in real time without leaving the tractor's cab except for the initial adjustments to the field's current soil moisture conditions.

Bone hoe used for tilling the ground
Photo credit - Aaron Daigh, NDSU

Native Americans and Colonists

From the beginning, many of the digging sticks used by Native Americans and the early settlers had wooden handles tethered to a strong shovel-like object to work the soil. In the Great Plains, bison shoulder blades were sometimes tethered to the wooden handle. In the Ozarks, a flat, sharp-edged stone and or even a thick mollusk shell was used. Although made primarily for farming, these tools were likely used to make foundations for buildings. In the desert regions of the west, Native Americans would also dig up and remove the soil above the caliche hardpans. This caliche layer (sometimes called petrocalic soil horizon or Kankar) is soil particles cemented together by the accumulation of calcium carbonate (also called lime). Native Americans would sometimes use this layer as the foundation and flooring for their buildings.

Most European settlers managed their soils by using the same methods they implemented back in Western Europe. They cleared forests, applied fertilizers and lime to the acidic soils, and plowed, harrowed, and cultivated by hand or draft-animal-pulled implements in the colony regions of what are now the eastern United States. These sloped soils began to lose their fertility and eroded in the humid, rain-abundant climate. In the century between the American Revolution and the Civil War, the nation's youth progressively moved westward to richer Midwestern and Great Plain soils, the prairies, leaving nearly all the northeastern farms to grow back to forest.

The Move to the Prairies

Farmers broke sod and cultivated the American prairies using horse- and oxen-drawn moldboard plows. They then used the moldboard plows, shovel plows, discs, harrows, and rolling baskets to prepare seedbeds on the rich, black soils. At this time, the moldboard plows had a wooden moldboard with an iron share and coulter. The coulter would vertically slice open the soil in front of the horizontal-cutting iron share. The moldboard would then lift and invert the soil off to the side. David Rankin reminisced on purchasing his first plow around the year 1840 in his book Modern Agricultural Methods Compared with Primitive Methods by the Life History of a Plain Farmer. He stated:

Horse drawn moldboard plow used to till the prairies
Photo credit - USDA Natural Resources Conservation Service

Wood plows
Photo credit - Jodi DeJong-Hughes

"With these plows (wooden moldboards) you had to carry a paddle and clean the plow about every twenty rods. A good team of oxen would plow about an acre each day"

In the 1830's John Deere fabricated the first steel moldboard plow. The polished steel had the advantage of cutting easier through the soil and the benefit of the soil easily sliding off the moldboard without sticking. This timesaving modification gave way to the end of the walking plows in the United States.

Although horse or oxen already drew plows, a plowman needed to walk behind the plow to steer and control the depth of tillage with a set of handles. Horses needed resting regularly throughout the day to maintain strength for timely operation. The easier plowing with the steel implement allowed plowmen to ride on a seat framed onto the plow with adjustable wheels to control a steady plow depth. Even with the added weight of the seat, wheels, and a plowman, the steel moldboard plow could turn two to three acres per day when its wooden predecessor could turn only one acre.

Soon after the invention of the steel plow, farmers and engineers began to build implements with two, three, and sometimes four rows of plows or cultivators to work the soil between plant rows (called gang plows and straddle-row cultivators). The use of the single plow implement (called a Sulky plow) was now starting to diminish. In David Rankin's book, he claims to have been the first to design and build a straddle-row cultivator in 1853. In these days, a single person could cultivate four acres per day by hand with a single shovel and eight acres per day with a single-row cultivator drawn by a horse. By attaching a second row of shovels to the cultivator, the same person could now cultivate both sides of a plant row at the same time, doubling their efficiently to sixteen acres per day.

As for the moldboard plow, double-sided steel moldboards (called lister plows or furrow plows among many other names internationally) began to be fabricated more often. These lister plows moved soil to both sides of the plow creating a furrow and ridge. As technology advanced, more rows of plows, shovels, and harrows were added in series to implements as steam-engine tractors and then diesel-powered tractors were invented. By the late 1950s, the average farmer had more tractors than draft animals and could pull several gangs of plows and cultivators in a single pass.

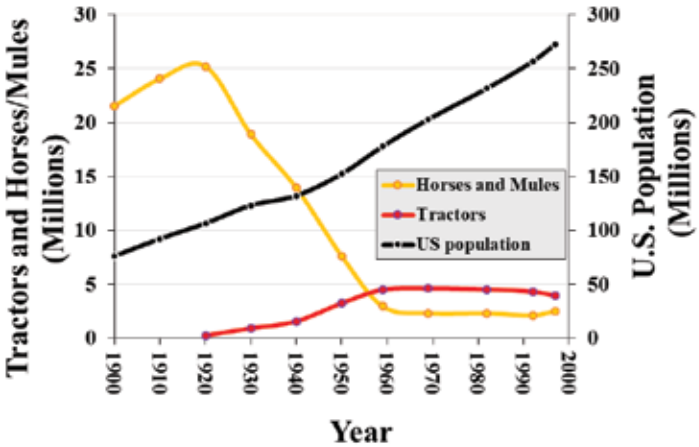
Post "Dirty Thirties"

After the "dirty thirties" or "dust bowl," emphasis was shifted from the moldboard plow method of inverting the soil to the need for soil conservation and the adoption of reduced tillage strategies. The chisel plow replaced the moldboard plow on many fields as the primary tillage pass. Chisel plow fractures and tills the soil while leaving approximately 30% cover of the soil surface with the previous crop's residue. Secondary tillage passes stayed relatively the same with discs, harrows, and cultivators with or without rolling baskets. As soils continued to erode in many regions, new strategies were developed to reduce tillage even further and leave more of the soil protected from wind and water erosion.

As modern use of herbicides developed, weeds were more easily controlled. Therefore, soil tillage was no longer the primary means for weed control, but only served to prepare a "good seedbed". Recalling the previous question, "Why do we want a good seedbed?" there was not yet a clean, short answer.

In the 1970s, no-till practices gained in popularity. By definition, no-till fields receive no primary or secondary tillage operations; the only disturbance to the soil occurs during planting. Engineering innovations of the no-till drill have helped producers obtain good crop stands in the presence of high crop residue quantities. However, no-tilled fields were difficult to manage in wet, clayey soils and in frigid regions. A number of other intermediate tillage implements** have been developed since then. These implements have the option of countless configurations and designs of shanks, coulters, disks and harrows with adjustable depths and pitches. These modern implements provide producers the ability to control the aggressiveness of their primary tillage and how much residue remains on the soil surface.

Figure 2. Farm statistics of industrialized and unindustrialized regions as of the year 2000



*Source: United States Department of Agriculture National Agricultural Statistics Service. 2016. Trends in U.S. Agriculture: Mechanization.
Data available at https://www.nass.usda.gov/Publications/Trends_in_U.S._Agriculture/Mechanization/

Tractor pulling a moldboard plow to till the fields
Photo credit - Jodi DeJong-Hughes

The following chapter aims to describe some of the more popular of these implements, common tillage depths and number of passes to prepare a seedbed. Discussion on the expectations for crop residues during the following spring months and the benefits to the soil among these various tillage implements is also made. Including emerging technological advances, environmental factors, as well as how fuel use relates to tillage intensity.

**Many vague categorical terms are used throughout the literature when discussing these new tillage strategies that purposefully leave some portion of the previous crop residue on the soil surface to reduce soil erosion. Terms such as conservation tillage, minimal tillage, reduced tillage, no tillage, etc., are found throughout the internet as well as in textbooks and the scientific literature. Although some government agencies and scientific societies clearly define specific criteria for each of these terms (typically a range of percent soil cover by crop residue), their actual use in any level of literature or personal discussions is terribly inconsistent. Therefore, in the proceeding chapters, we avoid these terms (with the exception of "no-till" in its literal sense of the phrase) and use only the names of the tillage implements themselves in hopes to reduce any confusion.

Soybeans grow in a no-till field in Western Minnesota
Photo credit - Jodi DeJong-Hughes

Credits:
Upper Midwest Tillage Guide is a collaboration between the University of Minnesota and North Dakota State University

Peer review by Richard Wolkowski, Extension Soil Scientist, Emeritus, University of Wisconsin - Madison

Tillage Implements, Purpose, Ideal Use

Jodi DeJong-Hughes (University of Minnesota) and Aaron Daigh (North Dakota State University)

A DIFFERENT TILLAGE IMPLEMENTS

Tilling the soil has been a practice used for centuries to produce crops. Tillage is defined as the mechanical manipulation of the soil with the purpose of managing crop residue, incorporating amendments, preparing a seedbed, controlling weeds, and removing surface compaction and rutting.

Since the mid-nineteenth century, most farmers used the moldboard plow as their primary tool. This implement over-turned the soil and buried the previous crop's residue, leaving only fragments covering less than 15 percent of the soil surface. In the last 50 years, farmers across the country began to use less aggressive primary tillage tools such as the chisel plow. This tool allowed farmers to conduct tillage more efficiently, at a lower cost, and had the benefit of reducing soil erosion due to wind and water.

Today, numerous additional tillage implements are available on the market that increase tillage efficiency and reduce soil disturbance and erosion even more. These new implements have options of countless configurations of shanks, coulters, disks and harrows with adjustable depths and pitches. Modern implements allow farmers to control the aggressiveness of their primary tillage and to manage the amount of residue left on the soil surface.

This chapter describes some of the more popular implements, common tillage depths, number of passes needed to prepare a seedbed, and expectations of crop residue coverage during the spring months when the soil is most vulnerable to erosion. Included are emerging technological advances, environmental factors, and methods to successfully leave more residue.

Moldboard plow
Photo credit - Jodi DeJong-Hughes

Deep tillage (>10 inches)

Moldboard plow: Moldboard plowing inverts the soil to a depth of 8-12 inches, which is measured to the moldboard share's bottom edge. Typically, moldboard plowing is conducted in the fall, requiring farmers to make one or two secondary tillage passes with a field cultivator or tandem disk before planting to smooth the soil and pulverize any remaining large soil clods.

Moldboard plowing is the most aggressive tillage practice available and leaves less than 15 percent percent of the soil surface protected with crop residue during the months after planting. Because it is the most aggressive tillage option, it also has the highest potential for soil erosion by wind and water and has high fuel, time, and labor cost requirements.

Moldboard plow in the field
Photo credit - Jodi DeJong-Hughes

Disk ripper: Unlike the moldboard plow, a disk ripper does not completely invert the soil. Instead, it tills the soils to a depth of 12-16 inches with a series of shallow disks, shallow leading shanks (optional), and then deeper, larger shanks. Some models have broad or winged points on the shanks that increase the amount of soil disturbance. Disk ripping often leaves 35-45 percent of the soil surface covered by crop residue, even though it tills deeper than a moldboard plow.

After disk ripping in the fall, one or two secondary tillage passes with a field cultivator or a tandem disk are needed in the spring before planting. Since more crop residue is left on the soil surface, the potential for erosion is less than the moldboard plow. However, disk ripping has high fuel, time, and labor cost requirements due to the deep depth of tillage.

Disk ripper
Photo credit - Jodi DeJong-Hughes

Disk ripper in the field
Photo credit - Jodi DeJong-Hughes

Deep Zone till (in-line subsoiler, ripper, paraplow): In-line subsoiling, ripping, or paraplowing are more generally referred to as deep zone tillage. These "in-line" implements create evenly spaced rows (30-inch spacing) of deep slots to a depth of 15-20 inches using a narrow subsoil shank. Shanks may be completely straight or have a bent leg (paraplow). Deep zone tillage is done in the fall and the crop is then planted directly over the tilled rows.

These implements fracture and break up deep compaction zones and incorporate little crop residues. Therefore, crop residue coverage at the soil surface is left nearly intact. Farmers should only consider zone tillage if deep soil compaction is known to exist. If the subsoil is not compacted, then farmers will not see yield benefits from subsoiling. These implements also have a high horsepower requirement of 30-50 hp per shank.

In-line ripper close up
Photo credit - Jodi DeJong-Hughes

Medium depth tillage (5-10 inches)

Ridge Till implements build 6- to 8-inch high ridges on 30-inch centers leaving chopped crop residues left on the soil surface between ridges. Ridges are typically built in the fall and then the tops removed for seeds to be placed in during spring planting. The ridges provide a dry and warm seedbed at planting. Tillage is then limited to that performed by the planter and one to two in-season row cultivations for controlling weeds and rebuilding ridges. The height of rebuilt ridges within the season should be controlled to not bury the lower pods if fields are planted to soybeans. After planting, crop residues can cover up to 40 to 50 percent of the soil surface. This percentage will decrease after the first cultivation pass, which should be done before the crop canopies.

Ridge till
Photo credit - Brad Carlson, UMN Extension

Chisel plow tills the soil to a depth of 6-8 inches using rows of staggered shanks that can be configured in several different designs. The choice of chisel plow point (shovels, straight points, or sweeps) will vary the level of soil disturbance and affects the amount of crop residues remaining on the soil surface. Preceding the shanks are a gang of straight coulters or disks that size the residue to reduce plugging. Chisel plowing is typically conducted in the fall and is followed by secondary tillage with a field cultivator or tandem disk in the spring before planting. The secondary tillage pass in the spring further lowers the residue coverage. It is ideal to leave more than 30 percent residue coverage after planting to reduce erosion. Therefore, fall chisel plowing should leave 40-45 percent residue on the surface after the chisel pass.

Farmers have the choice of numerous designs and adjustments to the shanks, shovels, and sweeps to effect the amount of residue incorporation. For example, a chisel plow equipped with 2-inch straight shovels will leave 11 percent more residue than a 3-inch twisted shovel (Hanna et al, ISU).

Fall chisel plowing that results in 30 percent crop residue cover after planting can reduce the gross amount of soil erosion by 50 to 65 percent as compared to moldboard plowing that leaves less than 15 percent residue. Additionally, chisel plowing in the fall has a medium fuel, time and labor cost requirement.

Chisel plow shank
Photo credit - Jodi DeJong-Hughes

Chisel plow in the field
Photo credit - Jodi DeJong-Hughes

Strip till combines the benefits of chisel plowing and no-till simultaneously in row crop fields. The setup of strip-till implements can vary but most have the following tools set in a series: a flat or wavy residue-cutting coulter, followed by adjustable row cleaners, a primary mole knife (or coulters) for tilling the strip, two disc blades to gather and berm soil into the tilled strip, and then rotary packing wheels or conditioning baskets to firm the tilled strip of soil. This prepares narrow 7- to 10-inch wide bands of soil for planting, while leaving the soil and residue between the plant rows untouched as in no-till.

Fertilizer is often placed 5-8 inches deep in the soil immediately behind the primary shank (or coulter) during tillage. This combines the best of both tillage worlds. Strip till has a warmer, drier seedbed compared to no-till that makes it possible to match the early planting dates and high yields of conventional tillage, while its higher residue cover provides the erosion control and improved water infiltration that no-till offers.

The spacing of tilled strips corresponds to planter row widths of the next crop so that seeds are planted directly into the tilled strips. As a result, strip till is well suited for controlled traffic management. Most strip-till equipment manufacturers in the northern Great Plains produce strip till implements with 30-inch, 22-inch, or 20-inch row spacing. Strip tilling is normally done in the fall, but it also can be done in the spring before planting. The cost per acre is similar to chisel plow, however, chisel plow systems need an extra pass for broadcasting fertilizer and an additional tillage pass for fertilizer incorporation and seedbed preparation.

Strip till
Photo credit - Jodi DeJong-Hughes

Strip till in the field
Photo credit - Jodi DeJong-Hughes

Disk loosens and lifts the soil to a typical depth of 5-8 inches with rows or gangs of concave disks set at an angle. If the gangs are arranged with two sections adjoined on one side, it is called an offset disc harrow. If the gangs are arranged with four sections in an X or a diamond shape, it is called a tandem disc harrow. Disks are an aggressive tillage option that incorporates a large amount of residue, eliminates soil clumps and clods, and loosens the depth of tilled soil.

Disk in the field
Photo credit - Brad Carlson, UMN Extension

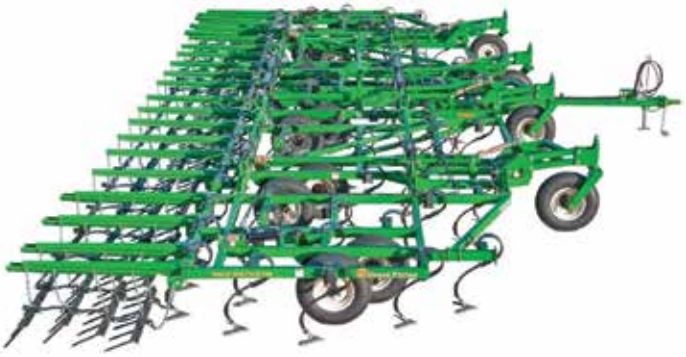
Vertical till
Photo credit - Jodi DeJong-Hughes

Shallow tillage (1-4 inches)

Vertical till cuts or sizes crop residue and lightly tills the top 1-4 inches of soil. For the purpose of this publication, vertical till is any tillage operation that does not cause a horizontal shearing or a smearing plane in the soil profile. This eliminates any use of shanks, points, and disks. Most vertical-till equipment consists of vertical coulters set between 0-degree and 10-degree angles. Vertical till typically maintains a crop residue cover of at least 50 percent of the soil surface. However, a potential downside to vertical till may occur if crop residues are sized too small and become easily blown or washed away reducing soil coverage. Vertical till is not recommended for incorporating nitrogen fertilizers since much of the nitrogen may be left on the soil surface and is susceptible to volatilization loss.

Field cultivator is a common secondary tillage practice done once in the spring before planting to pulverize smaller soil clods remaining after primary tillage and incorporate broadcasted fertilizers. Field cultivators are also used as a less aggressive primary tillage practice that is used in soybean stubble prior to planting corn. It leaves soybean crop residues covering 20-30 percent of the soil surface and tends to be a good option for medium textured, well-drained soils. Field cultivation in the spring has a much lower fuel, time and labor cost requirement than deep and medium depth tillage systems.

Vertical till in the field
Photo credit - Jodi DeJong-Hughes



Field cultivator
Photo credit - Great Plains - http://www.greatplainsag.com

Field cultivator in the field
Photo credit - Walker-cat.com/sunflower

Tandem disk is similar to the disk but is less aggressive and therefore provides a shallower tillage option for the top 2 to 4 inches of the soil. Tandem disking is a common secondary tillage practice used in the spring to prepare a smooth seedbed and incorporate broadcasted fertilizers. However, if used as a primary tillage tool, the tandem disk can have the same potential downside as vertical till as crop residue becomes prone to blowing or washing away.

Tandem disk
Photo credit - kansas.all.biz

Tandem disk in the field
Photo credit - youtube.com/watch?=u106-Ow2Ha8

Soybeans growing in no-till corn residue
Photo credit - Jodi DeJong-Hughes

No-till

No-till is the complete absence of any primary or secondary tillage practices with the goal of leaving the soil undisturbed as much as possible during the entire year. Most no-till planters have residue managers, finger coulters and double disk openers that move some residue from the row and improve seed to soil contact. Similarly, grain drills have a wavy coulter ahead of the seed tube to provide optimal seed placement. This is the only soil disturbance in no-tilled fields. The high amount of crop residues remaining on the soil surface helps maintain or increase soil organic matter, improve moisture retention and decrease soil erosion.

No-till requires special fertilizer application techniques for corn, complete chemical weed control, and specially equipped planters. Due to the potential slower soil warm-up in the spring, no-till typically has been successful in regions with lower precipitation or well-drained coarse or medium-textured soils.

Cost and soil structure impact of tillage

Below is a chart that categorizes tillage implements based on their relative cost per acre to operate and the potential to have negative soil effects. These numbers are based on an estimate created from the Soil Tillage Intensity Rating (STIR) values of the tillage practice and the Iowa State University Custom Rate Survey.

Negative soil effects of tillage include soil crusting, soil erosion, losing soil organic matter, and poor soil structure. Lower numbers from the chart indicate that tillage systems such as no-till, strip till, and vertical tillage

- Have less potential for soil loss by erosion
- Will maintain soil aggregation
- Can maintain or build organic matter
- Are less expensive to operate

Aggressive systems such as moldboard or chisel plowing and deep ripping have a much higher potential for destroying soil structure, creating individual soil particles that are prone to wind and water erosion, and cost the most in fuel and wear and tear on machinery. Note there is a variety of tillage implements that cover the spectrum of cost and soil impacts.

TABLE 1.
Relative comparison of common tillage practices with respect to cost ($) and soil impact (E).

	1	2	3	4	5	6	7	8	9	10
Moldboard Plow									$	E
Disk-rip							E	$		
Zone Till					$	E				
Chisel Plow							$	E		
Strip Till			E			$				
Ridge Till				E			$			
Disk-harrow						$		E		
Vertical Till				$	E					
Field Cultivation			$			E				
Tandem Disk				$		E				
No-till	E	$								

From lowest (1) to highest (10) soil impact due to depth and aggressiveness of tillage pass.
E = structural impact on the soil due to depth and aggressiveness of tillage pass.
$ = the associated cost of the tillage equipment.
Sources: USADA-NRCS STIR equation, 2016 ISU Custom Rate Survey

Cover crop roots growing through a dense soil in North Dakota
Photo credit - Jodi DeJong-Hughes

Earthworm burrows in the soil
Photo credit - Jodi DeJong-Hughes

Bio-tillage

Field activities performed under wet conditions often cause surface compaction. Primary tillage alleviates the problem, provided fields are not re-compacted. However, tillage is not the only way to correct surface compaction. Biological "tillage" from rotating forage crops or planting cover crops can also help. Perennial crops such as alfalfa, or cover crops such as annual rye or "tillage radish," may help break up compacted layers. Additionally, in Minnesota many soils have a high content of expanding smectite clay minerals and experience annual wetting and drying cycles. These properties shrink and swell the soil, creating deep cracks that can repair compaction damage naturally.

Earthworms are another form of bio-tillage. They create large pores, which increase water infiltration and root growth. Their castings improve microbial growth, nutrient availability and soil structure. Earthworms are quite active and feed by bringing organic debris (residue) from the surface down into their burrows. In a well-populated Minnesota soil, earthworms can recycle 8,000 pounds of soil per acre per year. Full-width systems, such as moldboard and chisel plowing disrupt earthworm channels resulting in reduced numbers in tilled fields compared to no-till or similar low-disturbance systems.

New technology

Tillage equipment manufacturers have recently been developing new technological advances for tillage implements. Companies are investing in research and the development of variable-depth or variable-intensity tillage implements that can be controlled by wireless touchscreen devices or integrated with emerging soil sensor technologies and decision-support tools for a fully automated tillage management system.

Gates Manufacturing, a North Dakota based company, has patented technology to sense or "read" the crop residue levels and automatically adjust the vertical-till gangs to be more or less aggressive based on the sensed reading. Other features include using preset gang adjustments for different fields with differing residue levels and soil texture.

Salford, an Ontario based company, has recently introduced a variable-depth tillage implement that combines a chisel plow and a wavy coulter vertical till. A farmer can engage both the chisel plow and vertical till for high crop residue conditions or for clayey soils and then automatically raise up the chisel plow for use of only the vertical till coulters when on slopes, sandier soils or low residue areas.

Gates Manufacturing On-the-Go adjustable gang angles
Photo credit - Gates Mfg

Salford variable depth tillage with chisel plow and vertical tillage units
Photo credit - Salford Group Inc.

B IMPLEMENT AGGRESSIVENESS AND RESIDUE COVER

Each tillage implement will disturb the soil differently based on the depth of tillage, size and set-up of shanks, coulters, disks and harrows, speed of operation, the number of passes, and whether the implement turns the soil over or slices through the soil.

A Soil Tillage Intensity Rating (or STIR value) of 10 or less is required to qualify for Natural Resources Conservation Service (NRCS) no-till incentive programs. The STIR value is calculated using the RUSLE2 computer model that predicts long-term average annual erosion by water. This model is based on crop management decisions applied in a field. The NRCS assigns a numerical value to each tillage operation. STIR values range from 0 to 200, with lower scores indicating less soil disturbance. Based on the STIR values, most strip till systems can be used to qualify for the NRCS conservation management/no-till incentive programs.

TABLE 2.
USDA-NRCS STIR values for common tillage operations.

Operation	STIR
No tillage	0
Double-disk opener planter	2.4
Strip till – coulter, 5” depth, 8” berm	7.7
Strip till – shank, 7” depth, 10” berm	15
Tandem disk, light finishing	19
Vertical till	20
Field cultivator, 6 to 12 inch sweeps	23
Tandem disk	32-39
Ripper	33
Chisel, twisted shovel or sweeps	42-49
Moldboard plow	55-65

C TILLAGE EFFECTS ON EROSION AND LOSS OF ORGANIC MATTER

Soil structure is formed by the aggregation of individual soil particles (clay, silt, sand, pieces of organic matter) into structural units or peds. Soil aggregation is the movement and then sticking of soil particles together. Microscopic bacteria and fungi in the soil, as well as plant roots, play a vital role for soil particles to stick and stay together as peds. Their sticky exudates and hyphae physically hold the soil together, helping soil structure to form and persist over time. The more diverse and abundant the microbial population, the faster soil aggregation can build. Between aggregates, many large pore spaces allow roots to penetrate the soil easier, and air and water to pass readily through. Additional benefits of improved soil structure are:

- Reduced bulk density
- Increased aggregate stability
- Resistance to soil compaction
- Enhanced soil fertility
- Improved water infiltration and drainage
- Enhanced retention of plant available water
- Less soil erosion
- Enhanced biological activity
- Protection of soil organic matter

All these benefits are based on building and preserving soil structure. Tillage breaks apart soil aggregates, damaging the existing soil structure, and adds oxygen to the soil that facilitates the breakdown of organic matter by microbes. Over time, tillage reduces soil biological life. The deeper and more aggressive the tillage, the weaker the soil structure. This leads to more fine aggregates and individual soil particles, which can clog pores

A well aggregated soil
Photo credit - Jodi DeJong-Hughes

A poorly aggregated and compacted soil
Photo credit - Jodi DeJong-Hughes

Windblown soil that has moved from a low residue field to the adjoining ditch
Photo credit - Jodi DeJong-Hughes

Compacted layer created by annual tillage
Photo credit - Jodi DeJong-Hughes

and crust the soil surface, slowing water infiltration and increasing runoff. Smaller soil particles are also highly susceptible to being swept away by wind and water. Valuable topsoil moves into the ditch, or the neighbor's field, or the next state, and is lost forever.

The loss of topsoil severely diminishes a field's productivity. The soil that is moving downslope or off the field is the field's most productive soil. It contains carbon, nitrogen, phosphorus, sulfur, and other nutrients, is lower in salts, and has a more favorable pH than the soil remaining after erosion occurs.

Additionally, as the soil loses structure, it becomes denser and more susceptible to compaction because of the loss of larger pore spaces. Compaction inhibits root growth and decreases water-holding capacity. Repeated tillage operations at the same depth may cause serious compacted layers, or tillage pans, just below the depth of tillage. Higher horsepower equipment is needed to get through compacted soil, which results in more wear-and-tear on equipment. Reducing tillage helps preserve the soil's natural structure, making the soil more resistant to erosion and the negative effects of heavy field equipment.

D ACCOUNT FOR INDIVIDUAL FIELD CONDITIONS

There is not one tillage management system that will work for every field. Factors such as soil moisture and physical characteristics, slope, and crop rotation play a vital role when deciding which implement is best for each field.

Soil Texture: In the Midwest, sandy and loamy sand soils warm up faster and have good internal drainage. However, they have lower organic matter content and do not have soil structure. It is not possible to create soil structure on sands and loamy sand soils, but the addition of organic materials can improve water holding capacity and internal drainage. Reducing tillage or using no tillage on these coarse soils protects soil productivity and cuts yield risk.

Clay and clay loam soils in the upper Midwest are rich in organic matter, which gives them their characteristic dark brown or black color, and if managed properly, develop well-defined structure. These fine-textured soils have poor internal drainage, drying more slowly than sands. In addition, light-colored residue reflects the sun's heat, impeding spring warm-up. With high levels of residue, these poorly drained soils may remain cool and wet long into the spring months, resulting in delayed planting. That is why, traditionally, more tillage is performed on clayey soils. However, improving soil structure will boost internal drainage, speeding up spring warming and drying. Furthermore, systems such as strip till and no-till do not destroy the continuity of large pores and therefore increase infiltration and aeration. Subsurface drainage (tile drains) also improve soils with poor internal drainage, making it more feasible to reduce tillage.

Soil structure difference with a loamy sand (above) and a clay loam soil (below)
Photo credit - Jodi DeJong-Hughes

Wet Soil Conditions: This is probably the most important factor to evaluate. If the soil is too wet for proper soil fracturing in the fall, tillage may be creating more damage to the soil than benefits from the residue incorporation. If the soil is dry near the surface but wet below, shallow up the shanks or disks so that they do not smear the wet layer of soil. A smeared soil will need an additional, deeper pass or two in the spring to break up the dense layer.

For example, if a chisel plow is used in a wet soil to a depth of 8", using a 3" spring field cultivation will not alleviate the smeared soil layers created by the chisel plow. This situation might need an in-line ripper set at a 9-10" depth to eliminate the smeared layers created by the chisel operation during wet conditions.

Field cultivating at 3-inch depth in a wet soil restricted the corn roots from growing much deeper
Photo credit - Jodi DeJong-Hughes

Moderate Soil Moisture Conditions: If the soil has moderate moisture in the fall (moisture levels below field capacity), a chisel plow or a disk ripper will incorporate some residue and break through compaction and cloddy soils. However, note that disks are extremely destructive to soil structure, creating a fine, pulverized soil that can easily blow or wash away. Disks can also create a plow layer. For example, if you look where a roadbed is being built, you will usually see a disk sitting along with the other construction equipment. These implements are extremely effective at creating a dense soil. Also, recall that soil with poor structure can compact more easily. Use the disk sparingly. Conversely, equipment with points and shanks lifts and separates the soil more along its natural fracture lines and is less destructive than a disk.

Dry Soil Conditions: If the soil is exceptionally dry in the fall, do not use deep tillage equipment. A chisel plow set at an 8" depth will heave-up large clods of soil. Experience has shown that the deeper the tillage in these extremely dry soils, the larger the clods lifted to the surface. In 2011, basketball-sized and larger clods were seen across western Minnesota due to tillage during extremely dry soil conditions. Two to three tillage passes were needed in the spring to create an acceptable seedbed.

Cloddy soil due to deep tillage in a dry soil
Photo credit - Jodi DeJong-Hughes

Natural alleviation of soil compaction is possible in soils that shrink and swell (crack in dry conditions) during dry conditions. Consider this a form of free, deep tillage. Since dry soils are naturally "tilling" deep into the soil, farmers can focus on creating a good seedbed in the top 3 inches with shallow tillage. In dry conditions, reduced-tillage systems preserve moisture in the seedbed, enhancing uniform germination and plant establishment.

Cracks in the soil created by dry soil conditions are breaking up compacted areas in the soil
Photo credit - Jodi DeJong-Hughes

Soil Compaction: In the Midwest, research results evaluating the effects of subsoiling have shown few positive yield responses. When yield benefits do occur, they are variable and relatively small.

Accurately predicting the effects of subsoiling on crop yields is very difficult, due to differences in soil texture, the level of subsoil compaction, the soil water content, subsequent traffic, and differences in the crop grown and in tillage methods.

In a University of Minnesota study near Waseca, MN, a field was uniformly compacted with a grain cart weighing 20 tons an axle. The field was subsoiled to a depth of 16 inches to break up the compacted soil. Subsoiling failed to increase yields on the 20 ton per axle treatments for either corn or soybeans and decreased corn yield 11 bu/ac in one of the two years. Similarly, a two-year study near Elrosa, MN, found that corn and the following soybean yields were not affected by subsoiling down to 20-inch depth.

A field subsoiled in a wet soil to a depth of 20 inches near Elrosa, Minnesota
Photo credit - Jodi DeJong-Hughes

To increase the probability of obtaining beneficial effects from subsoiling, the following steps should be considered:

- Determine that a compaction problem actually exists. Dig some plants to examine rooting. Are visual crop symptoms consistent with past wheel traffic? Is there standing water after a rain that also shows a pattern consistent with wheel traffic?
- Determine the depth of the compacted layer.
- Set the tillage implement 1-2 inches deeper than the compacted zone depth. Make sure the soil is dry and fractures to the depth of the shank when subsoiling.
- Leave some areas of the field not subsoiled for yield and visual comparison.
- Avoid re-compacting loosened soil by avoiding future operations on wet soils and using the controlled traffic concepts.

Slope: Sloping fields are prone to water erosion. Erosion potential depends on the length and steepness of slope and the soil texture. Highly erodible land (HEL) may require large reductions in tillage intensity to limit erosion and maintain soil productivity. Flat fields have less erosion potential, but sediment loss can be a problem on these fields during intense rain or wind events. Reduced tillage leaves more residue on the soil surface. This residue protects the soil from raindrop impact and slows the downhill movement of soil and water. In addition, standing residue will slow the wind's erosive speed and wick rainfall into the soil faster than bare soil.

Eroded hilltops near Fergus Falls, Minnesota
Photo credit - Jodi DeJong-Hughes

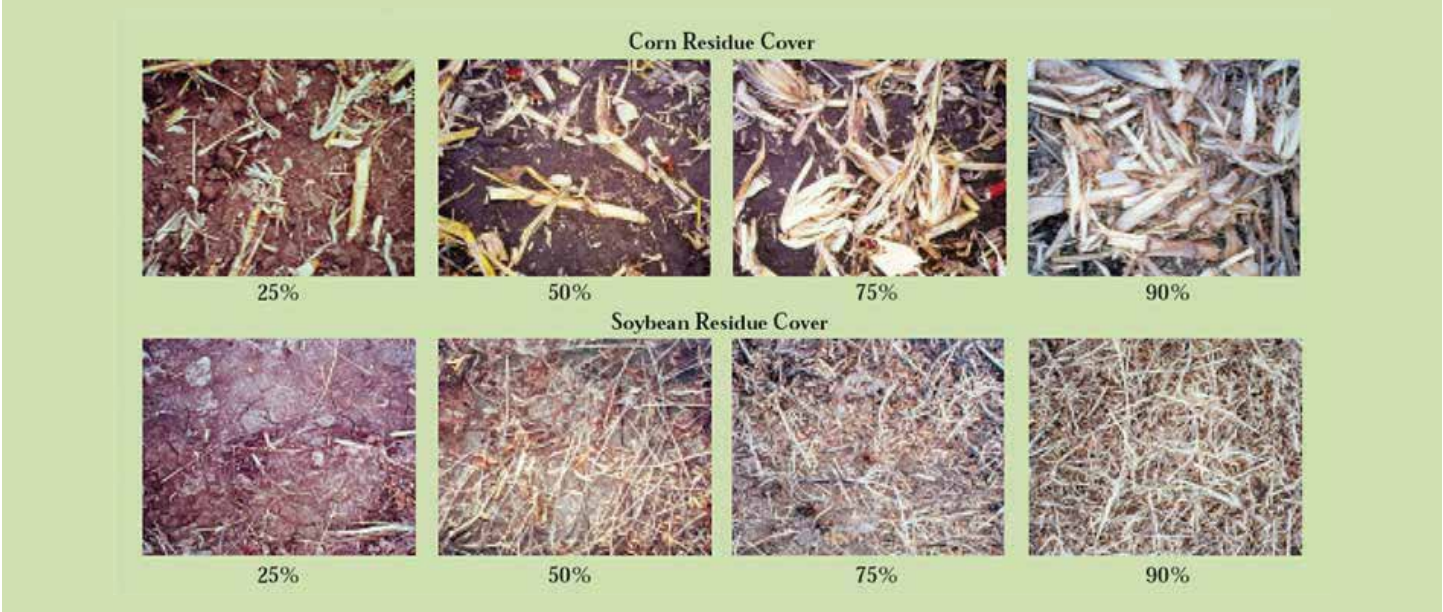
If fields have more than a 3 percent slope, minimize the depth and intensity of the tillage pass. The steeper the slope and the more aggressive the tillage, the more mid-slope buffers and planting on the contour are needed and have a return on investment. A handful of creative farmers will not till the tops and sides of slopes in the fields leaving the residue to protect the vulnerable soil.

Crop Rotation and Residue Levels: Crops differ in their adaptability to respond to soil temperature and moisture. Corn, a determinant crop, is sensitive to moisture and temperature. High levels of crop residues can cause uneven emergence and may decrease corn yields. On the other hand, soybean and wheat have greater ability to thrive in a large range of crop residue levels.

The amount of residue in a field before tillage depends on the previous crop and yield. Corn, for example, generates much more biomass than edible beans, soybeans, potatoes, or sugarbeets. Therefore, it is easier to maintain higher residue levels following corn using a variety of tillage systems. Residue durability also differs by crop. While corn residue breaks down slowly, soybean residue is fragile and easily destroyed by tillage, so maintaining adequate residue cover following soybeans is more difficult. Consider the entire crop rotation when evaluating residue cover and tillage systems. In general, a corn-soybean rotation offers more tillage flexibility than continuous corn.

While not a tillage issue, it is very important to spread residue over the width of the combine to prevent strips of higher residue levels directly behind the combine. This area of high residue can create uneven residue incorporation during tillage and uneven seed placement during planting. Chopping heads and chaff spreaders can help spread stalks and chaff evenly across the field.

Many different tillage choices are available. If you have a 2 or 3-year crop rotation (corn-soybeans, corn-soybeans-wheat), a less aggressive tillage pass can be very effective at managing the crop residues. However, there are fewer choices available to handle the high residue levels of three or more years of continuous corn. Each implement has benefits and challenges.



Residue cover directly after harvesting corn (top) and soybeans (bottom)
Photo credit - USDA-NRCS https://www.nrcs.usda.gov/

Managed properly, the beneficial aspects of maintaining high levels of crop residue with reduced-tillage systems outweigh the few negative aspects. Look at your specific situation (soil texture, crop rotation, slope, and soil moisture) to decide what is right for you. In the end, reducing your tillage is key to the long-term productivity of your soil.

E RECOMMENDATIONS

- When possible wait until spring to till, especially on fields with soybean residue. Where fall tillage is conducted use systems that are done on the contour and leave 40-50% residue
- Reduce the number of tillage passes
- Set chisels and disks to a shallower depth
- Use straight points or sweeps on chisel plows instead of twisted points
- Plant a cover crop, especially after low residue or early season crops
- Spread residue evenly with the combine
- Minimize tillage operations up and down slopes
- Avoid working the soil when it is wet

Spreading out the chaff evenly behind a combine
Photo credit - Jodi DeJong-Hughes

Credits:
Upper Midwest Tillage Guide is a collaboration between the University of Minnesota and North Dakota State University

Peer review by Richard Wolkowski, Extension Soil Scientist, Emeritus, University of Wisconsin - Madison

Reducing Tillage Intensity

Jodi DeJong-Hughes (University of Minnesota) and Aaron Daigh (North Dakota State University)

Reducing soil tillage intensity presents many benefits, challenges, and some required changes to your field operations. Benefits range from reduced soil erosion, fuel use, time, and labor; as well as building soil organic matter, improved soil structure, and maintaining options for soil warm up and dry down in the spring months. Whereas the challenges include the learning curve for your new system, equipment costs, plans to manage residue build-up over time, patience, and perhaps going against local traditions.

A BENEFITS

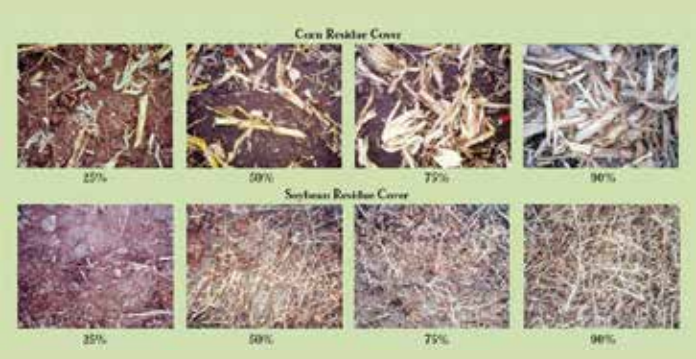
1 SEEDBED PREPARATION

Seedbed preparation is all about setting a hospitable environment for seeds to germinate and thrive. Much like your own home, you optimize your house's heating, cooling, and insulation, while also stocking the pantry to provide comfort throughout the winter, spring, summer and fall seasons. The seedbed is no different. By optimizing your seedbed to handle whatever Mother Nature decides to throw at you, you are providing your crop the best chance to quickly develop a stronger stand and produce to its full potential.

Spring Soil Temperature - Why We Care and How it Works

The higher the soil temperatures in the spring months, the faster your crop will emerge and establish a strong stand. Early crop emergence and stand establishment promotes an earlier crop canopy closure, reducing the germination of weeds during the mid- and late-season as well as providing your crop a better chance to withstand disease and insect pressure.

Crop residues on the soil surface have a low density, which means they are light and have a large amount of air in and around them. This air gives crop residues an insulating effect on soils similar to fiberglass insulation in many people's attics. The thickness of the crop residue layer covering the soil surface is what governs how fast heat from solar radiation will move into the soil during the spring months until the crop canopy closes. A soil with a thick crop residue layer covering 70% of the surface will heat up more slowly than a soil with a few fragments of residue covering 10%. Additionally, crop residues are typically a light color, which means they reflect more solar radiation back up into the atmosphere than a darker color. Therefore, less heat will reach the soil surface. It is also important to make sure residue is spread evenly behind the combine to avoid areas of excessively thick residue.



A visual guide of differences in corn and soybean residue cover.
Photo credit - USDA-NRCS www.nrcs.usda.gov

Spring Soil Temperature - Linking Your Tillage Practices

Soil temperature changes due to the depth and aggressiveness of the tillage implement used. Deep tillage implements, such as the moldboard plow and disk ripper, leave less than 15% and 45% of crop residues covering the soil surface, respectively. Medium depth tillage implements, such as the chisel plow, strip till, ridge till, and disk also leave 30% to 60% of crop residues covering the soil surface. If a field cultivator is used as a secondary tillage option, the amount of crop residue covering the soil surface will decrease to 20 to 30%. Soil temperatures "in the plant row" may differ somewhat among all

these tillage options during the hottest portion of a few select days in the spring. However, the soil temperatures will most often tend to be quite similar, particularly during the evening, nights, and morning, as well as after rainfall.

Strip-till implements move crop residues to the side of where the plant row will be placed. Because the residue is all but completely removed from the plant row, soil temperatures in the strip will be similar to soils tilled with a moldboard plow, disk ripper, chisel plow, and disk. North Dakota State University research in the Red River Valley (Prosper, ND, and Moorhead, MN) during 2007 indicated comparable soil temperatures between a single fall strip till pass and a fall primary chisel plow pass followed by a spring secondary field cultivation pass (Overstreet et al., 2007). The University of Minnesota performed similar research during 2011 and 2012 in southern Minnesota with an aggressive strip till implement, a disk ripper, and a moldboard plow in a corn-soybean rotation (Figure 1 and 2). They also observed similar soil temperatures among these tillage options. However, soil temperatures were lower and more soil moisture was conserved in the areas where the strip tiller moved crop residues between the plant rows.

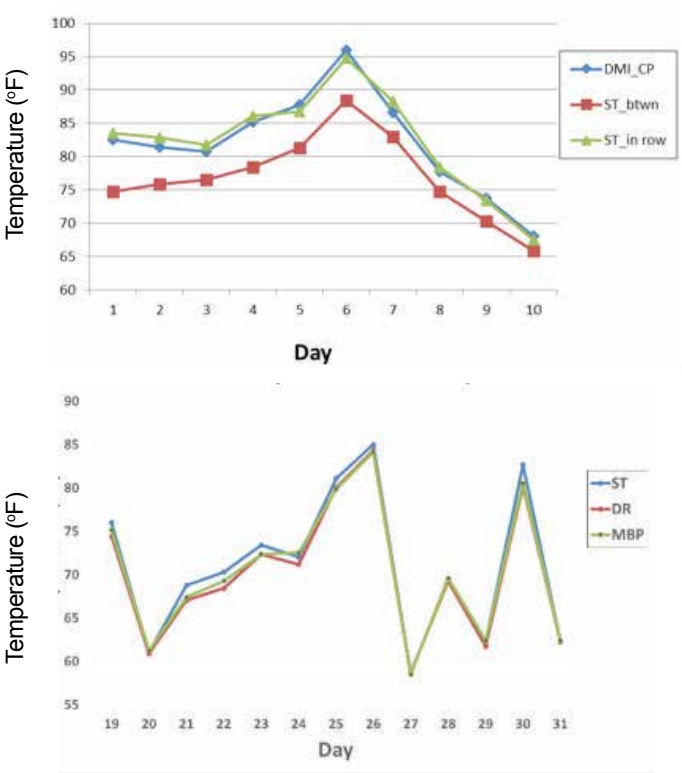


Figure 1 and 2.
Hourly soil temperatures taken at a 2 inch depth across three tillage systems in a two fields near Clarkfield, Minnesota. Figure 1 taken in June 2011 and figure 2 in May 2012.

In 2015, a joint project by the University of Minnesota and North Dakota State University at four field sites with varying soil textures (sandy loams to silty clays) demonstrated similar patterns among these tillage practices. However, in these fields, shallow vertical tillage and no-till were included and evaluated for soil temperatures. As expected, the shallow, less aggressive vertical-till implement caused soils to be several degrees cooler and no-till temperatures to be the coolest due to the higher crop residue cover during the spring months as compared to strip till and chisel plow implements (Figure 3).

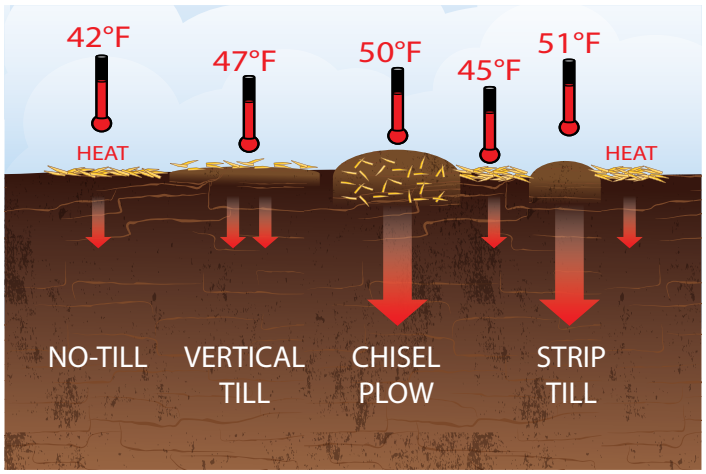


Figure 3
Average soil temperatures taken from thaw to crop canopy closure in 2015 to a depth of 2 inches below four tillage systems near Wahpeton, North Dakota and Fergus Falls, Minnesota.

Research on strip till has consistently shown over time that soil temperatures in the spring depend more on where crop residue is placed rather than the percent soil covered of the whole field. The advantage of higher soil temperatures in strip till berms as compared with no-till is demonstrated by faster plant emergence and crop development. This advantage is greatest when soil temperatures approach the lower threshold for crop seed germination. For example, early-planted strip till corn or soybeans will likely emerge sooner than in a no-till system. Early plant establishment frequently translates into higher crop yields and quality.

Soil Moisture - Why We Care and How it Works

Crop residues left on the soil surface help snow and rainwater enter the soil and then conserve that water as soil moisture for later use by the crop. Crop residues covering the soil surface over winter help to trap snow. The trapped snow can help prevent the soil from freezing as deeply as a bare soil without crop residue cover. When the snow melts, it can then move through the residue layer and easily into the soil.

When spring and summer rains come, the crop residue protects the soil from the falling water, preventing it from forming a crust and sealing. As the crop residue intercepts rainwater, the water can gently

Standing crop residue trapping snow in field near Fergus Falls, Minnesota
Photo credit - Jodi DeJong-Hughes

move through the layer of residue and into the soil. However, the crop residue's job is not done yet. The layer of residue then reduces the amount of soil water lost to the atmosphere via evaporation by acting as a barrier. By reducing evaporative losses and conserving the soil moisture, that water will be available for plants, particularly later in the growing season during the plant's reproductive stages.

However, too much moisture can be as bad as too little moisture. During planting in the spring months excessively high soil moisture can create issues with trafficability on weak, poorly structured soils. Nearly all soils are most vulnerable to compaction when 80-85% of the soil pores are full with water. Additionally, if compaction layers prevent the soil from adequately draining excess soil moisture, the vulnerability of the seedling to seed rot and damping-off diseases, such as Pythum, increases as the soil warms up.

Soil Moisture - Linking Your Tillage Practices

Aggressive tillage implements, such as moldboard plow, disk ripper, chisel plow and disk harrow, cause the soil to quickly lose some of its moisture to the atmosphere. In a USDA-ARS study, researchers measured the loss of soil moisture during the first 80 hours after using a variety of soil tillage implements. Areas tilled with a moldboard plow (MBP) lost 23% more moisture than areas tilled with a chisel plow (CP) and lost 54% more moisture than areas with no tillage (NT) (Figure 4). In 2015, during the same joint project by the University of Minnesota and North Dakota State University, four field sites of varying soil textures (sandy loams to silty clays) showed soil moisture differences among tillage practices during the spring months. In these fields, shallow vertical tillage resulted in the soils being 22% drier on average (Figure 5) than no-till. In contrast, the more aggressive chisel plow and strip till implements caused soils to be 40-45% drier than no-till, due to little crop residue covering the soil surface. However, soil moisture between the strip till berms was between the moisture levels measured in the no-till and vertical till plots. Soil in the strip tilled berm dried down and warmed up similar to the chisel plowed plots. However, while the areas between the strip till berms, which were just a few inches away, were not disturbed, they still provided a modest amount of drying and warming (9% more than the no-till plots). Strip till tended to present the best of both chisel plow and no-till management. The promotion and preservation of soil structure between the strip till berms will provide better drainage of excessive moisture during high rainfall springs, as well as provide more strength for spring traffic as compared to tillage practices that demote soil structure.

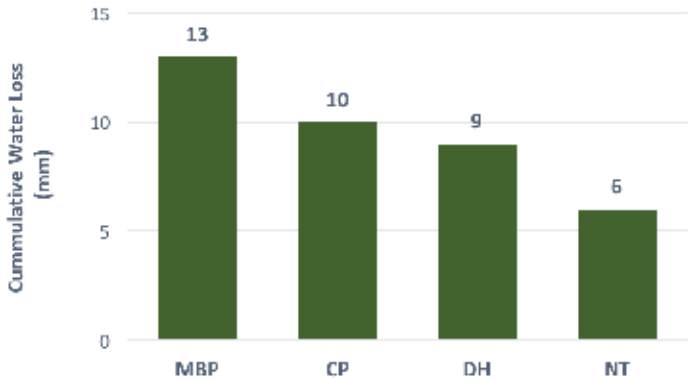


Figure 4
Soil water loss 80 hours after four tillage systems (Reicoski, et al. USDA-ARS in Morris, MN).

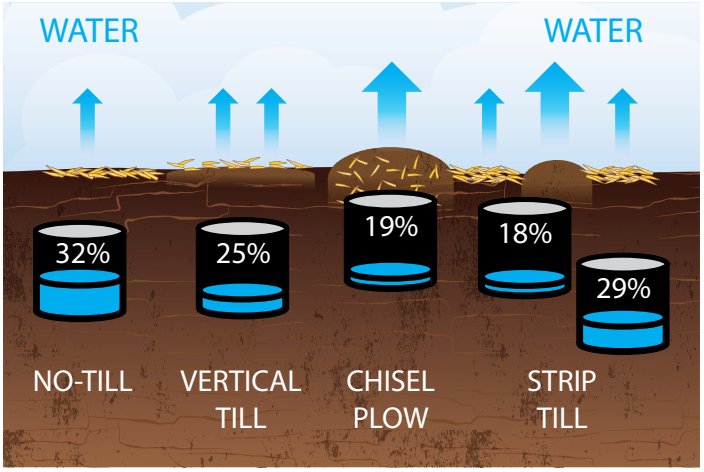


Figure 5
Average soil moisture levels (actual percentage points of the soil) taken from thaw to canopy closure to a depth of 2 inches below four tillage systems near Wahpeton, North Dakota and Fergus Falls, Minnesota.

Aeration - Why We Care and How it Works

Plant roots require a minimum amount of oxygen to be delivered at all times to maintain the plants metabolic functions. The roots and soil microbes also breathe out carbon dioxide, which needs to be removed and not allowed to build up in the soil. Oxygen moves through water 10,000 times slower than through air. Therefore, if soil moisture persistently stays near saturation, your crop has a high likelihood of drowning. This emphasizes the need for soils to be able to quickly drain the excess soil moisture during years with heavy or persistent rainfall.

Different crops have different minimum soil oxygen diffusion rate requirements before nearly every metabolic process in the plant deteriorates (Figure 6). This means that some crops in your rotation may handle wet springs fairly well, whereas other crops may be affected severely in a matter of a few days of enduring high soil moisture.

Tillage trials at NDSU in Fargo, North Dakota
Photo credit - Dave Franzen, NDSU

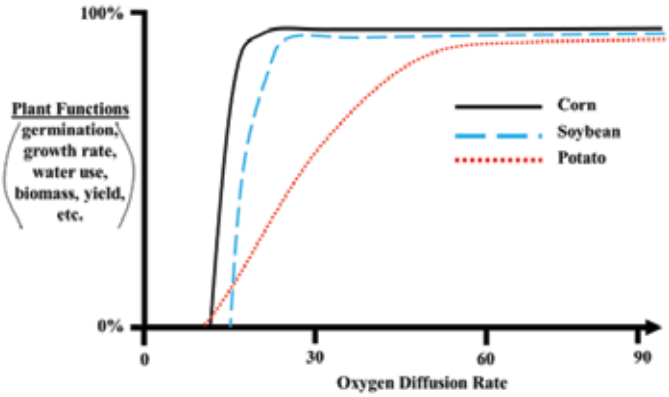


Figure 6
Oxygen diffusion rates in soil for ideal plant growth functions for three agronomic crops (Glinski and Stepniewski, 1985).

Aeration - Linking Your Tillage Practices

Aggressive tillage implements 'fluff' up the soil increasing the amount of pore space and the amount of air in the soil. The fluffed-up soil can readily dry by evaporation after most rainfall events allowing oxygen to meet crop needs. However, drying by evaporation can only provide so much benefit. If rainfall becomes heavy or frequent, high soil moisture levels may persist for long periods causing risk to the crop. During these times, soils with good soil structure (soils with several years of reduced or no tillage) are much more efficient at draining this excess moisture from the seedbed and allowing air to enter through the largest pores. However, if rains are so heavy and frequent to bring the groundwater level up within the topsoil, then evaporation or drainage may not be able to provide much relief to the crop unless fields are tile drained.

2 SOIL STRUCTURE

Soil structure is formed by the aggregation of individual soil particles (clay, silt, sand, pieces of organic matter) into peds. Soil aggregation is the movement and then sticking of soil particles together. There are many large pore spaces between the aggregates, which allow roots to penetrate the soil easier, and air and water to pass readily through. Microscopic bacteria and fungi in the soil, as well as plant roots, play a vital role for soil particles to stick and stay together as peds. Their sticky exudates and hyphae physically hold the soil together, helping soil structure to form and persist over time. The more diverse and abundant the microbial population, the faster the soil aggregation. Benefits of improved soil structure include the following:

- Reduced bulk density
- Increased aggregate stability
- Resistance to soil compaction
- Improved water infiltration and drainage
- Enhanced retention of plant available water
- Reduced nutrient leaching
- Less soil erosion
- Enhanced biological activity
- Increase in soil organic matter

A well aggregated soil and fungal hyphae taken from a long term strip tilled field in Southern Minnesota
Photo credit - Jodi DeJong-Hughes

Crusting of soil due to excessive tillage
Photo credit - Jodi DeJong-Hughes

Additionally, as the soil loses structure, it becomes denser and more susceptible to compaction, which is the loss of larger pore spaces. Compaction slows root growth and limits water holding capacity. Repeated tillage operations at the same depth may cause serious compacted layers, or tillage pans, just below the depth of tillage. As a result, higher horsepower equipment is needed to get through compacted soil and it suffers more wear-and-tear.

Reducing tillage helps preserve the soil's natural structure, making the soil more resistant to erosion and the negative effects of heavy field equipment.

3 SOIL EROSION

Soil is a non-renewable resource and cannot be built within our lifetime. When it is gone, it is gone. While erosion is a natural process, cultivation of the prairie and the dominance of annual crops have significantly sped up soil erosion. The loss of topsoil severely diminishes a field's productivity. The soil that is moving downslope or completely off the field is the most productive soil. It contains carbon, nitrogen, phosphorus, sulfur, is lower in salts and, in the upper Midwest, has a more neutral pH than the remaining soil left behind. The USDA-NRCS estimates that cultivated land in Minnesota and North Dakota has 4 to 7 times more water erosion than non-cultivated land and 30 to 50 times more wind erosion.

Water Erosion – Crop residues absorb the energy from high-speed raindrops, reducing the likelihood of aggregate dispersion and soil crusting. Residue also slows down the overland flow of runoff, allowing more time for the water to infiltrate and move through soil pores.

Water erosion in a chisel plowed field in northern Minnesota
Photo credit - Jonathan Wolff

Wind Erosion – Crop residues protect the soil from winds near the soil surface. These residues shift the column of wind upwards away from the soil. In Minnesota, the average wind erosion rate is 5.2 tons of soil loss per acre per year. North Dakota is slightly lower at 4.7 tons and South Dakota is at 2.4 tons per acre per year. While these levels have decreased in the past three decades, wind erosion is still occurring at detrimental rates. The most severe areas of erosion are well above the general estimates of 5 tons per acre per year.

Wind erosion in a region of west central Minnesota where many of the fields are aggressively tilled
Photo credit - Jodi DeJong-Hughes

Tillage Erosion – Tillage can erode more soil than wind and water erosion combined. A team of USDA-ARS researchers in Western MN studied highly erodible fields, observing that moldboard plowing loosened and moved 27 tons of soil per acre per year. Once loosened, the soil was also vulnerable to further movement from runoff flowing downslope. The researchers calculated that on this field, water moved almost 9 tons of soil per acre per year. As expected, crop yields were also severely affected. In 2003, areas of the field where the soil accumulated, wheat yields were between 80-95 bu/ac. In the area of the worst erosion (hill tops and shoulder slopes), yields were as low as 45 bu/ac, a yield loss of near 50% or loss of $180 per acre if wheat is $4.00 per bushel.

Aerial photo of tillage and water erosion on a sloped field in Western Minnesota (notice the backhoe in upper right corner for perspective) Photo credit - Jodi DeJong-Hughes

Soil loss via wind and water erosion cuts your profits and reduces productivity by removing a non-renewable resource. Erosion is very costly in terms of nutrient removal, lower water holding capacity, and loss of productive organic matter. Management to reduce the potential for erosion include the following:

- Maintain at least 30% residue cover after planting to protect the soil surface
- Reduce tillage to improve soil aggregation and structure
- Keep the soil covered for longer periods using cover crops and perennials
- Increase the height of standing stubble and replace shelter belts to reduce wind speeds across your fields

4 SOIL ORGANIC MATTER

A producer cannot change the soil texture in a field. However, the level of soil organic matter can be increased or decreased due to the chosen set of management practices. This makes a producer's management choices very important, since soil organic matter is related directly to soil fertility, soil structure, and agricultural productivity potential. Other advantages to increasing or maintaining a high level of soil organic matter include the following:

- Reduced bulk density
- Increased aggregate stability
- Resistance to soil compaction
- Enhanced fertility
- Reduced nutrient leaching
- Resistance to soil erosion
- Improved water infiltration and drainage
- Enhanced retention of plant available water
- Enhanced biological activity and diversity

You may have read articles where the term soil organic matter (SOM) is used interchangeably with soil organic carbon (SOC). This is because soil organic matter is 58% organic carbon. Carbon is invisible to our naked eye and therefore difficult to understand how our management can affect it. Luckily, researchers can measure carbon in the soil and in the atmosphere.

Soils continuously store carbon and then release some of it in natural processes. Soil tillage speeds up this process by warming the soil and incorporating oxygen and crop residues into the soil. The soil microbe population, particularly bacteria, increases in response to the tillage, and these additional food sources. Microbes consume the carbon from the crop residue and the soil organic matter, accelerating the conversion of organic carbon into the gas, carbon dioxide (CO_2), which is then released into the atmosphere.

By accelerating this process, the carbon in the crop residue quickly turns into a gas and leaves the soil instead of slowly breaking down and forming soil organic matter. Over time, soil organic matter levels decrease with soil tillage and the advantages listed above also decrease.

Identifying tillage methods that reduce the amount of carbon released into the atmosphere is important. A Minnesota study conducted in 2005 compared soil CO_2 emissions following fall moldboard plowing (MBP), disk ripping (DR) and strip tilling (ST) and determined that strip tillage maintained more soil carbon than moldboard plowing and disk ripping. Disk ripping and strip tillage released 53% and 83% less CO_2 from the soil than moldboard plowing (Figure 7). Moldboard plowing disturbed and exposed the greatest amount of soil, allowing carbon as CO_2 or previously stored as organic matter to escape into the atmosphere. The deeper and more aggressive the tillage, the more soil carbon was lost.

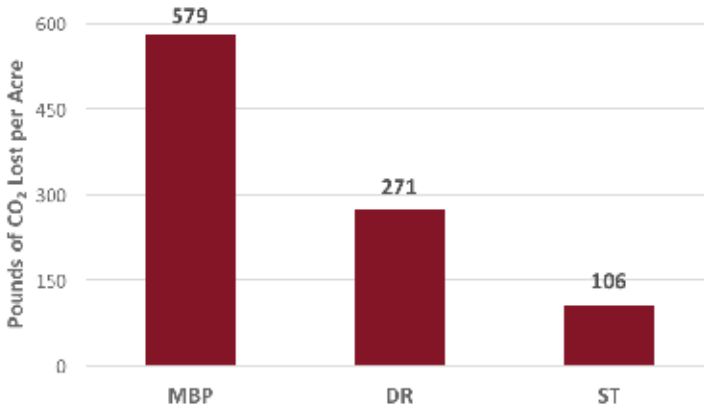


Figure 7. Pounds of CO_2 per acre lost to the atmosphere in 24 hours using three different tillage operations near Jeffers, Minnesota (Faaborg et al., 2005).

In another Minnesota study, three tillage systems ranging in soil disturbance were compared to no-till. In this study, wheat residue produced from the previous season's crop added 2,840 pounds of organic matter per acre. When the soil was moldboard plowed (MP), the soil lost over 3,800 pounds of organic matter per acre within 19 days after the primary tillage pass, which is 1,000 pounds more than what was added by the previous crop's residue. In addition, this system will continue to lose more carbon in the spring when the field is prepared for planting. If this MP system is used continuously, the organic matter content will decrease over time. These values are substantially greater than the no-till (NT) treatments, which lost only 770 pounds of organic matter per acre due to natural carbon cycling processes. The disk harrow (DH) and chisel plow (CP) were in the middle range of organic matter lost.

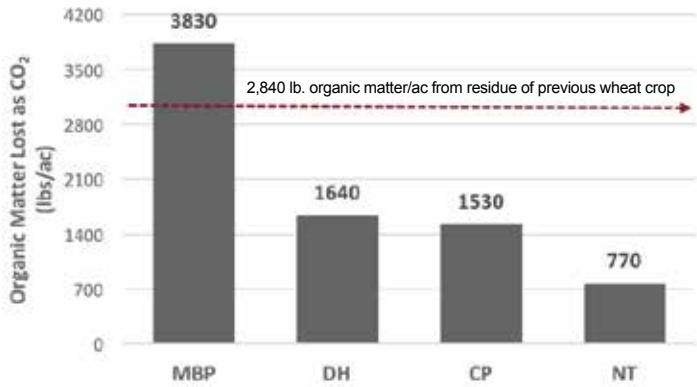


Figure 8. Pounds of CO_2 lost to the atmosphere in 19 days under four different tillage operations in Western Minnesota (Reicoski et al.).

5 ECONOMICS

Evaluating the economics of tillage systems is very complex. Consideration must be given to the initial cost of the implement, financing charges, maintenance costs, the size of tractor needed to pull the implement, equipment depreciation, labor costs, conservation program incentives, and increased management costs related to fertilizer and pest management.

Reducing tillage means fewer trips across the field, conserving energy, fuel, and labor, and reducing machinery maintenance. Refer to Chapter 4, Economics of Tillage for more information.

B CHANGING THE TILLAGE MEANS A CHANGE TO THE SYSTEM

When considering a change in tillage practice, producers will need to make changes to many other parts of their system. For instance, weed control and fertilizer applications that worked with chisel plowing will likely not work well for no-till, and vice versa. Changes to the system may not always line up well with family or neighbor traditions and perceptions. A keen eye and willingness to increase a farm's efficiency will likely require a combination of traditional and innovative adjustments to field operations in order to achieve the greatest economic gains.

1 WEED MANAGEMENT

Shift to Perennials - Reduced tillage and additional surface residue may increase perennial weed pressure, therefore, it is important to adjust your weed management program to fit your tillage system. When reducing tillage, start with relatively weed-free fields. Effective weed management in a reduced tillage system includes the use of soil-residual herbicides, well-timed post-emergence herbicide applications, crop rotation, and use of multiple herbicide modes of action.

Tillage Effect on Weed Seed Survival – The persistence of the weed seed bank varies by tillage system and weed species. Less-intensive tillage will likely favor small-seeded weeds that emerge from shallow depths. More-intensive tillage buries weed seeds, protecting them from seed predators and increasing their persistence.

Weed seed bank degradation is greatest near the soil surface. Seeds near the soil surface are more accessible to seed predators like rodents and insects and are more likely to be degraded by soil microorganisms. No-till systems do not have tillage to incorporate weed seeds, which concentrates the weed seeds near the soil surface where they are more likely to be degraded. More intensive tillage buries weed seeds deeper in the soil and results in a more uniform distribution of weed seeds in the soil.

Strip tilled field of soybeans
Photo credit - Jodi DeJong-Hughes

Weed seeds become more dormant when buried, which prevents them from germinating until they are brought back to the soil surface. No-till and minimum-till systems that concentrate weed seeds near the soil surface generally result in an increase in small seeded weeds that germinate at shallow soil depths. Large-seeded weeds generally decrease in prevalence with less tillage, as seed predators can easily find weed seeds on the soil surface and large-seeded weeds generally do not germinate unless incorporated. Although tillage system influences seed bank degradation and seed persistence, there is a large amount of variation among weed species (Table 1).

TABLE 1.
Weed seed persistence in soil. The approximate number of years it takes to reduce weed seed population by 50 and 99%. Adapted from Michigan State University, 2005.

	Species	50% reduction (years)	99% reduction (years)
Broadleaves	Lambsquarter	12	78
	Velvetleaf	8	56
	Redroot Piqweed	3	20
	Curly Dock	3	17
	Waterhemp	2	16
	Common Ragweed	1.5	10
	Giant Ragweed	0.5	2
	Kochia	0.5	2
Grasses	Yellow Foxtail	5	30
	Barnyard Grass	2	10
	Large Crabgrass	1.5	8
	Giant Foxtail	1	5

2 SOIL FERTILITY

Nutrient management practices will be affected by tillage system choices. For example, surface-applied nitrogen (N) fertilizer, such as granular urea or UAN solution, should be incorporated mechanically or by rainfall within three days of application to eliminate N loss from volatilization. Other N application alternatives in a reduced tillage system include applying urea or UAN to the side of the row with a coulter at planting time. Additionally, because anhydrous ammonia is injected into the soil, it is considered a minimum tillage pass.
Stratification of immobile nutrients in the soil does occur with no-till and shallow tillage, but in the Northern Corn Belt, this is rarely a problem for plant growth. Research shows that crops respond similarly to broadcast, planter-banded or deep-banded phosphorus (P) and potassium (K), regardless of tillage system.

It is more important to apply the P and K at rates recommended by the soil test. No-till and strip till greatly reduce P losses to surface waters. Injecting or subsurface-banding P also reduces dissolved P loss, compared to broadcast application (source: Antonio Mallarino, Iowa State University).

Livestock manure should be incorporated for maximum agronomic benefits and minimum environmental risk. This can be a dilemma in a minimum tillage system; nitrogen use is greatest when manure is applied before corn, but incorporation largely destroys fragile soybean residue, leaving the soil unprotected. In continuous corn systems, incorporating manure with a chisel plow or by injection allows for good residue management. New application tools, such as vertical manure injection, are being developed to incorporate manure with minimal soil disturbance.

Soil pH management can be an issue in long-term no-till fields. Surface applications of ammonium-containing fertilizer such as urea and UAN acidify the surface. Lime must be incorporated to be effective, as the neutralizing benefit migrates very slowly in soils that are not tilled. A grower may consider collecting soil samples separately from the 0-2 and 2-8 inch depth. Where acidification is present only at the surface apply one-third the recommended lime rate in no-till.

Farming is ever-changing. Practices that were at one time the norm have been replaced by more efficient, profitable, and environmentally sound systems. This is very true for tillage, where within one's lifetime moldboard plowing has been replaced by chisel plowing, and chisel plowing has been replaced by low disturbance systems such as strip till and no-till. Change is difficult for some, but those that are willing to break with tradition to try something different are often rewarded.

3 TRADITION, PERCEPTION AND PATIENCE

The perception of agriculture in today's society is changing. Currently about 1% of the US population is comprised of farmers (USDA-NASS Census of Agriculture). People less and less understand the intricate nature of modern farming practices and some believe meat and dairy products "come from the store". There is more frequent criticism for the consequences of what are commonly accepted farming practices. Examples include the siting of large animal operations (24,000 hog operation proposed on the shore of Lake Superior), movement of nitrate-N into the groundwater either through tile lines (City of Des Moines) or karst topography (Kewaunee Co. Wis.), and runoff of P into Lake Erie (NW Ohio). Tillage plays a role in many of these controversies, and while it might not solve all issues selecting the proper tillage system for one's operation, it will help keep the soil and nutrients on the land.

As farmers deal with change, they must display patience. They should be seeking to produce crops at the lowest cost per unit of yield possible. Tillage selection and how well it is implemented is a part of the calculation. Adaption to a tillage system may take a farmer time, as it is fine-tuned to the soil, crop rotation, and the farmer's ability. Patience will be an important key to reaching success.

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Credits:
Upper Midwest Tillage Guide is a collaboration between the University of Minnesota and North Dakota State University

Peer review by Richard Wolkowski, Extension Soil Scientist, Emeritus, University of Wisconsin - Madison

Economics of Tillage

Jodi DeJong-Hughes (University of Minnesota) and Aaron Daigh (North Dakota State University)

Farmers see an immediate benefit to leaving crop residues on the soil surface in regions with annual rainfall less than 20 inches due to soil moisture conservation. However, farmers are often reluctant to farm with more crop residue in Minnesota and the Eastern Dakotas, where higher precipitation, cool springs, and short growing seasons are common. The primary concern is the potential for slower crop growth and reduced yield due to cooler, wetter soils in the spring. Crop residue management is even more challenging when corn follows corn, or on poorly drained soils with a high clay content.

A HIGHER RESIDUE DOESN'T MEAN LOWER YIELDS

1 CORN AND SOYBEAN YIELDS IN A CORN-SOYBEAN ROTATION

Research by the University of Minnesota (UMN) and North Dakota State University (NDSU) showed that reduced tillage systems increased crop residue cover and reduced soil erosion while having a minimal effect on crop yields. These results are often accompanied by lower tillage management costs (equipment, fuel, labor) compared to those for aggressive tillage systems.

On-farm research conducted by UMN researchers from 2010 through 2012 in west-central Minnesota compared four full-width tillage systems with varying crop residue levels in a corn-soybean rotation. Tillage treatments included:

ST – Fall strip till: fluted coulter and residue managers, followed by a mole knife that operates six to eight inches deep, followed by notched coulters that builds a three to four inch berm.

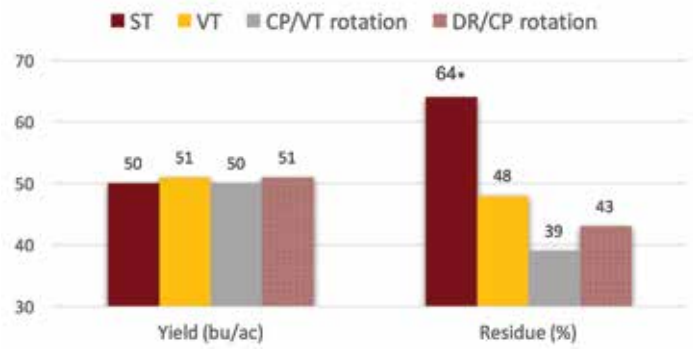
VT – Fall vertical till pass plus a spring vertical till pass: either large wavy coulters or a gang of coulters operated at less than 4 degree angle.

CP/VT rotation – Fall chisel plow plus spring field cultivation before planting corn rotated with a fall vertical till pass plus a spring vertical till pass system before planting soybeans.

DR/CP rotation – Fall disk rip plus spring field cultivation before planting corn rotated with fall chisel plow plus a spring field cultivation before planting soybeans.

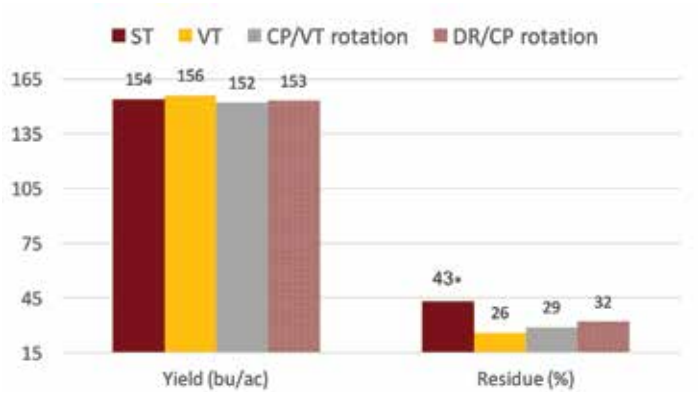
The study revealed that corn and soybean yields were not affected by the type of tillage system, although tillage costs were substantially lower with strip till. However, the type of tillage did affect crop residue levels. Strip till retained the highest crop residue cover following both corn and soybean planting, while the chisel plow/vertical till rotation had the lowest residue levels for following corn and soybean planting (Figure 1 and 2). These data show that Minnesota growers can increase profitability with reduced tillage (Table 1).

Figure 1. Average soybean yield and surface residue for three tillage systems near Clarkfield, Minnesota during 2010-2012.



* Yields are not statistically different from each other. Residue was significantly different with an LSD (0.10) = 7.

Figure 2. Average corn yield and surface residue for three tillage systems near Clarkfield, Minnesota during 2010-2012.



* Yields are not statistically different from each other. Residue was statistically different with an LSD (0.10) = 4.

For this study, costs per acre for a two year corn and soybean rotation ranged from $29.20 for strip till to $48.70 for fall disk rip and chisel plow rotation. Strip till saved $19.50 per acre over the DR/CP rotation with no loss in yield. By changing to strip till, a farmer could save almost $20,000 for a 2 year corn and soybean rotation on a 1,000 acre farm,

Figure 3. Soybean yield response to tillage for 17 site years across three locations in North Dakota and one location in Minnesota during 2005 to 2012.

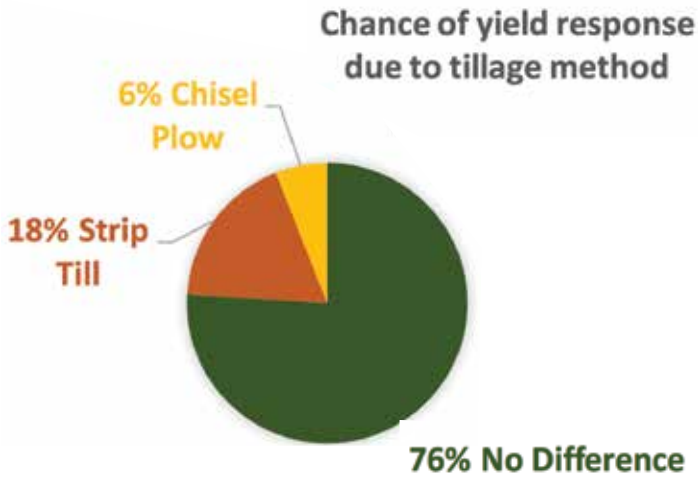


Table 1. Actual calculated tillage cost per acre using four different tillage implements options in a corn and soybean rotation near Clarkfield, MN.

	Corn Year Cost/Acre	Soybean Year Cost/Acre	2 yr Rotation Cost per Acre*
Vertical Till (2 pass)	$19.70	$19.70	**$39.40**
Strip Till	$14.60	$14.60	**$29.20**
CP/VT Rotation	$20.50	$19.70	**$40.20**
DR/CP Rotation	$28.20	$20.50	**$48.70**

*Costs includes tractor, fuel, labor, depreciation on new implement, parts and repair.

Table 2. Average soybean yields for three tillage systems at four locations in North Dakota and Minnesota during 2005 to 2012 (Nowatzki et al., 2011).

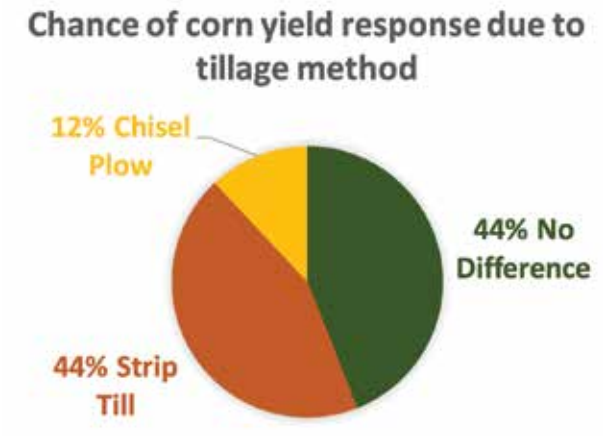
	Average Soybean Yield (bu/ac)			
	Fargo 5 site years	Carrington 4 site years	Prosper 4 site years	Moorhead 4 site years
Chisel Plow	28	28	52†	33
No-Till	29	29	--	--
Strip Till	29	30	48	40*

† Chisel plow had statistically higher yields in one of the four years.
* Strip till had statistically higher yields than chisel plow in three of the four years

Between 2005 and 2012, NDSU conducted a small plot tillage studies at three locations in North Dakota and one location in northwest Minnesota. Researchers found that 76% of the time, where soybean followed corn, yield was not affected by tillage (Figure 3). In the years where tillage type did have an effect on soybean yield, strip till had higher yields than chisel plow and no-till. In Carrington, when there was a yield difference, strip till and no-till had higher yields than aggressive roto-tilling (Table 2).

The results change slightly when growing corn following soybean or wheat. During 18 site years, 44% of the site years, corn yield was not affected by the type of tillage (Figure 4). When tillage treatment had an effect, strip till had higher corn yields than chisel plow and no-till 44% of the time, whereas chisel plow had higher corn yields than strip till and no-till only 12% of the time. In other words, more aggressive tillage only increased yield about one out of every nine site years.

Figure 4. Corn yield response to tillage for 18 site years across three locations in North Dakota and one location in Minnesota through 2005 to 2012.



In Fargo, ND the tillage treatments included chisel plow (two passes with a chisel plow and one field cultivation), strip till, and no tillage. The site was on a clay loam soil. Four out of the five years in Fargo, corn yield was not affected by tillage method (Table 3). At Carrington, ND the tillage treatments were aggressive tillage (two fall passes with a roto-tiller and two spring field cultivations), fall strip till, and no tillage on a loam soil in a wheat, corn, soybean rotation. There were no yield differences due to tillage over the five years of the study.

At sites in Prosper, ND and Moorhead, MN the tillage treatment included chisel plow (fall chisel plow with a spring field cultivation) and strip till. During the four years at the two locations, strip till had an average yield advantage of 14 bushels an acre (Table 4). If corn was priced at $3.30 a bushel, strip till resulted in a profit increase of $46 an acre, while reducing the cost of additional tillage passes and maintaining more residue.

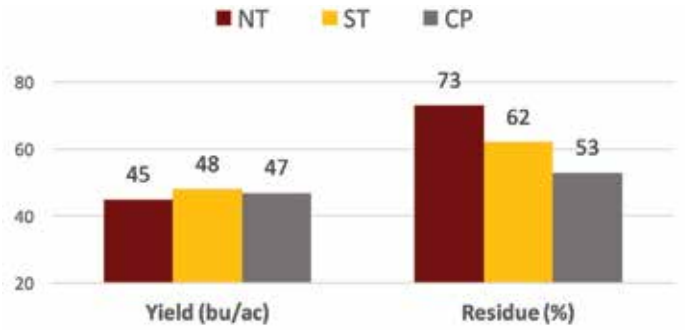
Table 3. Average corn yields for three tillage systems at four locations in North Dakota and Minnesota during 2005 to 2012 (Nowatzki et al., 2011).

	Average Corn Yield (bu/ac)			
	Fargo 5 site years	Carrington 4 site years	Prosper 4 site years	Moorhead 4 site years
Chisel Plow	130	145	184	161
No-Till	124	144	--	--
Strip Till	128	145	198*	175*

*Yields were higher for chisel plow than strip till in only the first year of the study. For the following three years, strip till had a higher yield than chisel plow.

In a separate 3-year study during 2006 to 2008 in southern Minnesota, UMN researchers compared soybean yield between chisel plowing plus spring field cultivation, strip till, and no-till for fields previously planted in strip tilled corn. Even with the higher residue levels, the type of tillage had no effect on the soybean yields during the three years (Figure 5). This demonstrates soybean adaptability among various tillage systems.

Figure 5. Average soybean yields and surface residue for four tillage systems near Jeffers, Minnesota during 2006-2008.



* Soybean yields were not statistically different due to tillage treatment.

"Researchers surmised that "the superior soil conditions may have facilitated greater rooting depth in the strip till treatments and may have contributed to higher yields, especially in drier years."

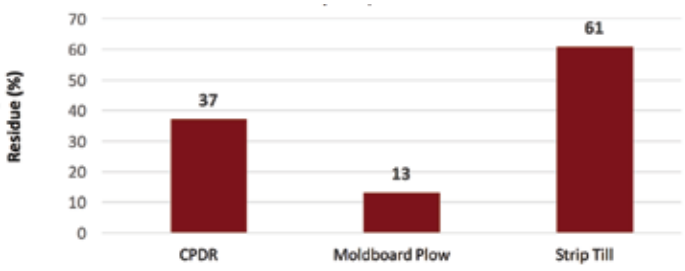
- (Franzen et al., 2013)

2 CORN YIELDS IN CONTINUOUS CORN

A UMN tillage study from 2008 to 2011 on poorly-drained loam and clay loam soils at four sites (two located at research centers and two located in full-scale farm fields) in southwest and west central Minnesota compared the effects of three tillage systems on continuous corn yields. Tillage treatments included moldboard plow plus one or two spring field cultivations (MP), strip till with a shank (ST), and chisel plow or disk rip plus spring field cultivation (CPDR).

Moldboard plow had the lowest residue levels averaged over the four locations at 13% (Figure 6). This level of residue is not sufficient to protect the soil from wind and water erosion and is the system with the highest fuel and time requirement of the three tillage treatments. The chisel plow/disk rip tillage treatment had almost three times the level of residue (37%) than moldboard plow and is considered adequate to protect the soil from erosion and maintain soil productivity over time. Strip till had the highest level of residue in the continuous corn system at 61% soil coverage.

Figure 6. Average residue levels for three tillage systems for 15 site years across West Central and Southern Minnesota.

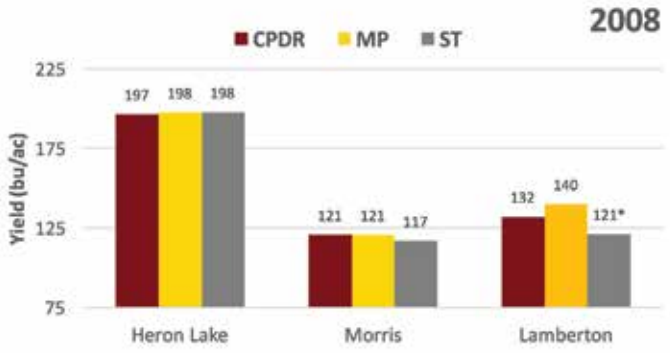


The continuous corn yields with fall strip till were similar to moldboard plow during the first year but lower in the second and third years except when a secondary spring strip-till pass was performed to manage the residue and warm the soil (Figures 7-10).

It was observed that the residue in the reduced tillage systems tended to build up in years 2 and 3 and covered the strip till berm creating a cooler environment for the seed. A second pass with a lighter, in-line coulter implement helped manage the residue and warmed up the soil similar to moldboard plow.

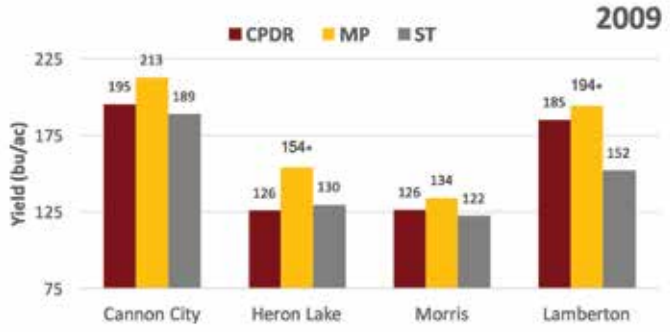
Yields shown in figures 8, 9, and 10 demonstrate this effect. In 2009, both Cannon City and Morris fall strip till plots received a secondary in-line coulter pass in the spring. In 2010, only the Cannon City fall strip till received the secondary pass in the spring. And in 2011, both Cannon City and Morris again received a secondary pass in the spring. When the second pass was added to strip till, the yields were statistically the same at moldboard plow and disk rip/chisel plow.

Figure 7. Average corn yields in 2008 for three tillage systems at three locations in West Central and Southern Minnesota.



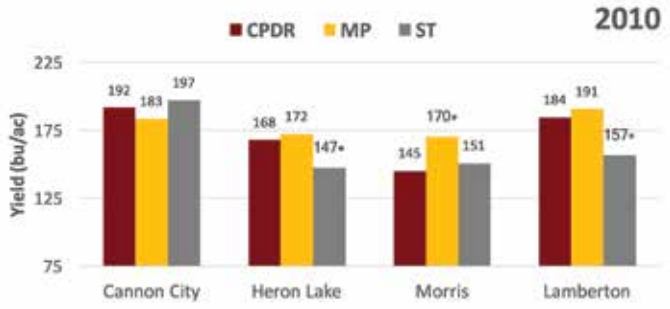
*Corn yields were not statistically different from each other except at Lamberton, where chisel plow and moldboard plow had a higher yield than strip till. Cannon City was not able to be harvested due to blow-down of corn.

Figure 8. Average corn yields in 2009 for three tillage systems at four locations in West Central and Southern Minnesota.



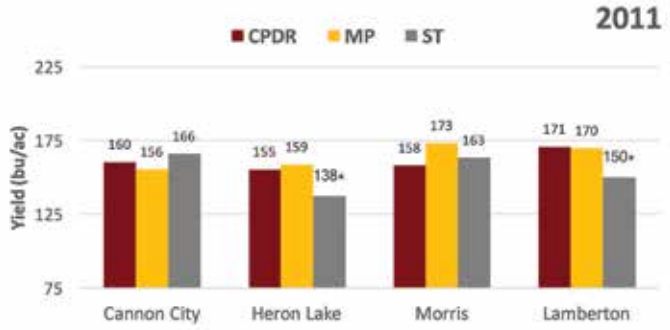
*Cannon City and Morris received a secondary tillage pass in the strip till plots. At Heron Lake and Lamberton, strip till had significantly lower yields with one pass of strip till and moldboard plow had higher yields than chisel plow and strip till.

Figure 9. Average corn yields in 2010 for three tillage systems at four locations in West Central and Southern Minnesota.



*Cannon City received a secondary spring tillage pass in the strip till plots. At the other three locations, moldboard plow had a higher yield than strip till and higher than disk rip at the Morris location.

Figure 10. Average corn yields in 2011 for three tillage systems at four locations in West Central and Southern Minnesota.



*Cannon City and Morris received a secondary spring tillage pass in the strip till plots. Statistically, moldboard plow had a higher yield than strip till with one pass at the Heron Lake and Lamberton locations.

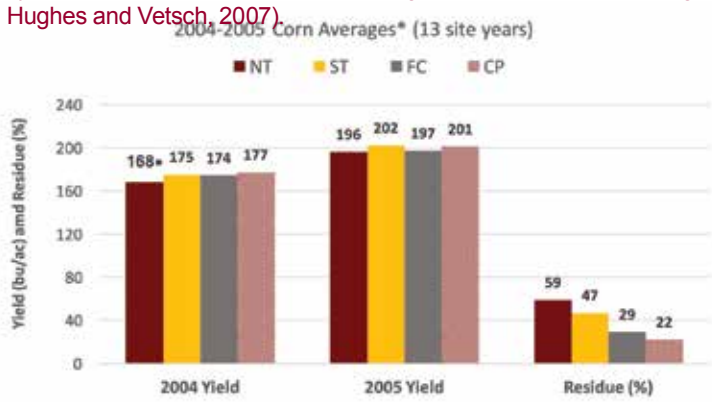
B ANNUAL WEATHER AFFECTS YIELD MORE THAN TILLAGE

An earlier UMN study in 2004 and 2005 across southern and west central Minnesota compared on-farm corn yields at 13 sites for chisel plowing plus spring field cultivation, strip till, one-pass spring field cultivation, and no-till. Tillage treatments had a larger effect on corn yields during 2004 when air temperatures were cooler than normal than during 2005 when air temperatures were warmer than normal (Figure 11).

In a cool spring, corn with no tillage yielded 6-9 bushel per acre less than the corn that received tillage. However, in a warmer than normal year, no-till yielded the same as the other tillage systems. The benefits of no-till included an average of 2.7 times more residue than chisel plowing with a field cultivation (Figure 11), and cost less per acre for equipment costs, tractor wear and tear, and labor.

Averaged over the two years, corn yields were similar among the chisel plowed and strip tilled fields while strip till had twice the residue. These results are the same as those observed in long-term small-plot tillage trials at Waseca, MN, where very little differences in yields have been observed among tillage systems in a corn and soybean rotation (Randall et al., 1987).

Figure 11. Average corn yields and surface residue for four tillage systems in Southern Minnesota during 2004 and 2005 (DeJong-Hughes and Vetsch, 2007).



*In 2004, no-till had yields significantly lower than the other tillage systems (LSD = 3 bu/ac) with no tillage affect in 2005.

C TILLAGE COSTS

1 TILLAGE COSTS WHEN GROWING SOYBEAN

Choosing the best tillage system for your farm is not a "one-size-fits-all" decision. It is similar to selecting hybrids to meet specific conditions and needs. When it comes to improving soil health and reducing soil erosion, while maintaining yields, it is not necessary to leave the field completely covered with residue.

Evaluating the economics of tillage systems is very complex. Depth and intensity of tillage should be adjusted based on factors such as the field's slope, soil texture, internal drainage, crop grown, and previous crop residue remaining. Consideration must be given to the initial and maintenance costs of equipment, the size of tractor needed to pull the tool, equipment depreciation, labor costs, conservation program incentives, and increased management costs related to fertilizer and pest management. In addition, there are human factors that influence the choice of tillage system, such as farming and family tradition, age, commodity markets, government programs, and neighbor perception.

It is important to compare differences in production costs when selecting a tillage system, as well as potential yield differences. Using the 2016 Iowa State University Custom Rate Survey, Table 4 illustrates four typical tillage options when planting soybeans into corn residue in the upper Midwest. One pass of tillage can cost $14-21 per acre depending on the implement. When planting soybeans, costs can range from $54.90 per acre for no tillage up to $85.15 per acre for chisel plow plus a spring field cultivation. This represents a $30 per acre difference. With soybeans at $9 per bushel, chisel plowed fields would need over 3 bushels per acre increase to pay for the tillage.

Fortunately, research has shown that soybean yields are more consistent across soil conditions and tillage options making no-till a viable and economical option. Standing stalks in no-till and strip till maintain more surface residue, improving water infiltration, and minimizing soil erosion. Therefore, many no-till and strip till farmers do not use a chopping head on their combine leaving stalks standing and lowering the cost of harvest. However, farmers who have high residue systems frequently will have residue managers on their planter, which increases the cost slightly from conventional planters.

Table 4. Cost of equipment options and number of tillage passes using four management options when planting soybeans.

	No-Till	Vertical Till or Field Cultivation	Chisel Plow + Field Cultivation	Strip Till
Planter (tillage specific)	$20.15	$19.90	$19.90	$20.15
Primary Tillage	$0	$14.05	$16.45	$17.15
Secondary Tillage	$0	$0	$14.05	$0
Combine	$34.75	$34.75	$34.75	$34.75
TOTAL COST/AC	**$54.90**	**$68.70**	**$85.15**	**$72.05**
# of passes	2	3	4	3

2 TILLAGE COSTS WHEN GROWING CORN

On the other hand, corn often needs incorporated fertilizers and seedbed preparation in the spring, which requires 2 to 4 additional field passes. This adds to the overall fuel costs, labor, and wear and tear on equipment. Table 5 uses four different tillage examples farmers may use when growing corn in the upper Midwest and the cost of each pass.

When fertilizing a corn crop, a majority of the fields with chisel plow, disk rip, or moldboard plow, the fertilizer is broadcast in one pass and then incorporated with a secondary tillage pass in the spring. Strip till saves a pass by applying phosphorus and potassium (nitrogen where appropriate) in the fall with the strip tiller and additional fertilizer can be applied with the planter and/or at side dress.

Using the 2016 Iowa State University Custom Rate Survey, strip till costs $40 less per acre than moldboard plow with two field cultivations in the spring. With corn priced at $3.30 a bushel, moldboard plow would need a yield increase of 12 bushels to pay for the extra tillage.

Chisel plow and disk rip with one pass of a spring field cultivation had similar rates and cost $25 more an acre than strip till but $16 less an acre than moldboard plow.

"Even with the higher residue levels, MN and ND research data shows yields remain similar in a corn-soybean rotation regardless of tillage method."

In some regions, no-till is an option when growing corn especially on sandier soils or in a rotation with very little residue from the previous crop. Fertilizer and lime are usually broadcasted with no incorporation and nitrogen may be side dressed after the corn has emerged. The cost for no-till is just over $66 per acre, which is half the cost of the moldboard plow system.

Table 5. Cost of equipment options and number of tillage passes using four management options when planting corn.

	Strip Till	Chisel Plow + Field Cultivation	Disk Rip + Field Cultivation	Moldboard Plow + Field Cultivation
Planter (tillage specific)	$20.15	$19.90	$19.90	$19.90
Side dress N Fertilizer	$11.15	$0	$0	$0
Broadcast Fertilizer	$0	$4.90	$4.90	$4.90
Anhydrous Ammonia	$0	$12.20	$12.20	$12.20
Primary Tillage	$17.50*	$16.45	$17.80	$18.80
Secondary Tillage (1st pass)	$0	$14.05	$14.05	$14.05
Secondary Tillage (2nd pass)	$0	$0	$0	$0
Combine w/o chopping	$34.75	$0	$0	$0
Combine with chopping head	$0	$40.10	$40.10	$40.10
TOTAL COST/AC	**$83.20**	**$107.60**	**$108.95**	**$124.00**
# of passes	4	6	6	7

*Strip till price includes the cost of applying fertilizer with the strip tiller. In continuous corn, ST may need an additional lighter tillage pass in the spring to 'freshen' the berm at a cost of $11.00 per acre.

D FUEL USE

Reducing tillage means fewer trips across the field, conserving fuel, time, and labor, and cutting machinery maintenance. The power requirement and fuel used for tillage equipment varies depending on the equipment design, number of row units, components used, soil properties, shank or disk depth, field conditions, and operator adjustments.

Fuel use rises with tillage intensity, depth, and increased number of passes. Effectively pulling aggressive tillage implements, such as a disk ripper or moldboard plow, requires that tractors must use lower gears and consume more fuel. Using a lighter, less aggressive tillage implement can save fuel costs by operating the tractor in higher gears. In a 2013 study at Iowa State University (ISU), fuel use was reduced 18% to 34% when operating the tractor in a higher gear and at reduced engine speed while maintaining travel speed.

In the same ISU study, raising disking depth from 5 inches to 3 inches saved 6% in fuel use. However, dropping tillage depth from 9 inches to 18 inches in continuous corn almost doubled fuel use, with no added yield advantage.

Another way to lower fuel costs is to eliminate a primary tillage pass or two secondary tillage passes.

ISU conducted another study comparing fuel usage with different tillage implements (Table 6). Moldboard plowing with two passes of a spring field cultivator would use 546 gallons more diesel ($1,910) than a shallow disking and 406 gallons more diesel ($1,420) than strip till over 1,000 acres.

Table 6. Cost of equipment options and number of tillage passes using four management options when planting soybeans. (Adpated from Hanna and Schweitzer, 2015)

Operation	Fuel Use (Gal/1,000 acre)	Cost per 1,000 acres (Fuel $3.50/gal)	Cost per 1,000 acres (Fuel $2.50/gal)
Shallow disking	35	$123	$88
Field cultivation	73	$256	$183
Strip till	175	$613	$438
Moldboard plow + 1 field cultivation	508	$1,778	$1270
Moldboard plow + 2 field cultivations	581	$2,034	$1,453

In 2015, researchers from the University of Manitoba partnered with the Prairie Ag Machinery Institute to calculate the cost of four tillage systems. The study, compared two passes with a double disk (DD), two passes with vertical till at a 6 degree angle (high disturbance or VT 6), two passes with vertical till at 0 degrees (low disturbance or VT 0), and one pass with strip till (ST). All were pulled by the same tractor, on a sandy loam soil, in corn residue. Residue levels after tillage were over 60% for strip till and low disturbance vertical till and under 30% for double disk and high disturbance vertical till. There were no differences in soybean yield due to tillage (data not shown), therefore, this study was able to use tractor and tillage costs alone to calculate a total cost per acre.

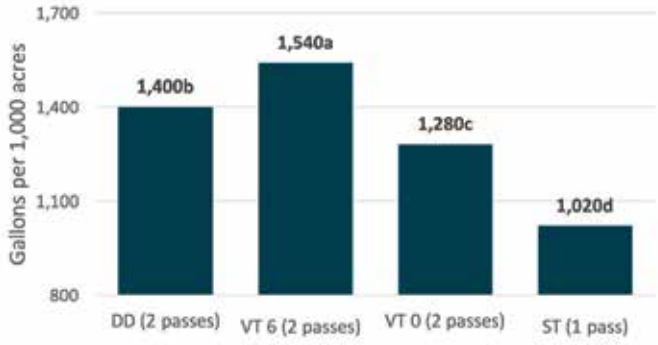
Both vertical till units could effectively run at a higher speed compared to either the strip till or double disk. This equated to more acres tilled per hour by vertical till, with 7 more acres an hour than strip till, and 10 more acres per hour than double disk (Figure 12).

Figure 12. Acres tilled per hour using a work rate efficiency of 80% for four tillage systems on sandy loam soil near MacGregor, Manitoba. (Adapted from Walther, 2017)

Fuel usage ranged from 1,020 gallons to 1,540 gallons over 1,000 acres, with strip till using the least amount of fuel (Figure 13). This is due to effective corn residue management with only one pass of the strip till equipment. Strip till used 34% less fuel than high disturbance vertical till.

Another way to reduce fuel usage is to lessen the aggressiveness of the implement. By reducing the angle of the gang from 6% to 0 on vertical till, 260 gallons less fuel was used (17%). While this research was conducted on a sandy loam soil, other studies have shown that the higher the silt or clay content, the higher the draft forces, and fuel usage can increase.

Figure 13. Fuel usage in gallons for four tillage systems on a 1,000 acre farm near MacGregor, Manitoba (Adapted from Walther, 2017).



When comparing tillage systems, keep in mind the cost of fuel per implement pulled, the depth of the implement, and the number of passes across the field. Small savings can add up across each field.

E LANDLORD BENEFITS

Across Minnesota and North Dakota, almost half of cropland is being rented by the operator. More than 74% of that land (23 million acres across Minnesota and North Dakota) is owned by landlords who have limited to no connection to the land (Table 7).

Table 7. Rented crop acre statistics for Minnesota and North Dakota (National Agriculture Statistics Service, Bigelow et al and Petrzelka et al).

	Total Acres in Cropland	Rented Cropland (%)	Rented Cropland Owned by Non-Farmers (%)	Total Rented Acres by Non-Farmers
Minnesota	26 million	45	78	8.1 million
North Dakota	39.3 million	49	74	14.3 million

Generally, land owners have a stake in the earning potential of the land that have more of an interest in soil health and conservation practices. A Utah State University study of absentee owners of farms or wooded acreage found that absentees express high environmental concern, especially those who used the land for recreation. When asked whether conservation is important on their property, 88 percent responded yes to soil, 56 percent said yes to wildlife and 66 percent said yes to water. However, the land owner may not be knowledgeable about their options or how to find programs or farmers who share their goals.

While farmers and land owners may have conflicting views regarding conservation and production practices, using no-till or strip till improves the long-term productivity of the soil and can represent both environmental and economic benefit for the land. It is worth a conversation with the land owner about the benefits of reduced tillage for preserving their land legacy.

In summary, yield differences from soil tillage is more often the exception rather than the normal. This is particularly the case for soybean yields as well as rotated corn systems. Due to the cost associated with soil tillage and the number of extra passes on fields, reducing soil tillage is a great means to cutting cost, labor, and soil erosion while promoting soil health and obtaining the same crop yields.

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