

# Conservation Tillage for Corn

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# Introduction

In the past decade, many changes have taken place in agriculture. One of the most recent involves tillage methods. Time constraints and economic pressure have caused the landowner to seek more cost-effective tillage techniques. In the past, the farmer may have made as many as 10 passes through the field in order to till, fertilize, plant, cultivate and harvest the crop. In some of today's systems, this can be limited to as few as two. In addition to the potential for greater net-profit, many of these practices have the advantage of improving surface water quality by reducing contaminant loads in the runoff water. For this reason, conservation tillage promises to be one of the most effective "best management practices" (BMP's) for controlling nonpoint pollution from cropland.

Several conservation tillage methods exist. Their impact on crop yield and water quality varies with soil type and geographic region. The purpose of this publication is to point out some of the practical aspects of the different conservation tillage systems in terms of their impact on water quality and crop production. A discussion of the water quality impacts of conservation tillage methods and their potential as a remedial measure for controlling nonpoint source pollution follows general background information and a description of the most popular systems. The final section reviews several factors relating to crop production.

## Background and Description of Systems

The purpose of tillage is to control weeds, incorporate crop residue and prepare a proper seedbed. The term "conservation tillage" is often used without adequate definition. In the context of this publication, conservation tillage (CT) refers to "any tillage system that attempts to reduce the loss of soil or water compared to unridged or clean tillage." To meet this criterion, the tillage system must leave a rough surface and/or unincorporated plant residue on the surface of the soil. The previous year's crop provides the residue which protects the soil from raindrop impact (Figure 1). This is especially important around planting time because no crop canopy exists to protect the soil. Generally, this is also the period when the most intense storms occur in Wisconsin. Increased roughness of the soil surface increases depression storage and, therefore, decreases the amount and rate of water runoff. Many different forms of

conservation tillage have been developed to meet these criteria. Systems vary in the degree of roughness and amount of residue retained on the surface. However, stalks are usually shredded prior to primary tillage (Figure 1).

As early as the 1940's, researchers were experimenting with reduced forms of tillage to control erosion. In New York, one of the first experiments substituted disking and field cultivation for moldboard plowing. It was not until the mid 1960's, however, that conservation tillage became feasible for the general farming public. Two developments made this possible: first, dependable herbicides became available that reduced weed competition and, second, planting equipment was developed that operated successfully in roughly tilled surfaces. Nationally, the acres tilled by CT systems are increasing by about 3 million per year.



900 pounds/acre



1500 pounds/acre



3600 pounds/acre



6300 pounds/acre

Figure 1. Increased erosion protection is provided by the crop residue retained on the soil surface.

# Tillage Systems

## Conventional Tillage Systems

Although CT systems are gaining in popularity, conventional tillage is still the most widely used practice. Farmers using this system generally shred plant residue prior to fall or spring moldboard plowing. Secondary tillage consists of one or two trips with a disk, field cultivator or roller mulcher before planting. The distinguishing feature of this system is the moldboard plow. This system combines moldboard plowing with tillage to provide a smooth, even surface for planting (Figure 2).

## Conservation Tillage Systems

### Disking

Tandem or offset disks, once used only for secondary tillage, now are the primary tillage tools for many farmers. Although standard disks are used for primary tillage, recently developed heavy-duty disks are better adapted for working corn ground after harvest. These heavy duty units feature large disk blades, normally 22 to 27 inches in dia-

meter and spaced 8 to 10 inches apart, that incorporate up to 70 percent of the residue to a depth of 6 to 7 inches (Figure 3). Often a second disking with a lighter standard disk occurs before planting. These disks till 3 to 4 inches deep and incorporate approximately 30 percent of the remaining residue.

### Chisel Plowing

This tillage system substitutes chisel for moldboard plowing (Figure 4). When possible, chisel plowing is done in the fall following shredding of the stalks. Secondary tillage before planting varies from none to one or two trips with a disk, field cultivator or rotary tiller. Chisel plows consist of two or three rows of curved or straight shanks attached to a rigid frame. Chisel points or shovels are attached to the shanks which are generally spaced 12 to 15 inches apart. Most chisel plows operate at a depth of 8 to 10 inches; when run deeper, the operation is generally termed "subsoiling." Chisel plowing leaves soil ridges and from 40 to 75 percent of the residue on the surface. The chisel plow is rapidly gaining popularity in Wisconsin (Figure 5).



Figure 2. The moldboard plow incorporates nearly all the residue by inverting the soil.



Figure 3. Large-bladed offset or tandem disks are now used by many farmers for primary tillage.

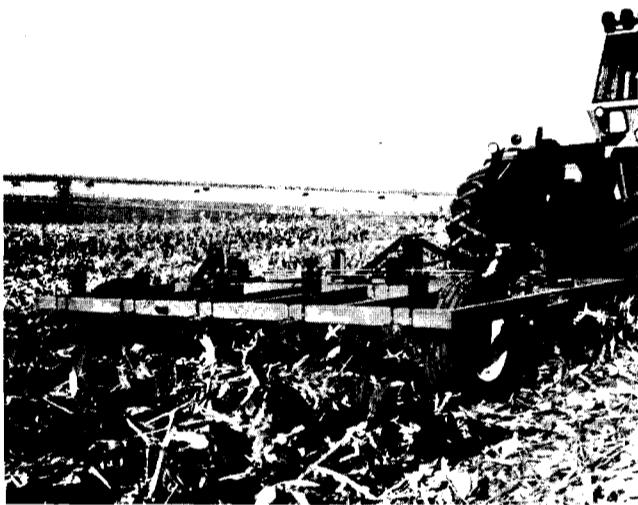


Figure 4. The chisel plow breaks up the plow layer and leaves 40-75 percent of the residue on the surface.

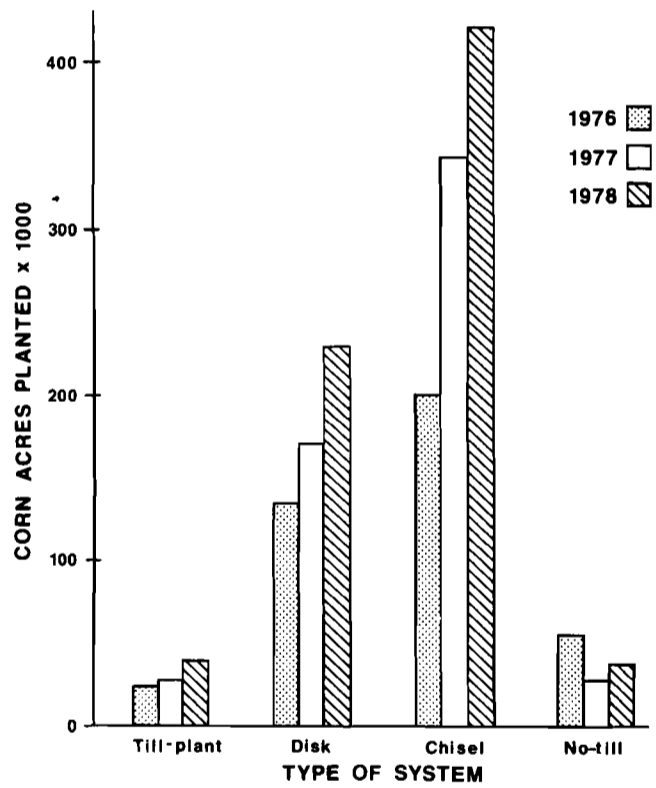


Figure 5. Chisel plowing is the most popular form of conservation tillage in Wisconsin (Enlow, J., USDA-SCS, Madison, Wisconsin, unpublished data).

## Till-Planting

This system combines tillage and planting into one operation. The planter plants in the ridges formed by the previous year's till-planting. An 8 to 10 inch sweep pushes the top 2 to 3 inches of the ridge aside and the deflector moves residue between the rows. A shoe opener behind the deflector places the fertilizer and plants the seed. A wheel for firming the seedbed, equipment to apply an insecticide, and a disk or drag to cover the seed and insecticide follow (Figure 6).

During the growing season, one or two cultivations are necessary. They control weeds and reconstruct the ridges for the next year's till-planting. Figure 7 shows the specialized cultivator used in a till-plant system. It has sweeps to uproot weeds and disk-hillers for building the ridges. Although there is no primary tillage, only 30 to 40 percent of the residue is left on the surface. As the planter sweep takes 2 to 3 inches of soil off the ridge, it not only exposes the ridges but also buries a portion of the residue between the rows.

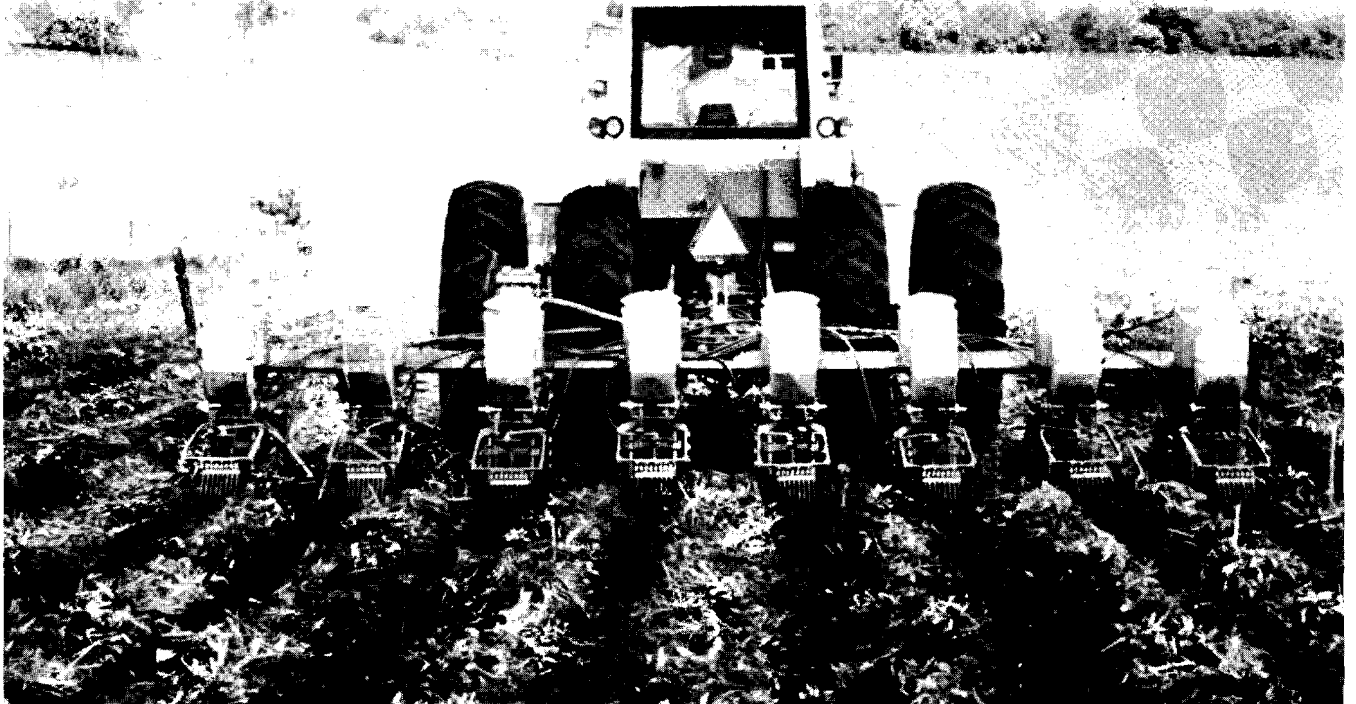


Figure 6. The till-planter combines tillage and planting into one operation. The seedbed is left smooth and clean while crop residue is left between the rows.



Figure 7. At least one cultivation is recommended with the till-plant system. This will clean out weeds between the rows and re-establish a ridge to plant on the following year.

### No-Till Planting

The no-till system disturbs the soil least of all the CT techniques (Figure 8). This one-pass tillage and planting operation opens a slot approximately 2 inches wide for seed placement. The soil is usually tilled with a fluted coulter running ahead of a planter unit. Other than the 2 inch slot opening, the soil is not disturbed. Consequently, more than 95 percent of the residue is left on the surface.

### Other Systems

Other systems used to a limited extent include listing, ridge farming and rotary tillage. However, they have not gained widespread acceptance because of their high operational cost or inadequate equipment design.



Figure 8. Fluted coulters, located in the front of the no-till planter, open a 2 inch slot for seed placement. Otherwise, the soil is not disturbed.

# Evaluation of Conservation Tillage Systems as a Best Management Practice for Controlling Nonpoint Pollution

Runoff from cropland is a basic example of agricultural nonpoint pollution. The runoff waters may contain sediment and dissolved nutrients, contaminants which can reduce water quality. The single largest pollutant to the nation's surface waters is sediment. In addition to problems caused by physical deposition, sediment carries the bulk of the nitrogen (N) and phosphorus (P) load, as well as adsorbed pesticides and toxic metals. The dissolved nutrient portion of the runoff, while a small percentage of the total load, is readily available to aquatic weeds and algae and can be one of the most important indicators of the quality of the runoff water.

Generally, traditional soil and water conservation techniques, such as cover crops, strip cropping, contouring and terracing, succeed in controlling runoff and erosion. However, these systems usually involve some cost and do not logically fit into all farming operations or specific fields. For example, cover crop rotations are impractical for a continuous corn operation. One of the most flexible methods in controlling runoff in this situation is some form of conservation tillage. Thus, CT is viewed as a "best management practice" (BMP) for limiting nonpoint pollution from these potentially high nonpoint source areas. This portion of the publication will evaluate the water quality aspects of the various CT systems.

## Effect of Conservation Tillage on Soil Erosion

Conservation tillage systems, which were successfully developed in the mid-1960's, are effective in reducing soil erosion on cropland. Initial development of these practices was aimed at maintaining soil productivity. Later, scientists began to realize the secondary benefits of CT systems for reducing inputs of sediment and sediment-bound phosphorus into lakes and streams.

The effectiveness of conservation tillage in reducing soil erosion is explained by the influence these tillage systems have on the following soil surface condition variables: 1) percent of soil surface covered by residue, 2) surface roughness and ridges, 3) soil incorporated residue, and 4) soil detachability. The interaction of these variables accounts for a reduction in either sediment concentration in the runoff or volume of water, or both. Before discussing these interactions, a description of the erosion process is provided to demonstrate how CT systems influence these variables.

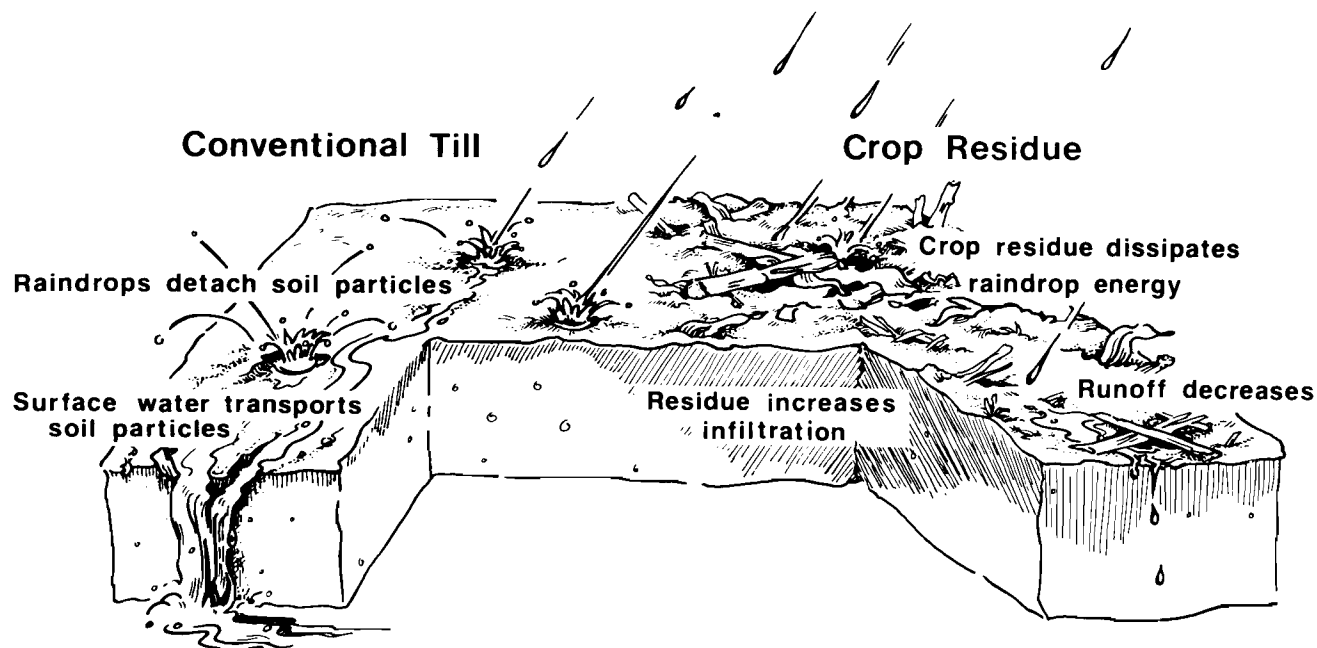


Figure 9. Note the increased erosion and runoff on conventionally tilled soil as compared to soil with crop residue. (Illustration by Sue Halvorsen.)



## The Erosion Process

The erosion process is one of both detachment and transport caused by rainfall and runoff (Figure 9). This process can be thought of as four separate but interrelated phases: 1) detachment by rainfall, 2) transport by rainfall, 3) detachment by runoff, and 4) transport by runoff. Most of the kinetic energy of raindrops is dissipated at the soil surface. It has been estimated that the kinetic energy of an intense summer storm can equal 900 foot-tons/acre. Obviously these storms have a high capacity for soil detachment, especially if the soil surface is not protected by plant residue or crop canopy.

The initial phase of the erosion process is brought about by the raindrop impact dislodging (detachment) soil particles (Figure 9). Some transport of soil material occurs during splash action. However, this is secondary to the major transport mechanism of surface runoff. The raindrop-splash-action process plays a major role, however, in accelerating erosion. As these particles are deposited, they tend to clog up the ports-of-entry of water into the soil, producing a condition called surface sealing or crusting. Infiltration of water into the soil is greatly reduced under these conditions and, if the rainstorm continues, water begins to collect on the surface and the runoff process begins (Figure 9).

Because runoff is the major means by which soil particles are transported, it is understandable that the more runoff, the greater the amount of erosion. Therefore, to control erosion, remedial measures must get at the source of the problem. To be effective, such practices must minimize the raindrop impact, limit surface sealing (crusting), and maintain or increase infiltration of water into the soil. When this is accomplished, erosion is minimized because the volume of runoff and/or sediment concentration is reduced. Several interrelated factors—residue cover, soil roughness and direction of tillage—are involved in accomplishing these goals. The following discussion examines these factors within the CT systems and their role in controlling erosion.

### Residue Cover—Raindrop Impact

Walter H. Wischmeier, an early worker in erosion control, conducted perhaps the most extensive research describing the factors responsible for reduced soil loss using CT systems. His studies showed that the percent of residue cover left on the soil surface is an important factor in determining the amount of soil loss. The effectiveness of surface residue in reducing soil loss has also been confirmed by several other researchers. A Midwestern study, for example, evaluated the effects of six rates of straw mulch following plowing on a silt loam (5 percent slope). These workers found that 0.25, 0.50, 1.0, 2.0, and 4.0 Tons/Acre of straw mulch reduced soil loss by 75, 83, 98, 100 and 100 percent, respectively, compared to unmulched plots. Results from similar investigations indicate that comparable mulch rates are effective in reducing soil loss on slopes

averaging as high as 15 percent. Obviously, residue is important; data indicate that under ideal conditions (a rare occurrence in most fields) erosion on rather steep slopes can be completely eliminated by high amounts of residue (2 Tons/A). Surface residue is effective in reducing erosion because it: 1) absorbs the kinetic energy of the raindrop which is responsible for particle detachment and some transport, and 2) decreases the rate of soil crusting and subsequently increases infiltration (Figure 9).

Because tillage systems vary in the amount of residue left on the surface, the rates of erosion and runoff between systems also vary (Figure 10). Except for the chisel plow system, a direct relationship exists between the amount of residue and rates of erosion. Runoff and erosion are highest under the conventional system which has little or no residue and lowest for the chisel system which combines residue and soil roughness to reduce erosion.

### Soil Roughness

Another factor influencing the amount of runoff and erosion is the roughness of the soil surface. To an extent, the rougher the soil surface, the greater the infiltration and depression storage. Surface crusts which may have existed prior to tillage are broken up and water infiltrating into the soil is increased. Also, the many clods and crevices that exist under a rough soil surface act as small dikes and dams, greatly increasing the ability of the field to store water

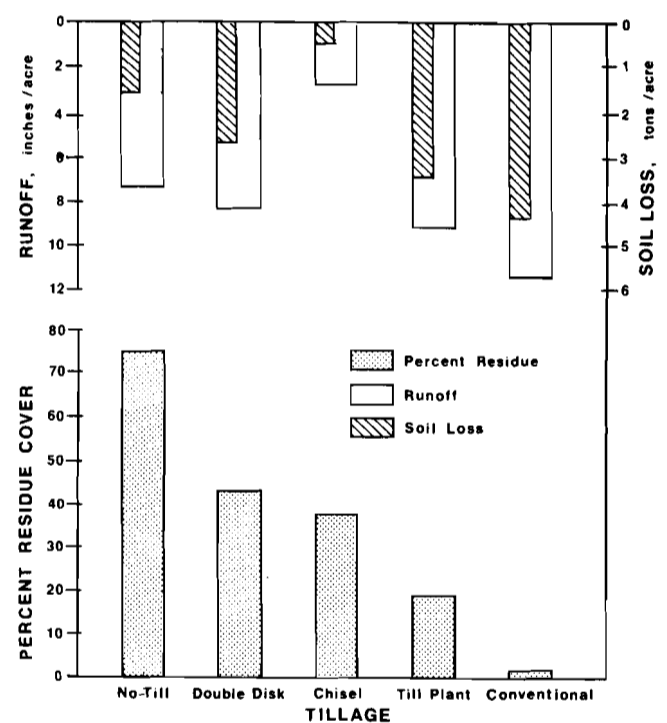


Figure 10. Effect of tillage on the percent residue remaining on the soil surface, volume of runoff, and soil loss (Romkens et al., 1975. *Nitrogen and Phosphorus Composition of Surface Runoff as Affected by Tillage Method*. *Journal of Environmental Quality* 2(2):292-295).

(depression storage). The net result is reduced erosion and runoff. In studies on a silt loam soil conducted in Indiana, three levels of soil roughness were developed by varying the type and amount of tillage (Figure 11). These studies found that surface roughness is a major factor in determining the amount of both runoff and soil loss. Roughness, the researchers concluded, increases water storage and reduces the velocity of the runoff.

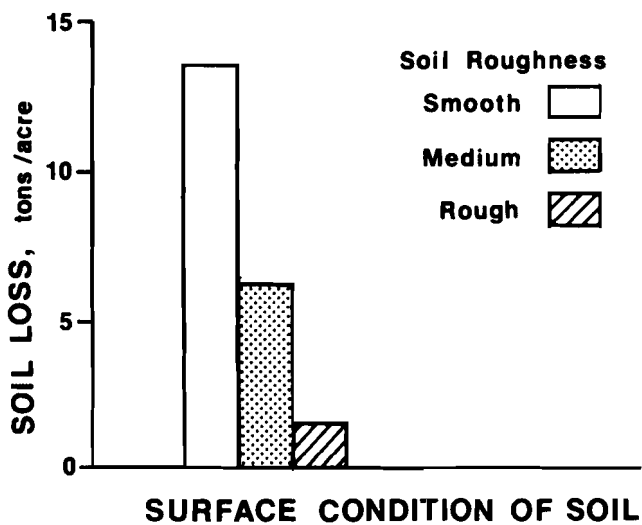


Figure 11. Effect of soil roughness on erosion (Johnson, C. B., et. al., 1979. *Soil Science Society of America Journal* 43:772-777).

At first glance, it appears that conventional plowing (moldboard) should be a recommended erosion control practice. Of all tillage practices, this one produces the roughest soil surface. However, it must be pointed out that crusting, even on a rough surface, will develop quickly if little surface residue is present. Researchers in Minnesota, for example, found that a single intense storm can effectively seal even the roughest surfaces and, consequently, drastically reduce infiltration. Where surface residue exists, high infiltration rates are maintained for a longer period of time. However, either factor (residue or roughness) operating alone will not produce the reductions in erosion and runoff that are possible when the two variables interact. The combined effect of residue and roughness is clearly demonstrated in Figure 10. Greatest reduction in runoff and erosion occurred when the chisel system was used. Soil loss values of less than 1 Ton/Acre are common under this system and these values approach natural levels. Clearly, the data indicate that the chisel system maximizes the interaction between surface residue and roughness into a tillage practice which minimizes erosion and runoff.

#### Direction of Tillage

There are several implied management factors which are basic to the successful operation of any CT system. Close supervision of potential weed, insect and disease problems, for example, is a must. Likewise, erosion control must be

maintained. We cannot disregard proven erosion control practices for the mistaken belief that CT systems control erosion regardless of management.

Perhaps the single, most cost-effective measure in controlling erosion is tilling across the slope as opposed to up-and-down slope farming. Figure 12 clearly demonstrates that under the conventional system, erosion losses can be reduced 50 percent by simply plowing across the slope. Erosion losses from chisel plowing up and down the slope are 10 times higher than from chiseling across the slope and comparable to losses obtained from conventional systems. Clearly, there is little benefit when these basic principles are ignored. In fact, additional problems can develop; poor stands and reduced yields are not uncommon because, as the runoff channels downslope in the seedbed, the seeds may be washed out.

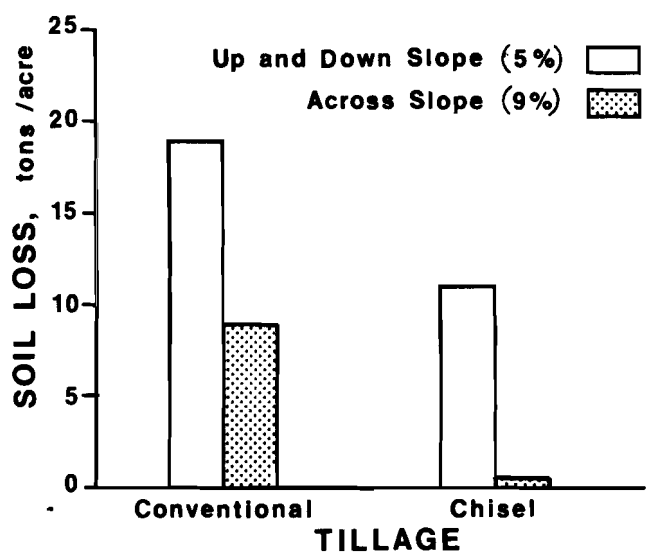


Figure 12. Effect of direction and type of tillage on the amount of soil loss (Mannering, J. V., 1979. *Conservation Tillage for Erosion Control and Improved Water Quality*. Department of Agronomy, Purdue University, Lafayette, Indiana.)

#### Effect of Conservation Tillage on Phosphorus Loss

Nutrient transport to lakes and streams is cause for concern because it can increase the growth of aquatic weeds and algae. Of all the elements known to influence aquatic growth, phosphorus (P) is the key nutrient to limiting overfertilization of natural waters (eutrophication). Two reasons often cited are 1) phosphorus is often present in natural waters at concentrations which limit growth, and 2) phosphorus inputs most often result from man's activities, not natural sources and, consequently, can be controlled.

The forms of P in natural waters are many and varied. Some phosphorus is dissolved in the water; some adheres to soil particles and is available to algae under certain conditions. In terms of water quality, however, the two most meaningful runoff variables (parameters) are total P and that portion available for aquatic plant growth. Total P load is important because it provides an estimate of the total reservoir of P (sediment and dissolved) entering the surface waters and allows investigators to judge long-term water quality impacts. For an estimation of the more immediate water quality impacts from runoff, investigators look for the amount of P available to algae. A recently developed procedure helps them determine the amount of P already in solution and that adsorbed onto soil particles available to algae. This portion is termed algal available P (AAP) and is a reliable indicator of runoff impacts on water quality.

Because the water quality aspects of runoff are relatively new compared to erosion considerations, the total picture in terms of P loadings (amount/unit area/time) from agricultural runoff is just coming into focus. It is clear, however, that commercial P fertilizers contribute little, if any, to the P load reaching surface waters if properly managed. Midwestern researchers compared broadcast surface applications of P to the more traditional methods of banding or incorporation. Their data showed that, if broadcast, the P in the commercial fertilizer could be transported by the runoff and thus would have no economic value to the farmer. However, if soil incorporated, P levels in the runoff were comparable to loads from other areas not receiving fertilizer. Similar findings from other watershed and plot studies have confirmed these results.

Total P loading is directly related to the sediment load. Researchers consistently confirm that approximately 90 percent of the total P load is associated with the sediment. Thus, dramatic reductions in erosion rates transfer into similar reductions in the total P loads. Clearly, loadings of this parameter are best limited by controlling erosion.

Because of limited data, it is too early to clearly define the effect of conservation tillage on the P fractions available to algae. Two aspects of the parameter are of concern: 1) that portion dissolved in the runoff water and 2) that portion adsorbed by the soil particle available to algae. Increased surface residue is a major objective of any CT system. Because of this, an increased concentration of dissolved P has been shown to occur in the runoff from conservation tilled land. As the residue undergoes decomposition, the dissolved P in the plant cell is easily leached out in the runoff process. It is unclear whether this increase in concentration results in increased loads of available P. However, preliminary data from Wisconsin have shown that, even though the concentration of available P in the runoff from CT plots may be higher than from conventionally tilled plots, the reduced volume of runoff results in reduced loadings of AAP (Figure 13). We need additional information before making any sound conclusions concerning

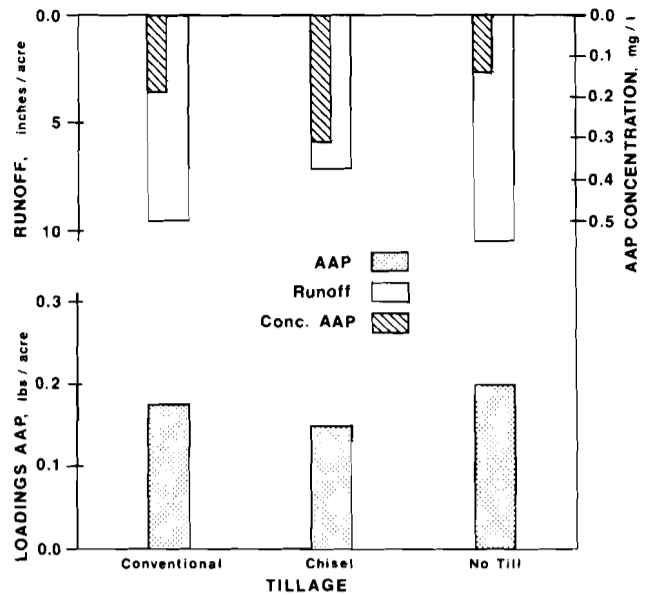


Figure 13. Effect of tillage practices on the loadings of algal available P. (AAP). (Mueller, D. H., 1979 M.S. Thesis, Department of Soil Science, University of Wisconsin-Madison).

available P loadings from CT systems. However, the initial results appear optimistic due to the interaction between concentration and runoff.

### Summary

Clearly, conservation tillage systems are effective in minimizing sediment loads to streams. If properly managed, CT systems dramatically reduce soil erosion and, in turn, the total P loads. Still unclear, although the initial results are promising, is the question of their effect on available P load. Also, the fertilizer program recommended for CT systems does not appear to present a problem in terms of water quality. The chisel plow appears to maximize the interactive effect between residue and soil roughness into a system which limits erosion and potential available P problems.



# Tillage Effect on Soil Condition and Plant Growth

A crop's immediate environment can vary substantially with different tillage systems and, as a consequence, can affect yield. Some important environmental factors are soil moisture, soil temperature, soil structure, weeds, disease and insect control, seed-soil contact and nutrient availability. This section will briefly describe how these soil characteristics are influenced by conservation tillage practices. The discussion will center around corn, the primary row crop adaptable to CT practices in Wisconsin.

## Soil Moisture

Soil moisture content is generally increased when CT systems are used. Increased water infiltration and reduced evaporation are the primary reasons for this. Therefore, on droughty soils or during years when rainfall is inadequate, CT practices can significantly increase yields. However, with no-till on clay soils, soil compaction will reduce infiltration. Reduced infiltration, however, may be offset by reduced evaporation—the result of lower soil temperature.

## Soil Temperature

Soil temperatures are particularly important to the early growth of plants. Several researchers have shown that increased surface residue and fine soil textures (clays) slow the rate of soil warming in the spring (Figure 14). Because Wisconsin's early spring soil temperatures are well below the optimum growing temperature for many plants, increased surface residue can cause further delay in germination, emergence and early growth.

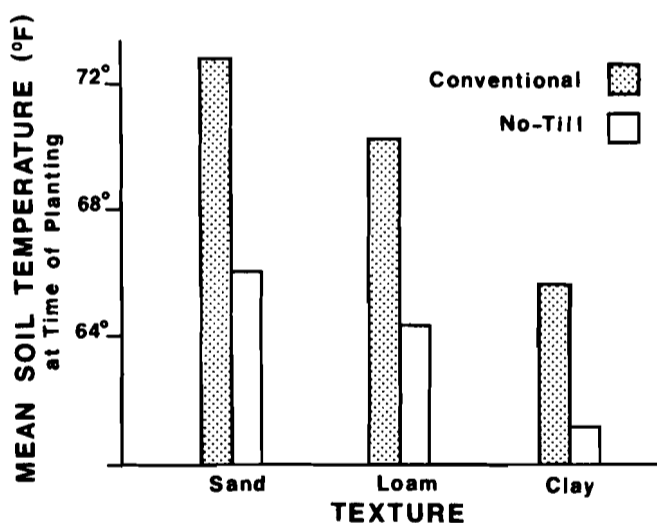


Figure 14. Effect of soil texture and type of CT system on soil temperature (Mueller, D. H., 1979, M.S. Thesis, Department of Soil Science, University of Wisconsin-Madison.)

Different types of tillage systems leave varying amounts of residue on the surface and, as a result, soil temperatures also vary with the season and time of day (Figure 15). Studies in Indiana have found a difference of 1-8°F between no-till and conventional practices. Other CT systems influence the temperature but not to the extent of the no-till system. As we will point out later, these temperature reductions on CT land are a major factor in explaining reduced yields for no-till in northerly climates such as Wisconsin's.

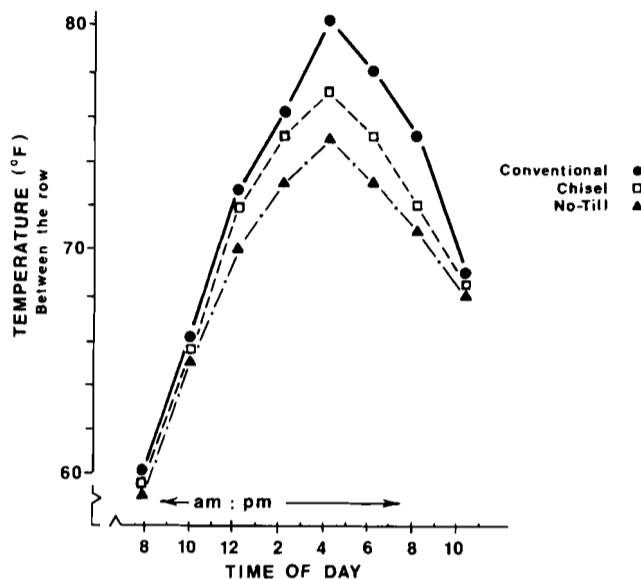


Figure 15. Effect of tillage practice and time of day on the rate and extent of soil temperature warm up (Moncrief, J., 1979, Department of Soil Science, University of Wisconsin-Madison, unpublished data. Lancaster Experiment Station corn plots. June 3, 1979. Two-hour interval temperature readings.)

## Weed Control

Until the mid-1960's when dependable herbicides were developed, weed problems were the major obstacle to CT use. Even now, weed control is a great challenge facing CT because all weed seeds remain at or near the soil surface and the accumulated surface residue intercepts and inactivates applied herbicides.

Specific herbicide recommendations depend on the soil type, amount of organic matter and weed species. However, researchers generally advise that the maximum recommended herbicide rate should be used when corn is planted using CT methods. There are two reasons for this recommendation. First, weed seeds accumulate at the surface and exert greater weed pressure than with conventional tillage and, second, surface residue not only intercepts pre-emergence herbicides but also inactivates part of

the application. When dense, green weed growth is present, some herbicides may be more effective when applied with greater amounts of water. Another problem with herbicide use occurs when rainfall is inadequate. Without sufficient moisture, herbicides will not activate, thus allowing more annual weed seeds to escape. Except on no-tilled land, this problem can be partially alleviated by cultivation. Weed control on no-tilled land is often more difficult than on land tilled using other CT systems. This is because no-tilling provides the least incorporation of residue and weed seeds and because mechanical cultivation often is impossible.

Deep-rooted perennial weed problems also tend to increase with conservation tillage systems. These can generally be controlled with appropriate selective post-emergence herbicide treatment but they may require treatments that crop producers are less familiar with. In addition, some problem annual weeds, such as wild cane or wild proso millet, or persistent perennial weeds, such as yellow nutsedge, require uniform herbicide incorporation to a soil depth of 2 to 3 inches. To accomplish this, appropriate soil incorporation implements need to run up to 6 inches deep. Where such problem weeds prevail, no-till crop production is out of the question. Growers may need to compromise between conservation tillage practices and weed control methods, if these problem weeds are present.

### Insect and Disease Control

Insect problems in corn are brought about by pests located in or above the soil. Researchers believe insects found in the soil pose the more serious threat when CT practices are used because proper incorporation of insecticides is difficult to achieve. In the Midwest, cutworms, wireworms and grubs (particularly following hay crops) are likely to cause the most serious problems on CT corn. Army worms and stalkborers are the two most damaging above-ground insects in CT fields. Other pests include flea beetles, bill bugs, seed corn maggots and corn borers.

The risk of disease is enhanced whenever there is a significant increase in the amount of residue left on the surface. For example, eyespot is a leaf disease shown to be more severe on corn grown under a CT system. Similar results have occurred with stalk rot. However, such corn diseases can be minimized by growing disease-resistant or disease-tolerant hybrids or by using crop rotation to break their cycle.

Results from long-term CT studies indicate that disease and insect problems are not as severe as first anticipated. Problems, however, have been shown to occur. Fortunately, these problems were localized rather than covering a broad geographical region. And generally they can be corrected through good management. Of course, good management requires a higher degree of in-the-field inspection and supervision.

### Fertility

Because the CT systems are relatively new, some questions remain concerning the effect these systems have on soil fertility. Part of this concern results from conflicting research findings from studies conducted in different geographic regions. It is clear, however, that CT systems are influenced greatly by local conditions, and this must be kept in mind when results are considered. Generally, the areas of concern are nutrient availability and the appropriate method of fertilizer application.

### Nutrient Availability and Method of Fertilizer Application

Because of the increased residue and reduced tillage, CT systems produce different conditions at the soil surface from those normally encountered with the conventional system. These deviations include differences in moisture, temperature, organic matter content and rate of decomposition, microbial population, etc. All of these differences influence the availability of nutrients and, in turn, fertilizer programs.

For several reasons relating to organic matter decomposition, it is possible that nitrogen (N) deficiencies will occur during the first years after converting to some form of CT, especially with the no-till systems. The exact reasons for this deficiency are not clear, but the lower soil temperatures and higher water content can cause more N to be immobilized by the crop residue, leaving less N available for the growing crop (Figure 16). Some evidence indicates that after several years of CT, a more stabilized system develops in which N fertility no longer varies from

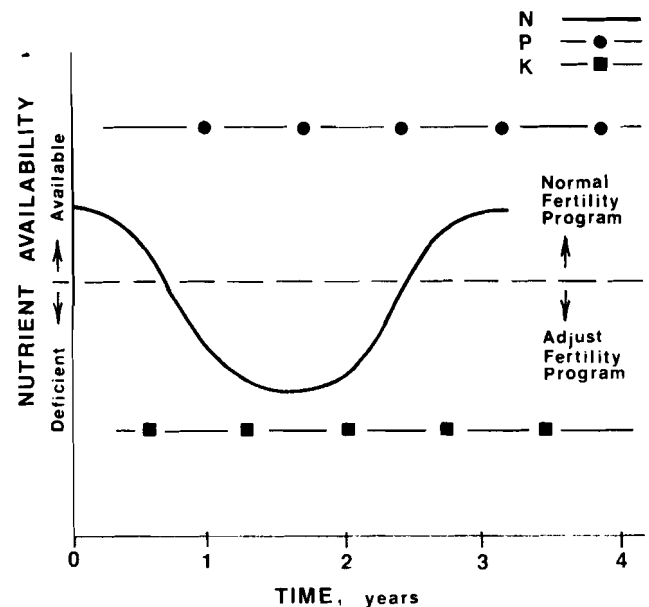


Figure 16. Anticipated effect of no-till on the availability of nutrients for plant growth (Extrapolated from Mueller, D. H., 1979, M.S. Thesis, Department of Soil Science, University of Wisconsin-Madison).

conventional systems. Conservation tillage systems also have the potential for greater gaseous losses of surface-applied fertilizer N due to the increased soil water content and, from this standpoint, injected fertilizer N may prove to be important for minimizing these losses.

Broadcast phosphorus (P) is equally or more available under no-till compared to the conventional system (Figure 16). According to researchers, this phenomenon occurs despite the fact that broadcast P accumulates in the top centimeter of the soil under no-till due to lack of incorporation and movement through the soil profile. It is reasoned that the residues on the surface allow sufficient moisture near the surface for root growth and uptake of P.

Unlike P, there is disagreement about the availability of potassium (K) under CT, particularly no-till. Several studies in West Virginia have shown that surface-applied K presents no nutrient deficiency problems in no-till corn. In contrast, several researchers in more northerly climates have found decreased K availability. In Ontario, it was found that K was less available when it was disked in than when it was plowed down or side banded. In Indiana, researchers found that available K was reduced on no-till plots when K was broadcast. However, they reported plant tissue K was adequate if initial soil K was medium or high. In a preliminary study conducted in Wisconsin, researchers found that broadcast K was less available on no-till plots and contributed, at least in part, to lower yields. The reduced K availability appeared to be due to greater soil compaction under CT systems. They also reported that side banding K increased its availability and, in turn, increased K in leaf tissue. These investigators pointed out that there is a limit to how much K can be side banded and stressed the importance of applying corrective K and plowing it down prior to implementing CT systems.

In summary, with the exception of no-till, adverse nutrient deficiencies would not be expected to occur from the use of CT systems. Because of greater soil compaction and surface residue using no-till, the fertility program must be watched closely in order to prevent N and K deficiencies. However, these problems may be avoided by following soil test recommendations. Phosphorus does not appear to present any problems, even with no-till.

## Yield

Profit margin is an essential consideration for the farmer. Higher net profits can be realized from CT systems provided the type of system selected fits the local soil and plant condition. Soil texture and internal drainage are important soil characteristics influencing yields from CT systems. In 20 years of reduced tillage trials at Arlington, Wisconsin, corn on plowed plots averaged about 6% higher yields than corn on unplowed plots (Plano silt loam). In an extensive study in Indiana, researchers found that when no-till was used on poorly drained soil, yields were considerably lower than with the conventional system.

In contrast, yields for all CT systems on well drained soils were equal to or greater than the conventional systems. Poor weed control, lower plant stands, and slower growth rate in the spring were given as reasons for reduced yields on the poorly drained soils. Similar findings have been shown to occur in states such as Iowa, Illinois, Ohio and Michigan.

Most investigators agree that the effect on yield results from an interaction of several factors. Clearly there exists a soil temperature-moisture relationship on yield. Factors known to influence this relationship include soil texture and drainage, type of CT system, climate and geographic region. Soil temperature appears to be one of the most important factors affecting yield. Apparently for the Great Lakes region, the lower soil temperatures (up to 8°F lower) in the spring bring about several conditions which result in reduced yield. These may include reduced stands brought about by lower and slower germination rates, reduced nutrient availability, increased susceptibility to disease and decreased herbicide effectiveness. The magnitude of the temperature effect depends upon the system being used. Because of the amount of residue left, no-till will have the greatest effect and conventional will have the least. Other systems fall somewhere in between.

Soil texture and drainage are also important (Figure 17). Fine textured soils (clay) naturally take longer to warm up in the spring than coarse textured soil (sands). Because the moisture content of the soil will also influence the rate of warming, the inherent drainage of the soil is important. Well drained soils will be warmer in the spring than their poorly drained counterparts. Where temperature and compressed growing season are already critical due to the climate or geographical region, the small reduction in temperature caused by CT systems can have a dramatic impact on yields. This certainly explains the

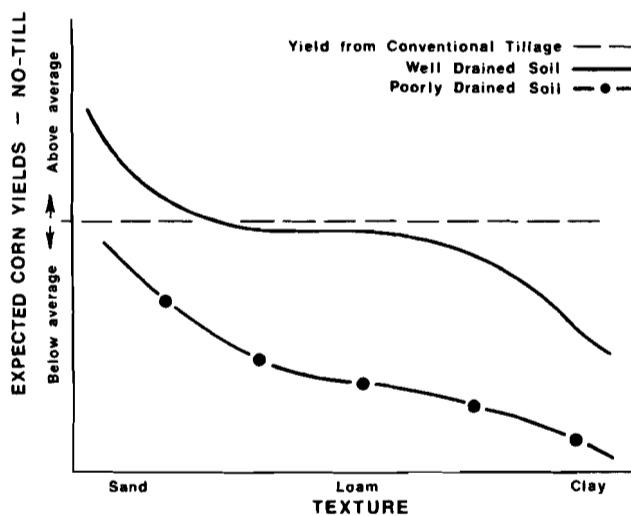


Figure 17. Anticipated effect of soil texture and drainage on no-till corn yields (Extrapolated from Mueller, D. H., 1979 M.S. Thesis, Department of Soil Science, University of Wisconsin-Madison).



success that the southern states have had with no-till and specifically why it appears to work better in some areas of the Great Lakes states (south) than in others (north). In some situations, the soil temperature-moisture relationship existing in CT situations can contribute to increased yield. For example, on coarse textured soils (sands) where moisture stress is the factor limiting yields, the increased soil moisture brought about by CT systems can result in yield increases (Figure 17). The extremes of the no-till system work to its advantage in producing better yields under these conditions than what will occur selecting a CT system.

For these reasons, it is important to match the type of CT system with local soil and climatic conditions (Table 1). Consider the following general recommendations when selecting a CT system:

1. In northern climates on poorly drained, clay soils, the no-till system will likely yield significantly lower than conventional tillage.
2. In northern climates on well drained, clay soils, other CT systems, particularly till-planting and chisel plowing, can produce yields similar to those from the conventional practice.
3. CT systems may produce greater yields than conventional tillage on unirrigated, droughty soils (sandy) or in more southerly climates.

**Table 1. Anticipated corn yields from various CT systems as a function of soil type. Yields compared to conventional systems. (Extrapolated from Mueller, D. H. 1979. M.S. Thesis. Dept. of Soil Science, Univ. of Wis.-Madison.**

Type	Soil type—Wisconsin		
	Sparta loamy sand <sup>1</sup>	Fayette silt loam <sup>2</sup>	Poygan silty clay <sup>3</sup>
Chisel	Increase	Equal	Equal
Till plant	Increase	Equal	Equal
No-till	Increase	Equal	Decrease

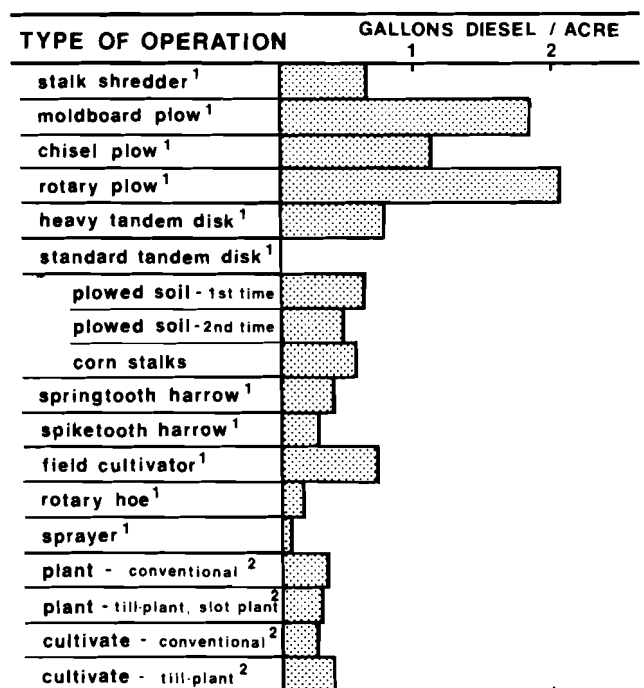
- <sup>1</sup>Sand, well drained.  
<sup>2</sup>Loam, well drained.  
<sup>3</sup>Clay, poorly drained.

A very important point to remember is that to obtain higher yields using CT practices, closer supervision of weeds, insects and planting equipment is required. Higher seeding rates to provide adequate plant stands may also be needed.

## Energy Requirements

As an industry, agriculture is unique in that it produces more energy than it consumes. For corn, energy produced normally exceeds that consumed in producing the crop by factors of about 2.5 to 3.5. Fertilizers typically account for about 50% of the energy required for conventionally tilled corn with drying accounting for another 20%. Mechanical operations (tillage, planting, harvesting) account for about 25% of the energy consumed with primary tillage being the greatest individual consumer.

Many CT systems allow for substantial reductions in the energy required for crop production. Fuel requirements for various tillage systems can be estimated by totaling the values listed in Figure 18. Table 2 lists estimated fuel requirements for a typical conventional system and some typical CT systems. The CT systems result in 34 to 76% reductions in fuel requirements. Obviously, as one deviates from the sequence listed in Table 2, the fuel requirement changes. For example, if the chisel system included a second chiseling and disking, the fuel requirement would equal that of the conventional system. Additionally, the amounts of residue remaining on the surface would be considerably reduced and, in turn, the loss of the erosion control benefits.



<sup>1</sup>White, R. C. Michigan State Extension, Bulletin E780, East Lansing, MI.

<sup>2</sup>Whittmuss, H. 1975. Journal Soil and Water Conservation 2:72-75.

**Figure 18. Average diesel fuel requirements for several tillage and tillage-related operations.**

**Table 2. Average diesel fuel consumed in producing a crop for representative tillage systems. White, R. C., Michigan State Extension Bulletin E-780, E. Lansing, Michigan.**

Operation	Tillage system			
	conventional	chisel plow	till-plant	no-till
	-----gal/acre-----			
Shred stalks	0.6	0.6	0.6	0.6
Moldboard plow	1.8			
Chisel plow		1.1		
Disk (1st-time)	0.6	0.6		
Disk (2nd-time)	0.5			
Plant	0.3	0.3	0.3	0.3
Spray	0.1	0.1	0.1	0.1
Cultivate	0.3		0.4	
Total	4.2	2.7	1.4	1.0

### Economics of Conservation Tillage

Many landowners who have converted to CT have done so because of convenience and a wide array of economic factors. A complete economic analysis is unavailable because of the many inherent variables common to programs as diverse and comprehensive as conservation tillage. However, some of the major variables known to influence the overall economics of the systems are:

1. Type of CT system being used.
2. Time and fuel savings.
3. Type, amount, effectiveness and cost of pesticides (herbicides and/or insecticides).
4. Kind, amount, cost and application method of fertilizer.
5. Crop yield and price/bu.
6. Management.

Soil type and climatic conditions play an important role in how variables 1-5 influence the economics of the system. Management is also a key variable which can result in success or failure. Lacking means to measure management, it is not possible to factor this important variable into an economic analysis. If time is saved through the use of a CT system, increased yields and higher net-profit may result. For example, a general rule of thumb for southern Wisconsin is that a bushel per acre per day of corn is lost for every day that planting is delayed past May 15. Though the time savings resulting from the use of CT may appear insignificant to an observer, they can greatly influence the economic outcome. However, because the value of time savings is difficult, if not impossible to quantify, this variable has not been included in an economic analysis.

Understanding the limits of conservation tillage systems as they relate to a specific farm is the key to making management decisions that are economically sound. The value of conservation tillage in reducing erosion, controlling runoff and protecting water quality has been proven. The short-term benefits of increasing net profit are highly dependent on good management decisions.

### Summary

Several different types of CT systems are in operation. Each has its own unique impact on crop growth and, in turn, on yield. Therefore, it is important to select a system which fits local needs and soil characteristics. With proper selection, CT systems can result in similar or increased yields to those of conventional systems. The potential for successful use of CT systems is higher on well drained, medium textured, loam soils. No-till is not recommended on clay, poorly drained soils. However, where moisture stress is likely to occur, such as on sands, the probability of success with no-till is high.

Conservation tillage systems require a higher level of management. Weeds, insects, and disease and fertility aspects of crop production must be closely supervised and planned. There appears to be no overwhelming economic incentive for adopting a specific CT system. However, there are intangible incentives which may be equally as important. Fuel savings (30-75%) are a reality now and will be more of a factor in the future. Presently and more so in the future as the trend to larger farms continues, the saving in time and trips per acre with CT systems allows the farmer additional flexibility in budgeting an already limited time and labor schedule.

## Conclusion

Conservation tillage systems are mentioned more and more often as a BMP because of their role in reducing soil and P losses from cropland. There is also considerable merit in using these practices because they can be readily incorporated into a farm operation.

Research to date has shed light on some of the problems and potential of these systems. For example, it is apparent that CT practices can produce yields equal to or better than the conventional technique if weeds and insects are controlled and the system is matched with local conditions. This is particularly true in more southerly climates and/or on better drained soils. On clay soils in northerly climates, CT systems, particularly no-till, are less likely to attain yields comparable to those obtained with the conventional technique. This is attributed to reduced soil temperatures and a shorter effective growing season. It is evident that more research is needed to better understand nutrient availability and weed and insect problems.

Researchers are confident that CT practices will reduce soil losses. In particular, no-till and chisel plowing on the contour are very effective in lowering soil losses, although all CT systems will reduce soil losses when compared to the conventional tillage techniques. Contoured chisel plowing reduces losses by reducing both runoff volume and sediment concentration while no-till reduces soil loss primarily by reducing sediment concentrations. In the Great Lakes region, a portion of the residue often is removed by the farmer for bedding. To date, research has evaluated these practices under residue-remaining conditions. Because residue is an integral factor in controlling soil loss, studies must evaluate these practices under different levels of residue management.

Because soil losses are generally reduced using CT practices, total P losses are also likely to be lowered. For systems such as chisel plowing and till-planting, it is important that tillage be done across the slope. For no-till, substantial amounts of residue must be present. If substantial amounts are not present, no-till's effectiveness in controlling erosion may be significantly lowered. A more important and as yet unresolved issue is the effectiveness of CT practices in reducing the algal-available forms of P.

Research to date has not adequately evaluated this aspect of P loss from CT systems. While investigators have found that placement of commercial fertilizer is important in determining available P loss, other factors have yet to be evaluated. Runoff losses may vary for the same tillage practices on different soil types. As a result, sediment and P losses and crop yields differ for each tillage system.

Despite unanswered questions, CT systems show strong promise of being an integral part of any sound management program to protect water quality. In particular, the chisel system, when used on the contour, demonstrates a high potential for the Great Lakes region because it maximizes the roughness and residue factors while minimizing the surface sealing problems common to other systems.



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