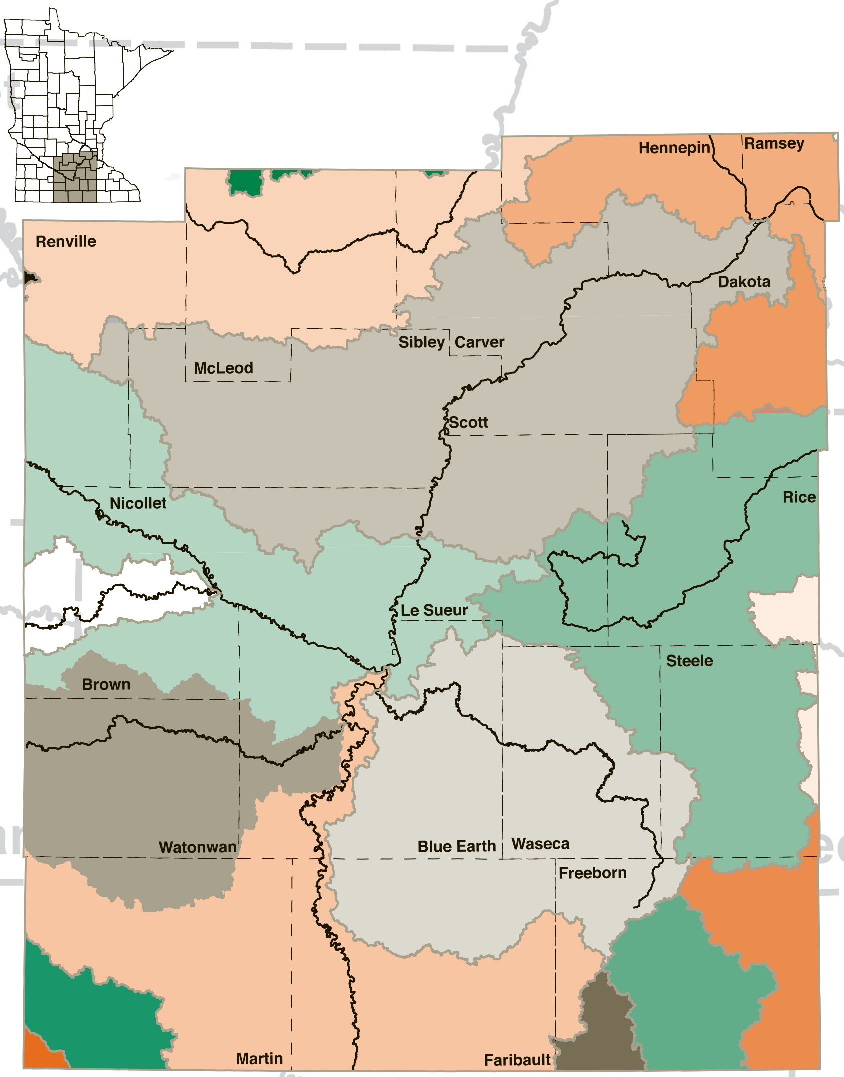
Optimum Tillage Systems for Corn and Soybean Production and Water Quality Protection in South Central Minnesota—Minnesota River Basin.

Gyles Randall and Jeffrey Vetsch



IN PARTNERSHIP...

The College of Agricultural, Food and Environmental Sciences

University of Minnesota Extension Service

Authors

Gyles Randall and **Jeffrey Vetsch**

Soil Scientist and Asst. Scientist, respectively, Southern Research and Outreach Center, University of Minnesota. Waseca, MN

Acknowledgements

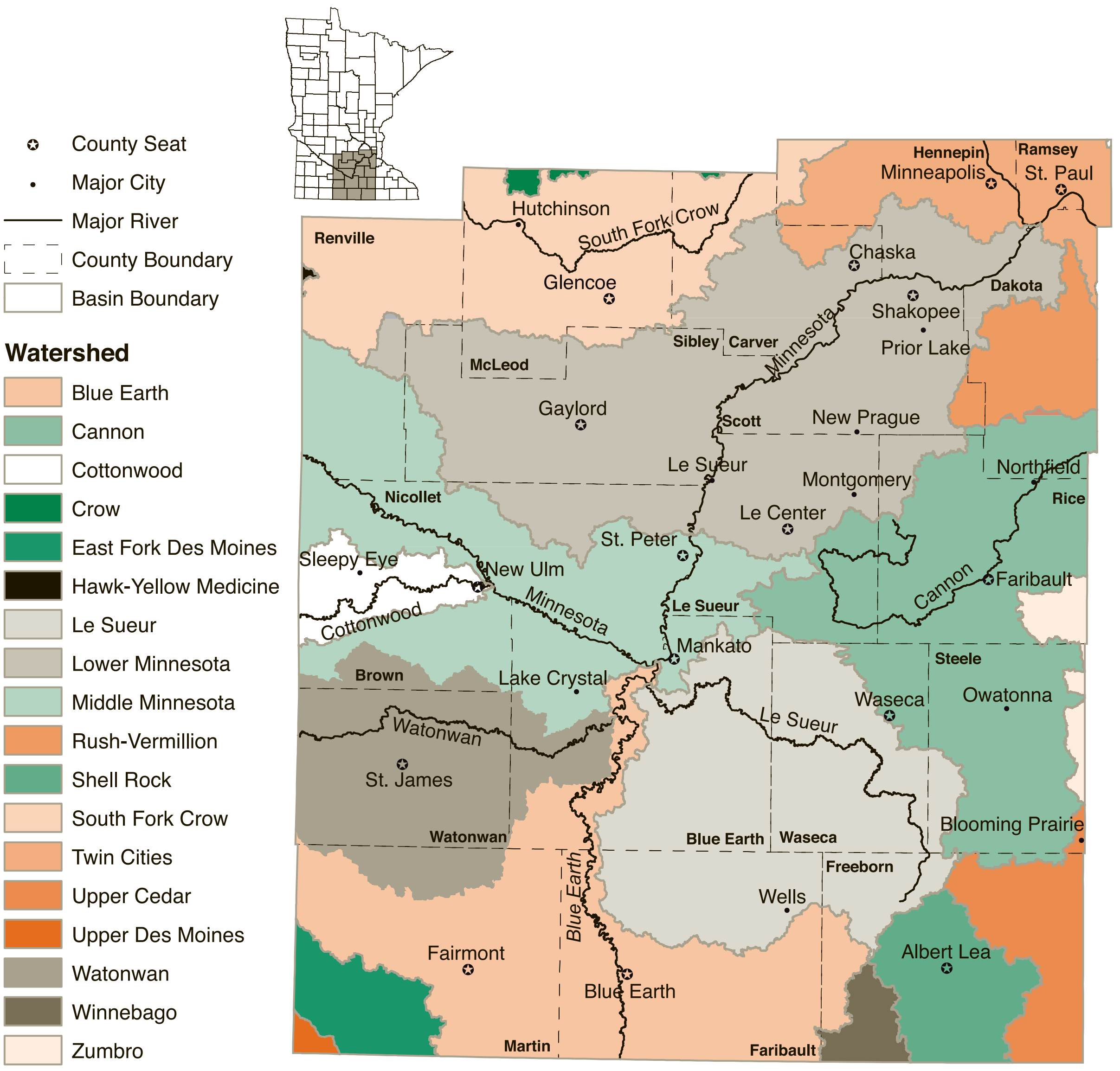
The authors sincerely appreciate and thank the Minnesota Pollution Control Agency, Fluid Fertilizer Foundation, Potash and Phosphate Institute – Foundation for Agronomic Research, and John Deere Company for their financial support of the research contained in and production of this bulletin.

Reviewers for this bulletin were Les Everett (Water Resources Center, University of Minnesota), John Moncrief (Department of Soil, Water and Climate, University of Minnesota), and Larry Gunderson (Minnesota Pollution Control Agency). Assistance was provided by Adam Birr (Department of Soil, Water and Climate, University of Minnesota) in the preparation of the figures and Les Everett in the publication process. The authors gratefully acknowledge and appreciate their many helpful suggestions and thank them for their contributions in developing this bulletin.

Table of Contents

Illustrations and tables:

Figure 1. Major watersheds in south-central Minnesota.



Purpose

This publication provides information that can help corn and soybean farmers in south-central Minnesota choose tillage systems that will optimize erosion control and associated pollutants as well as crop production profitability. It draws on over 30 site-years of University of Minnesota field research at Waseca including recent research on strip-till and deep zone-till systems and supplements more than 50 site-years of tillage research described in "Tillage Best Management Practices for Corn-Soybean Rotations in the Minnesota River Basin" published in 1996 (Randall et al., 1996b). Key factors affecting tillage, including soil erosion potential, internal drainage, crop grown, nutrient and weed management, and risk, are addressed. This bulletin identifies tillage and P management systems for improved crop production and water quality benefits in the eastern Minnesota River Basin (**Figure 1**).

Introduction

Tilling the soil to prepare a seedbed has been practiced for centuries. The moldboard plow, which was introduced in the mid-1800s, was used until the 1970s by most farmers to invert the soil, leaving the soil surface bare of residues. Because the potential for erosion and sediment loss is greater on residue-free surface soils, primary tillage tools that leave some residue on the soil surface to reduce soil erosion were introduced in the 1960s. Since then many styles and types of chisel plows, including V-rippers, have been developed to prepare a seedbed as well as leave some crop residue on the soil surface. Ridge-till systems, which began in the 1960s, were also upgraded, and now have been joined by strip-till and deep zone-till systems for in-row tillage that leave undisturbed soil and substantial amounts of residue between the rows. Lately, full-width coulter systems and rolling harrows have been developed to operate in high residue environments. They cut the residue and disturb the soil surface to facilitate planting and weed control while maintaining substantial residue levels. With improvements in planting equipment and plant genetics, including herbicide and pest resistant crops, these high-residue tillage systems are being used successfully.

The soils and climate of the eastern Minnesota River Basin can present significant challenges to corn and soybean producers who want to reduce tillage greatly. Poorly drained, high clay-content soils dominate the eastern Minnesota River Basin. In addition, this area annually receives an average of 30 to 34" of precipitation. This combination of poor internal drainage and higher rainfall can result in cool and wet soils in the spring, which is the greatest challenge facing corn and soybean producers desiring to greatly reduce tillage. Less tillage results in greater amounts of residue blanketing the soil surface, which keeps the soils even cooler and can delay spring planting. Crop growth tends to be retarded under these conditions, and yields may suffer. This is particularly true for corn following corn but can occur when corn follows other crops, especially where the residue has not been evenly spread after harvest.

However, a significant acreage of more well-drained agroecoregions exists within the Minnesota River Basin. These landscapes have steeper slopes, permitting more runoff, and are generally located near major rivers or in lateral moraine areas. These soils generally do not show pronounced negative effects of dense surface residue on crop growth, but soil erosion is much more prevalent. Thus, within the eastern Minnesota River Basin, a broad range of soils exists where a wide variety of conservation tillage systems can be suitable, depending on the field. In other words, choice of tillage is not a "one size fits all" decision.

Erosion and Water Quality Concerns

Total suspended solids (sediment) and phosphorus are major water quality concerns in the Minnesota River Basin. Soils in the Basin have a high silt and clay content. Eighty-six percent of the suspended sediment in the Basin is characterized by fine particles of silt and clay that are easily transported by water. The Minnesota River carries more suspended sediment than most of the state's rivers (MPCA, 1997). Excess sediment degrades the river system by filling reservoirs, destroying aquatic habitat, and reducing the river's aesthetic qualities. Phosphorus originates from many sources in the Minnesota River Basin. Elevated phosphorus concentrations during low flow often indicate point sources (municipal and industrial sources), whereas elevated concentrations that occur mainly during higher flow periods can indicate nonpoint sources, i.e., sediment from eroding fields and construction sites and runoff water from fertilizer, manure, and plant debris.

Soil erosion that delivers sediment into surface waters of the Minnesota River Basin has been identified as a key source of nutrient (phosphorus) enrichment and turbidity (cloudiness) of the rivers. Phosphorus enrichment and cloudiness promotes algal blooms, reduces oxygen levels, and interferes with the biological and aesthetic well-being of the rivers. Improved crop residue management on agricultural soils is one practice that can reduce erosion and subsequent sediment and nutrient losses from these fields. Crop residue on the soil surface protects the soil from the impact of raindrops and minimizes the dislodging of soil particles. Crop residue on the soil surface may also improve infiltration of precipitation into the soil, thereby reducing surface runoff and increasing stored water in the soil profile for crop use.

A comprehensive monitoring program was conducted at sites near the entrance of the major tributaries to the Minnesota River by the Minnesota Dept. of Agriculture and Metropolitan Council Environmental Services during 2000-2002. Sediment loading to the Minnesota River came primarily from the eastern side of the Minnesota River Basin, notably the Blue Earth and Le Sueur watersheds, which receive greater amounts of precipitation and have greater runoff compared to watersheds upstream from New Ulm (MPCA, 2002). Sediment concentrations and yield (pounds of sediment per acre) were greatest for the Le Sueur, High Island, and Sand Creek watersheds in all three years. Sediment concentrations averaged 918 mg/L in 2000 for the Le Sueur River, 508 mg/L in 2001 for High Island Creek, and 404 mg/L in 2002 from Sand Creek. These flow-weighted mean concentrations substantially exceeded the turbidity-based threshold of 58 mg/L and the sediment range of 10 to 61 mg/L considered typical for streams in the Western Corn Belt Plains (MPCA, 1993).

Similar to sediment, total phosphorus loading was greatest for the Le Sueur and Blue Earth Rivers. Total phosphorus yields (pounds per acre) and concentrations were generally greatest for the Le Sueur, High Island Creek, Sand Creek, and Blue Earth Rivers. Flow-weighted mean concentrations of total phosphorus in these rivers ranged from 0.24 to 0.93 mg/L, substantially exceeding the EPA guideline of 0.1 mg/L. Because 70 to 80% of the total P in the rivers was in a particulate form (soil particles), conservation practices that reduce sediment loading can be expected to reduce most of the total phosphorus loading.

Factors to Consider when Making Tillage Decisions

Selecting the best tillage system should involve a set of considerations much like those a farmer uses when selecting a hybrid. Often, certain hybrids are chosen to meet specific conditions or needs. A similar approach should be taken for tillage. Factors that should be considered in the tillage selection process are:

Crop rotation

The amount of residue present in a field before tillage depends on the crop previously grown and the level of production. Corn generates considerably more residue than soybeans, thus it is easier to maintain higher residue levels following corn with a variety of tillage systems. The durability of the residue is also crop dependent. Soybean residue is considered to be "fragile" or in other words is easily destroyed and/or rapidly decomposed. Maintaining adequate residue cover can be a problem following soybeans, especially when planted in wide rows or if poor yielding. Corn residue, on the other hand, is considered "non-fragile" and breaks down quite slowly. Because a corn-soybean rotation generates less residue than corn rotated with most other crops, tillage flexibility is greater. In summary, both crops need to be considered when making tillage decisions for a corn-soybean rotation.

Soil characteristics

Erosion potential – Erosion potential mostly depends on the length and steepness of slope and soil texture. If erosion potential is high, conservation tillage systems are essential. Fields or acres considered to be highly erodible land (HEL) may require large reductions in tillage to minimize soil erosion and to maintain soil productivity. On the other hand, flat fields have a lower erosion potential. Sediment loss can be a problem on these fields, however, if soil detachment occurs during intense rainfall and there are open tile inlets or other channels that serve as direct conduits for the sediment-laden runoff water to quickly reach drainage ditches, streams, lakes, or other surface water bodies.

Internal drainage – Poorly drained soils warm up more slowly and usually require more tillage than do well-drained soils. With high levels of residue, the poorly drained soils often remain cool and wet too long for intolerant crops such as corn, resulting in decreased yields. System tiling helps on soils with poor internal drainage but may not be enough to ensure consistent success with little or no tillage and high levels of crop residue.

Surface soil compaction – Field activities conducted under wet conditions often result in surface compaction. Short, yellow, and spindly corn and short soybeans are evidence of this compaction, which is highly visible in field headlands, spots within fields, and wheel tracks. Primary tillage is often needed to alleviate surface soil compaction. Without primary tillage, good seed-to-soil contact and rapid root development in the spring will be more difficult when soils are compacted.

Nutrient management

Management of fertilizer and manure nutrients is critical to the success of conservation tillage. High soil fertility levels must be established prior to initiation of a conservation tillage system. Moderate-to-low soil fertility will intensify yield loss and diminish the probability of long-term success.

Nitrogen – Nitrogen ***(N)*** is the most important nutrient for corn production. Nitrogen needs to be managed carefully for efficient use by the crop and for minimizing environmental risk of runoff and leaching. Surface-applied N fertilizer, such as granular urea and UAN (urea-ammonium nitrate) solution, should be incorporated mechanically or by rainfall within three days of application to eliminate loss of N to volatilization. Any significant loss of nitrogen to the atmosphere or by runoff or leaching will reduce yield and profitability. Alternative methods of N application in very reduced tillage systems include: (1) applying urea 4 to 6" to the side of the row with a coulter at the time of planting and (2) applying UAN 2 to 3" from the row at planting followed by coulter-injection of UAN midway between the rows at the 3- to 8-leaf stage. Anhydrous ammonia injected into the soil disturbs the soil surface and provides a minimum tillage pass without destroying the conservation tillage practice. For additional information see University of Minnesota Extension Service publications: *Fertilizing Corn in Minnesota* and *Fertilizer Management for Corn Planted in Ridge-Till or No-Till Systems* as listed in the Resource Section at the end of this publication.

Phosphorus (P) and potassium (K) – Soil testing should be used to maintain fertility at optimum levels. Fields testing low in P or K should be brought to high levels before implementing conservation tillage systems. For optimum crop production with all tillage systems, soil test P should be at least 16-20 ppm with the Bray test and 12-15 ppm when the Olsen extractant is used, and K needs to be 121-160 ppm. Soil testing should be done every two to three years to maintain soil fertility levels in reduced-tillage fields. If additional nutrients are needed, their placement in relation to the crop is important. Placing the fertilizer close to the corn seed gives the most efficient P and K uptake. Recommended application methods include: (1) starter fertilizer or (2) banding 4 to 7" deep randomly in no till or full-width tillage systems, within the ridge for ridge tillage, or in a residue-free strip for strip-till (zone-till) systems. With no-till, ridge-till, or strip-till systems, starter fertilizer should be used for corn when Bray soil test P is <25 ppm. Broadcast applications of fertilizer are best following corn where some tillage can be used to incorporate the fertilizer and maintain adequate crop residue levels for erosion control. Soluble phosphorus can be transported to surface waters if P fertilizer is broadcast applied to no-till fields or is spread on grass waterways.

Manure – Livestock manure should be incorporated for maximum benefit. However, incorporating manure when in a corn-soybean rotation presents a real dilemma. Greatest nutrient (nitrogen) utilization occurs in corn when manure is applied after soybeans; however, the small amount of "fragile" soybean residue can be completely destroyed in the incorporation process. Incorporating manure following corn with either a chisel plow or by injection or disk-covering of liquid manure allows for good residue management, but nitrogen utilization by the following soybean crop is inferior to corn. Liquid manure offers more tillage flexibility because it can be injected or disk-covered before planting. Fall application of liquid manure to sloping no-till soybean ground is not recommended unless extreme care is taken to avoid water erosion in the tilled injection or incorporation zones. Solid manure sources offer little flexibility. They should be incorporated by chisel plowing corn ground ahead of soybean or by chiseling very level soybean ground. Solid manure sources should not be applied to sloping land following soybeans.

Weed management

When a farmer begins using conservation tillage, starting with a relatively weed-free field greatly improves the likelihood of successful long-term weed management. Using reduced tillage on a weed-infested field requires greater weed management and can become very costly. In fields where tillage has been reduced and crop residue levels have increased, weed pressure may increase and shifts in weed species may occur. Post-emergence herbicide applications have become the primary weed control program. Timing of post-applications is critical and multiple applications may be needed. A wide range of effective post-emergence herbicide treatments is available today for crops grown with reduced tillage. As a result of equipment improvements, in-season row cultivation can be used with herbicides in fields with high crop residue. Row cultivation can be an effective tool for controlling problem weeds.

Planting equipment

Many of the newer generations of planters and drills have options available to handle higher crop residue levels. Most planter tool bars sold today can be modified with row cleaners and/or coulters to ensure optimum seed-to-soil contact. Modern no-till drills are designed to clear residue while dropping and covering seeds as small as alfalfa at precise depths for exceptional contact with the soil, which results in good plant emergence. In recent years, narrow row spacing has become more prevalent and can be used with conservation tillage. Farmers can modify their planters with row cleaners and/or fluted coulters at a relatively low cost. Also, equipping the planter with starter fertilizer attachments increases the potential for success in high-residue situations.

Reduced tillage risks and benefits

Many farmers are reluctant to farm with greater amounts of crop residues on their fields. They fear yield loss and don't like the appearance of a crop growing in heavy residue. Their perception is influenced by several factors: 1) upsetting the landlord, business partner or a family member; 2) ridicule from neighbors; 3) lack of crop management skills to adopt conservation tillage; 4) recent purchase of equipment for aggressive tillage; and 5) on-farm research results. Overcoming the aesthetics of crop emergence in a field covered with residue takes patience, time, and an understanding of the system. Farmers who have used conservation tillage learn to appreciate the "look" of a crop growing in higher levels of residue and the lower cost of production.

When evaluating potential yield loss that may result from adopting a very high-residue system such as no-till, it is important that farmers compare differences in production costs as well as expected differences in yield to arrive at a sound business management decision. Each farm will have its own production costs and risks based on equipment, management skills, and crop rotation. The long-term yield information presented later in this bulletin will help farmers decide on an appropriate tillage system(s) as they consider their field- and farm-specific factors.

Using Conservation Structures to Control Erosion

An integrated system of reduced tillage practices and conservation structures is needed for successful soil and water conservation. Crop residue on the soil surface reduces the effect of rainfall intensity and helps to keep sediments in place, especially on flat fields. However, conservation structures such as terraces, grass waterways, and conservation buffers are needed to reduce the velocity of water and sediment transport off fields.

Conservation tillage systems need to be combined with crop rotations and conservation structures to control surface runoff and soil erosion effectively on many sloping south-central Minnesota fields. In a corn-soybean rotation, soil erosion can often be controlled by conservation tillage in combination with grass waterways or terraces. Even if corn is planted without tillage into soybean stubble, grass waterways or terraces are often needed to minimize erosion on steeper or longer sloping fields.

Grass buffers at the edge of a field, drainage ditch, or stream should be installed to supplement conservation tillage practices in the field, and not be considered as a replacement for conservation practices. In fact, field buffers are effective mainly against sheet and rill erosion, and can be easily breached by gully erosion or channeled flow that is the result of insufficient erosion control on the uplands.

Conservation plans illustrate how combinations of management practices and conservation structures can successfully control erosion. Individual farms may need site-specific designs that differ from typical systems. Farmers can contact their local Soil and Water Conservation District or Natural Resources Conservation Service office for help in determining which combination of conservation tillage, crop rotation, and conservation structures is best for their farm.

Crop residue in combination with a waterway or other structure would have protected the soil from erosion damage.

Maintaining Crop Residue with Different Tillage Systems

Tillage implements leave various levels of crop residue on the soil surface. The effectiveness of seven tillage systems at protecting crop residue is described below.

Moldboard Plow-Plus secondary tillage (MP+): Moldboard plowing followed by one or two secondary tillage operations with a field cultivator or disk before planting. This system is an aggressive tillage practice that often leaves less than 10 percent of the surface covered with crop residue after planting.

Chisel Plow-Plus secondary tillage (CP+): Fall chisel plowing or "ripping" to a depth of about 10" plus spring secondary tillage with a field cultivator or disk. This tillage practice is quite aggressive and can reduce crop residue, especially after soybeans, to levels that are inadequate for erosion control.

Shallow spring tillage: Single pass with a field cultivator (SFC) in spring before planting corn after soybeans or with a tandem disk (SD) before planting soybeans after corn. These are less aggressive tillage systems that may leave adequate residue after planting when SFC follows soybeans and SD follows corn.

Ridge-Till (RT): Tillage is limited to that performed by the planter (ridge leveling) and one or two in-season row cultivations (ridge building). Preformed ridges provide a drier and warmer seedbed at planting. Adequate levels of crop residue remain after planting.

Strip-Till (ST): Strips about 4 to 6" wide and 7 to 8" deep matched to the row-spacing of the planter are prepared in the fall with mole fertilizer knives mounted on a tool bar. Fertilizer P and K can be injected directly into the strip at the time of strip tillage. Corn is planted into the tilled "residue free" strip without any secondary spring tillage. Adequate levels of crop residue remain after planting.

Deep Zone-Till (DZT): Deep slit tillage to a depth of 15 to 20" is done in the fall using a narrow subsoil shank on 30" spacing. The crop is planted directly above the deep "residue-free" slit zone. This tillage system often buries more residue than the strip-till system and may not leave adequate residue following soybeans.

No-Till (NT): The planter performs all seedbed preparation including clearing residue away from the seed rows. The crop is seeded into a relatively "residue free" zone. Maximum surface residue coverage occurs with this system.

Chisel plowing fragile soybean residue does not leave sufficient soil cover for protection against erosion on sloping soils.

Strip tillage removes crop residue from only the row area.

Chisel plowing heavy corn residue leaves some residue for protection of soil from erosion.

No-till leaves the maximum crop residue for soil protection.

Tillage Recommendations for South-Central Minnesota

Below are the performance indicators used in **Table 1** to summarize the tillage recommendations for both corn and soybeans in south-central Minnesota based on the research described in this publication.

1) Recommended with good management
No yield penalty is expected if the farmer observes all relevant recommended management practices. Surface residue coverage may be inadequate following soybean, however.

2) Excellent management required
A slight yield penalty is possible, even if all recommended management practices are observed. Above average crop management is needed to ensure good performance.

3) Reduced yield potential
None of the tillage systems shown in **Table 1** fit into this category in a corn-soybean rotation. However, the potential exists for substantially reduced yields when multiple years of corn are coupled with one year of soybean, i.e., a corn-corn-soybean rotation.

4) Inadequate residue to minimize erosion
Less than 30 percent of the soil surface is covered after planting. Greatest yield may be obtained, however.
Table 1 shows the residue management/yield performance indicators for both corn and soybean on soils with slopes <4% and slopes >4% using the different tillage systems described earlier. Maintaining adequate levels of surface residue with tillage management is more difficult for corn after soybean than for soybean after corn. This is illustrated by the "4" indicator appearing frequently for corn, especially on slopes >4%. Because of logistical and practical reasons, SFC, DZT, and ST are not applicable (N/A) for soybeans following corn.

Table 1. Residue management/yield performance indicators for corn and for soybeans in a corn-soybean rotation on soils with slopes <4% and >4% in south-central Minnesota.

Tillage system	Slope:	Corn <4%	Corn >4%[1]	Soybean <4%	Soybean >4%[1]
MP+		4	4	4	4
CP+		4	4	1	1
SFC		1	4	NA[2]	N/A
SD		4	4	1	1
RT		1	2	2	2
DZT		1	4	N/A	N/A
ST		1	2	N/A	N/A
NT		2	1	2	1

[1] Some of the more steeply sloping, highly erodible soils in south-central Minnesota include: Blooming, Bold, Clarion, Collinwood, Copaston, Dakota, Dickinson, Dickman, Estherville, Fairhaven, Grays, Grogan, Guckeen, Hawick, Hayden, Kamrar, Kasota, Kilkenny, Lamont, Lerdahl, Lester, Moland, Ocheyedan, Ridgeport, Shorewood, Storden, Terril, Truman and Ves.

[2] N/A = not applicable

Corn following soybeans

Maintaining 30 percent surface coverage after planting corn is challenging whenever full-width tillage practices are used before planting, especially if soybeans are planted in 30" rows. The MP+, CP+, and SD tillage systems will not leave adequate residue to minimize soil erosion and will often not result in greater yields than other tillage systems. Thus, these tillage systems are not recommended with the exception of when broadcast manure needs to be incorporated on 0-4% soils or if severe surface soil compaction occurred during the last year. In those situations, using a CP+ tillage system may be helpful. The SFC system is commonly used to destroy early-emerging weeds, and level the field to prepare the seedbed. To avoid burying too much residue, the field cultivator must be carefully configured and operated. The SFC tillage system is appropriate on very level fields where vulnerability to erosion is minimal, but as slope increases and erosion potential increases, SFC tillage becomes problematic. Strip tillage, RT, and DZT leave adequate amounts of residue and prevent yield losses if managed well, and thus are recommended on fields with slopes of preferably <4%. No tillage maintains excellent surface residue coverage, but yield penalties can occur, especially if NT has been practiced for both corn and soybeans the previous few years and a dense residue mat covers the soil surface. Our experiments suggest that some form of minimal residue disturbance in a continuous NT corn-soybean rotation is necessary to optimize yield without compromising residue cover. Practices such as in-season row cultivation, coulter carts on soybean drills, full-width rolling coulters that slice the residue and surface soil, or full-width rolling harrows that stir the residue and surface soil may be the "extra" management step that enables more consistent, better performance of the continuous NT system across a range of soil environments and past tillage systems. They may also enable the soil to warm slightly faster and break surface sealing, a concern often expressed by NT farmers.

Residue management to achieve high corn yields and minimize soil erosion is a major challenge in a corn-soybean rotation on slopes >4%. First, the amount of soybean residue is not sufficient to limit runoff and erosion in many instances. Second, any simple tillage practice results in some "downhill" movement of soil and over the long term, this "erosion" reduces soil productivity. Thus, NT is the system of choice for greatest soil productivity and profit on these steeply sloping fields. But with excellent management, ST and RT may also work on some landscapes. When slopes exceed 6% or are sufficiently long, growers are encouraged to employ other conservation practices, i.e., terraces and grass waterways with NT, or switch to cropping systems that produce more residue or maintain season-long ground cover.

Soybeans following corn

Because substantially more residue exists following corn, there is somewhat greater flexibility in tillage choices. Moldboard plow-plus is not recommended, but full-width CP^+ and SD are appropriate for slopes <6%. When fertilizer P and K or manure are to be incorporated, CP^+ is recommended with care not to chisel directly up and down the slopes. Residue coverage can also be maintained with RT and NT, with NT having the advantage of narrow rows, more row-direction flexibility, and perhaps higher yields. On slopes >4%, NT is highly preferred. Similar to corn following soybeans, some minimal form of surface residue/soil disturbance may be helpful to achieve optimum performance of continuous NT.

Tillage Research in South-Central Minnesota

Numerous tillage experiments on a corn-soybean rotation have been conducted at the University of Minnesota, Southern Research and Outreach Center at Waseca since 1997. All experiments have been located on Nicollet and Webster clay loam soils that are subsurface tile-drained at a lateral spacing of 75 feet. One experiment was conducted on two low and two high P-testing sites for a continuous 6-year period to determine the effects of tillage system and phosphorus rate and placement on corn and soybean yield and soil test P. Information from this study is presented in **Tables 2-8** in the section entitled "Tillage Systems and P Management." Another 4-year study was conducted to determine the effects of rotational full-width tillage compared with long-term no-till (NT), strip-till (ST) and deep zone-till (DZT) systems with and without in-season row cultivation on corn and soybean production. Information from this study is presented in **Tables 9-12** in the section entitled "Rotational Tillage Systems." Two 1-year experiments were conducted in 2004 to determine the effect of tillage system on soybean and second-year corn production in a corn-corn-soybean rotation. Information from these two studies is found in **Tables 13** and **14** in the section entitled "Tillage for a CCS Rotation." Another 3-year experiment compared effects of tillage system and time and placement of N fertilizer on corn yield. Yield data are shown in **Table 15** in the section entitled "N Management for Tillage Systems." In summary, average corn yield from 29 and 21 experimental site years are shown in **Table 16** and **Figure 2** (page 19), respectively, to illustrate the effect of various tillage systems on corn production across many site-years. This information is found in the section entitled "Multi-Site Tillage Performance."

Tillage systems and P management

Summary:

Tillage studies were conducted on high and low P-testing soils to determine the effects of tillage and phosphorus (P) placement on corn and soybean production. Six-year average corn yields were 5 to 7% lower for no-tillage (NT) compared to one-pass, spring field cultivation (SFC), strip-till (ST), and chisel plow-plus (CP^+) with no difference between SFC, ST, and CP^+ at both the high and low P-testing sites. Corn yields at the high-P site began to respond to the phosphorus treatments after the soil test values in the zero-P treatments had declined into the medium range. At the low-testing site, corn yields were increased 49 bu/A for the 50-lb starter (seed-placed) treatment and 62 bu/A for the 100-lb broadcast treatment. Phosphorus-banded 6 to 7" deep did not improve yields compared with seed-placed P. Six-year average soybean yields were not affected by tillage on either the high or low P-testing sites. At the low-P site, soybean yields were increased 16 bu/A by residual P from the 50-lb starter (seed-placed) and deep-band P treatments and 19 bu/A for the 100-lb broadcast treatment. Surface residue coverage for corn ranked NT>ST>SFC >CP^+. Based on 0-2" soil tests, the potential for P loss to surface water is least for deep-banded P, regardless of tillage, and greatest for broadcast P, especially in the shallow SFC/SD tillage system.

Discussion:

A study comparing four methods of P placement for corn (none, seed-placed, fall 6 to 7" deep-banded, and broadcast and incorporated by chisel plow or field cultivator) and four tillage systems [NT, ST, field cultivation or disking (SFC/SD), and CP^+] was conducted on a very low to low P-testing site (4-5 ppm Bray P_1) and an initially high P-testing site (19 ppm Bray P_1) from 1997 to 2003. Three cycles of a corn-soybean rotation were grown with corn and soybeans planted each year. Corn was planted in 30" rows while soybeans were drilled or seeded in 8" rows. Phosphorus for corn was band-applied either in the seed furrow or in 6-7" deep bands at 30" spacings as 10-34-0 at rates of 40 and 50 lb P_2O_5/A and broadcast as 18-46-0 at rates of 80 and 100 lb P_2O_5/A for the high and low P-testing sites, respectively. Soybeans did not receive fertilizer P but responded to residual P from P applied for corn. A non-yield-limiting N rate was applied to all corn plots. Soil samples were taken to a depth of 6" in a transect perpendicular to the crop row with one core directly in the row and the others at distances of 7.5", 15", and 22.5" from the row. Three sets of cores were taken from each plot for a total of 12 cores per plot. Soil samples from the 0-2" depth (which relate better to potential P loss to surface water) were taken from a 3" wide x 2" deep x 30" long zone located perpendicular to the crop row.

Six-year corn and soybean yield averages from the high P-testing site were significantly affected by the tillage and P treatments (**Table 2**). A yield response to P did not occur in the first few years but did begin to occur when 0-6” soil test P (STP) in the zero-P treatments declined to <15 ppm. The relationship between soil test P at the end of the study and the 6-year average corn yield is clearly seen. This was not true for soybean. Soil test P in the 0-2” depth was greater than in the 0-6” depth because: (1) plant material containing P remained on the surface soil each year in the reduced tillage systems and (2) broadcast-applied P remained more concentrated near the soil surface. Soil test P in the 0-6” depth was affected significantly by P placement but not by tillage system.

Corn and soybean yield responses to tillage at the low P-testing site were similar to the high-testing site, but the responses to P management were markedly greater at the low-testing site (**Table 3**). Corn and soybean yields were increased 49 and 16 bu/A, respectively, by seed-placement of P in corn. Soil test P values from both depths clearly showed the effect of seed-placed (starter) and broadcast P.

Table 2. Corn and soybean yields and soil test P (Bray P_1) on a high P-testing soil as influenced by tillage and P management systems.

Tillage System for		P Management for Corn		Six site-year avg. yield		Soil test P at end of six years	
Corn	Soybean	Placement	Rate	Corn	Soybean	0-6″	0-2″
			lb P_2O_5/A/yr	- - - bu/A - - -		- - - ppm - - -	
NT	NT	None	0	156	50.5	12	16
“	“	Seed-placed	40	160	52.3	20	32
SFC	SD	None	0	161	53.3	10	14
“	“	Seed-placed	40	168	54.2	17	27
“	“	Fall deep-band	40	165	54.0	16	21
“	“	Spring broadcast	80	176	55.0	25	54
ST	NT	None	0	164	51.8	11	14
“	“	Seed-placed	40	168	52.2	21	26
“	“	Fall deep-band	40	165	52.8	16	19
CP+	CP+	None	0	165	50.6	11	16
“	“	Seed-placed	40	170	54.2	17	22
“	“	Fall broadcast	80	176	54.8	27	39
LSD[1/] (0.05):				6	2.2		

[1/] Least Significant Difference

Table 3. Corn and soybean yields and soil test P (Bray P_1) on a low P-testing soil as influenced by tillage and P management systems.

Tillage System for		P Management for Corn		Six site-year avg. yield		Soil test P at end of six years	
Corn	Soybean	Placement	Rate	Corn	Soybean	0-6″	0-2″
			lb P_2O_5/A/yr	- - - bu/A - - -		- - - ppm - - -	
NT	NT	None	0	97	32.5	3	4
“	“	Seed-placed	50	140	47.7	11	10
SFC	SD	None	0	102	34.1	4	5
“	“	Seed-placed	50	153	48.6	7	11
“	“	Fall deep-band	50	146	48.4	5	6
“	“	Spring broadcast	100	166	52.2	12	37
ST	NT	None	0	101	35.3	3	4
“	“	Seed-placed	50	152	48.9	8	12
“	“	Fall deep-band	50	148	47.0	6	5
CP+	CP+	None	0	103	30.0	3	4
“	“	Seed-placed	50	154	49.6	6	10
“	“	Fall broadcast	100	166	52.5	11	24
LSD (0.05):				8	3.2		

The effects of tillage on surface residue cover, yield, and STP at both sites are examined in the next five tables.

Surface residue coverage after planting corn averaged across six years was greatest for NT followed closely by ST (**Table 4**). Spring field cultivation of soybean stubble left 33 to 38% surface coverage, barely achieving the desired 30% minimum. Annual CP+ left inadequate amounts (20%) of residue for effective erosion control on many landscapes. The residue accumulation levels found for the NT, SFC, and ST systems for corn in this study are probably somewhat greater than would be found in most farmers' fields in SC MN because most soybeans are grown in wide-rows in the region. In this study, soybeans were no-till drilled into the standing corn stalks for the NT and ST (corn) systems, while a single spring disking (SD) of standing corn stalks was done for soybeans in the SFC (corn) system. Thus, residue accumulation on the surface during the 6-year period was substantial due to minimal disturbance and incorporation by tillage. This is particularly true for the NT and ST systems. Higher crop yields on the high P-testing site consistently gave slightly higher residue accumulations.

Table 4. Surface residue accumulation in May after planting corn as influenced by tillage for corn.

Tillage for Corn	Site High P	Site Low P
	- - - - - - - - - % - - - - - - - - -	
NT	74	68
SFC	38	33
ST	61	60
CP+	23	20

Corn yields for each tillage system averaged across the zero P and seed-placed P treatments for the 6-year period are shown in **Table 5**. Corn yields were significantly affected by tillage system at the low and high P-testing sites. Yields for NT were 8 bu/A (5%) lower at the high-testing site and 9 bu/A (7%) lower at the low-testing site compared to the SFC, ST, and CP+ systems. Yields were not different among the SFC, ST, and CP+ tillage systems.

Table 5. Corn yield after soybean from high and low P-testing soils as affected by tillage system.

Tillage System for Corn	Tillage System for Soybean	Six Site-Year Avg. Yield High P	Six Site-Year Avg. Yield Low P
		- - - - - - - bu/A - - - - - - -	
NT	NT	158	118
SFC	SD	165	127
ST	NT	166	126
CP+	CP+	168	128
	LSD (0.05):	4	6

Soybean yields for each tillage system averaged across the zero P and seed-placed P treatments for the 6-year period are shown in **Table 6**. Soybean yields were not affected by tillage system.

Table 6. Soybean yield after corn from high and low P-testing soils as affected by tillage system.

Tillage System for Corn	Tillage System for Soybean	Six Site-Year Avg. Yield High P	Six Site-Year Avg. Yield Low P
		- - - - - - - bu/A - - - - - - -	
NT	NT	51.4	40.1
SFC	SD	53.7	41.4
ST	NT	52.0	42.1
CP+	CP+	52.4	39.8
	LSD (0.05):	NS[1]	NS

[1] No Significant Differences

Soil test P (0-2") was greatly influenced by phosphorus placement and tillage on the high P-testing site (**Table 7**) and low P-testing site (**Table 8**). Starter (seed-placed) P applied at a total rate of 120 lb P_2O_5/A to the high-testing site and 150 lb P_2O_5/A to the low-testing site during the 6-year period increased STP by about 12 ppm and 6 ppm, respectively, compared with the control. When applied in a 6-7" deep-band, STP was increased only 5 ppm at the high-testing site and was not increased at the low-testing site. Broadcast applications totaling 240 and 300 lb P_2O_5/A for the high and low P-testing sites, respectively, during the 6-year period greatly increased STP at both sites. Moreover, STP was affected significantly by tillage. When the P fertilizer was incorporated to a greater depth by chisel plow tillage, STP values were 30 to 50% lower compared to the very shallow (2-3") incorporation with the SFC/SD tillage system. These data indicate the potential for P loss to surface water is least for the deep-band P treatments, regardless of tillage, and greatest for broadcast P, especially in the shallow SFC/SD tillage system, where STP is stratified near the soil surface.

Table 7. Soil test P (0-2″) in 2002 on a high P-testing soil as affected by tillage and P placement.

Tillage for Corn	Tillage for Soybean	P Placement None	P Placement Starter[1]	P Placement Deep-Band[1]	P Placement Bdct.[2]
		- - - - - - - - Bray P_1 (ppm) - - - - - - - - -			
NT	NT	16	32	—	—
SFC	SD	14	27	21	54
ST	NT	14	26	19	—
CP+	CP+	16	22	—	39

[1] 40 lb P_2O_5/A/yr applied for corn in 1997, 1999, & 2001.
[2] 80 lb P_2O_5/A/yr applied for corn in 1997, 1999, & 2001.

Table 8. Soil test P (0-2″) in 2002 on a low P-testing soil as affected by tillage and P placement.

Tillage for		P Placement			
Corn	Soybean	None	Starter[1/]	Deep-Band[1/]	Bdct.[2/]
		- - - - - - - - Bray P_1 (ppm) - - - - - - - -			
NT	NT	4	10	—	—
SFC	SD	5	11	6	37
ST	NT	4	12	5	—
CP^+	CP^+	4	10	—	24

[1/] 50 lb P_2O_5/A/yr applied for corn in 1997, 1999, & 2001.
[2/] 100 lb P_2O_5/A/yr applied for corn in 1997, 1999, & 2001.

Rotational tillage systems

Summary:

Similar to crop rotation, tillage rotation indicates the use of rotation of different tillage systems for different phases of the long-term corn-soybean rotation. A 4-year tillage study was conducted to determine if some form of full-width tillage may be needed periodically when using zone-till or NT systems in a high-residue corn-soybean rotation. Surface residues ranged from 31 to 86% for the conservation tillage systems with little difference between the corn and soybean phases of the rotation. Tillage for corn significantly affected yields of corn but not soybean in the subsequent year. Corn yields were greater in 2 of 4 years when CP^+ tillage was used for soybeans compared with NT. In some years, row cultivation of corn increased corn and soybean yields when NT was used for soybeans, but not when CP^+ was used. When both corn and soybean yields were considered, greatest production occurred when zone tillage systems (DZT or ST) were used for corn and CP^+ tillage was used for soybean. Finally, the data suggest some form of rotational full-width tillage (even shallow row cultivation) may be needed to disrupt surface soil consolidation that occurs with continuous NT and zone-till systems for corn in rotation with NT for soybean for achieving consistently higher corn and soybean yields. Economic return to these surface-disturbing, full-width tillage systems will likely be highly site-specific (soil and climate).

Discussion:

A study was conducted from 2000-2003 to determine the rotational effects of NT, ST, 14" deep-zone tillage (DZT), SFC, and CP^+ tillage systems with and without in-season row cultivation for corn rotated with NT or CP^+ tillage for soybean on surface residue accumulation and yield of corn and soybean. Two cycles of a corn-soybean rotation were grown on the same plots with corn planted in 30" rows and soybeans planted in 20" rows each year. One-half of each corn plot received in-season row cultivation in late June each year. Soil test P and K were very high. Starter fertilizer (10-34-0) was used, and N was applied at a non-yield-limiting rate to all corn plots.

Four-year average corn yields and 3-year average soybean yields were significantly affected by the 18 tillage/row cultivation treatments (**Table 9**). Surface residue coverage ranged from 24 to 79% in the year corn was grown and from 31 to 86% in the year soybean was grown. The specific effects of tillage for corn, tillage for soybean, and in-season row cultivation of corn are examined in the next four tables.

Table 9. Corn yield, soybean yield, and surface residue coverage as affected by tillage systems for corn and soybeans and in-season row cultivation of corn.

	Treatments			Four-year avg.		Three-year avg.	
No.	Tillage for Corn	Tillage for Soybean	Row cultivation	Corn yield	Surface residue	Soybean yield	Surface residue
				bu/A	%	bu/A	%
1	NT	NT	No	153	79	53.7	85
2	"	CP	"	157	61	56.5	34
3	DZT	NT	"	157	42	54.3	75
4	"	CP	"	166	40	58.1	35
5	ST	NT	"	153	62	55.7	86
6	"	CP	"	168	51	56.8	34
7	SFC	NT	"	150	50	55.1	77
8	"	CP^+	"	151	36	57.3	33
9	CP^+	CP^+	"	160	24	56.1	35
10	NT	NT	Yes	148	72	56.3	78
11	"	CP^+	"	153	58	57.2	33
12	DZT	NT	"	159	44	56.0	76
13	"	CP^+	"	163	39	57.0	32
14	ST	NT	"	159	63	55.7	78
15	"	CP^+	"	161	48	54.7	31
16	SFC	NT	"	155	46	57.3	79
17	"	CP^+	"	161	33	54.8	32
18	CP^+	CP^+	"	162	24	56.0	31
	LSD (0.05):			10	7	1.9	8

Four-year average corn yields and surface residue coverage averaged across tillage for soybean and in-season row cultivation were significantly affected by tillage for corn (**Table 10**). Yields for DZT and ST were identical to those for CP+ and were significantly greater than for SFC or NT. Surface residue accumulation was greatest for NT (67%); intermediate for ST (56%), DZT (41%); and SFC (41%); and lowest for CP+ (24%). Three-year average soybean yields and surface residue coverage when averaged across tillage for soybean and in-season row cultivation were not affected by the residual effects of tillage for corn in the previous year (**Table 10**). Residue coverage exceeded 50% for all tillage systems for corn except CP+ (33%).

Table 10. Effect of tillage following soybeans on corn yield and surface residue coverage and on soybean yield and residue coverage in the following year.

Tillage for corn	Corn yield	Surface residue	Soybean yield	Surface residue
	bu/A	%	bu/A	%
NT	153	67	55.9	57
DZT	161	41	56.4	54
ST	160	56	55.7	57
SFC	154	41	56.1	55
LSD (0.05):	5	3	NS	NS
CP+	161	24	56.0	33

Three-year average soybean yields shown in **Table 11** when averaged across all tillage and row cultivation treatments for corn were significantly greater for CP+ (56.5 bu/A) compared with NT (55.5 bu/A). This 1 bu/A advantage for CP+ is not considered to be economically significant, since it is offset by the costs of additional machinery, time, and fuel associated with the CP+ tillage operation. Surface residue coverage was considerably greater for NT (79%) compared with CP+ (33%). Four-year average corn yields shown in **Table 11** when averaged across the tillage and row cultivation treatments for corn were significantly greater when CP+ tillage was used for soybean in the previous year (159 bu/A) compared with NT (154 bu/A). However, a significant year by tillage interaction occurred showing a yield advantage of 4, 1, and 1 bu/A in 2000, 2001, and 2003 but a 15 bu/A advantage in 2002. These year-to-year yield differences were not explainable when examining monthly and growing season temperature and precipitation. Similar results showing periodic yield reductions with NT systems on these soils were reported by Randall et al. (1996). Surface residue accumulation for corn in the year following NT for soybeans was greater (57%) compared to CP+ (46%).

Corn and soybean yields, when averaged across years, tillage for corn, and tillage for soybean, were not affected by in-season row cultivation of corn (**Table 12**). However,

Table 11. Effect of tillage following corn on soybean yield and surface residue coverage and on corn yield and residue coverage in the following year.

Tillage for soybean	Soybean yield	Surface residue	Corn yield	Surface residue
	bu/A	%	bu/A	%
NT	55.5	79	154	57
CP+	56.5	33	159	46
Stat. Signif.:	**	**	**	**

** = Statistically significant at the 99% level.

significant interactions among year, tillage for soybean, tillage for corn, and row cultivation occurred. In two years, row cultivation increased corn yields by as much as 10 bu/A when NT was used for the previous soybean crop and decreased yields by as much as 10 bu/A when CP+ was used for the previous soybean crop. Weeds were not a factor as chemical weed control was excellent in all plots each year. These positive and negative effects of row cultivation were confined to the NT, DZT, and ST systems for corn but not the full-width SFC tillage system. Similar interactions between row cultivation for corn and tillage for soybeans, suggesting small yield responses to row cultivation when combined with NT for soybeans, were also found in the soybean phase of the rotation.

The 4-year corn yields and 3-year soybean yields for each of the 18 tillage system treatments shown in **Table 9** were combined to evaluate crop production for the corn-soybean rotation. Although the combined yield differences among tillage systems were not large, production was greatest for treatments 4, 6 and 13, which are characterized by some form of zone tillage (DZT or ST) for corn and CP+ tillage for soybean. Row cultivation for corn was not needed for optimum production. Lowest production occurred for treatments 1, 3, 5, 7 and 10, which are generally characterized by a combination of no row cultivation for corn and NT for soybean regardless of tillage for corn. Thus, these data, containing many significant interactions, suggest that some form of full-width tillage (even shallow row cultivation) may be needed to disrupt surface soil consolidation and/or disturb accumulated surface residues in continuous NT and ST or DZT systems in rotation with NT for soybeans. This disturbance appears to enhance early plant growth and gives greater consistency of slightly higher corn and soybean yields on these soils.

Table 12. Effect of in-season row cultivation on corn yield and soybean yield in the following year.

Row cultivation	Corn yield	Soybean yield
	bu/A	
No	156.8	55.9
Yes	157.3	56.1
LSD (0.10):	NS	NS

Tillage for a corn-corn-soybean rotation

Summary:

Two studies were conducted to determine the effect of tillage on second-year corn and soybean in a corn-corn-soybean rotation. Second-year corn yields were highly related to surface residue coverage and ranged from 212 bu/A for MP+ tillage (10% residue coverage) to 155 bu/A for NT (91% coverage). When surface residue coverage ranged from 50 to 76%, yields averaged 200, 191, 189, and 180 bu/A for DZT, CP+, ST, and SD tillage, respectively. All soybeans were NT drilled into six tillage systems that had been in place for corn in the two previous years. Soybean yields averaged 50 bu/A for a 3-year NT system, which was 4 to 8 bu/A less than for tillage systems that included ST, CP+ MP+, SD, and DZT for corn during the 3-year rotation.

Discussion:

Two studies were conducted in 2004 to determine the effect of tillage on yield of second-year corn and soybean in a corn-corn-soybean rotation. Tillage for second-year corn in 2004 was the same as for first-year corn in 2003 and consisted of NT, DZT, ST, CP+, SD (SFC was used in 2003), and moldboard plow plus (MP+) systems. Soil test P and K were very high. Row cleaners and starter fertilizer (10-34-0) were used for corn, and N was applied at a non-yield-limiting rate. Soybeans were no-till drilled in 8" rows into the same tillage treatments for corn as described above.

Second-year corn yields were greatly influenced by surface residue cover (**Table 13**). Highest yield was obtained with MP+ tillage (212 bu/A) where surface residue coverage was only 10%. When surface coverage ranged from 50 to 76%, yields ranged from 200 bu/A (DZT) to 180 bu/A (SD). At 91% surface coverage, yield for NT was only 155 bu/A — a 27% yield reduction.

Table 13. Second-year corn yield and residue cover in 2004 as affected by tillage system for corn in 2003 and 2004.

Tillage for corn in 2003 and 2004	Corn Yield	Residue Cover
	bu/A	%
NT	155	91
DZT	200	50
ST	189	76
SD	180	64
CP+	191	54
MP+	212	10
LSD (0.10):	8	12

A similar trend was shown for soybean where a 3-year NT system yield (50 bu/A) was significantly less than the 54 to 58 bu/A yields from the other treatments (**Table 14**). Soybean yields for the DZT, ST and SD tillage treatments applied for corn were not different from the CP+ and MP+ treatments. Residue amounts were not measured, but they likely were similar to those shown in **Table 13**, except for the MP+ treatment. In summary, these data show that continuous NT resulted in soybean yields 4 to 8 bu/A less than where NT for 2004 followed DZT, ST, SD, CP+ or MP+ tillage applied for corn in 2002 and 2003. These highly significant second-year corn and soybean yield differences among tillage systems in a corn-corn-soybean rotation probably were exacerbated by the cool and very wet conditions that prevailed in 2004. Earlier research showed a 3 bu/A average yield advantage over a 10-year period for MP+ tillage compared with CP+ on a well drained, sloping Nicollet soil at Waseca (Randall et al., 1996a). Thus, CP+ tillage is a recommended tillage practice for second-year corn to minimize erosion on soils with slopes >4%.

Table 14. Soybean yield in 2004 after second-year corn as affected by tillage system for corn in 2002 and 2003.

Tillage system for corn in 2002 and 2003	Soybean Yield
	bu/A
NT	50
DZT	58
ST	54
SFC, SD	58
CP+	55
MP+	55
LSD (0.10):	3

N management for tillage systems

Summary:

A 3-year study comparing late October vs. spring, preplant application of anhydrous ammonia across four tillage systems (NT, ST, SFC, and CP+) indicated that corn yield response to N timing was greatly affected by April-June rainfall. Under normal to slightly below-normal rainfall, yields were not different between fall and spring-applied ammonia. But when rainfall was above normal, corn yields were reduced an average of 36 bu/A, regardless of tillage system. These results do not support late October application of anhydrous ammonia without N-Serve and should be a warning to those desiring to apply N with their fall strip-till operation.

Discussion:

A study was conducted from 1997-1999 to determine the effect of time and placement of N in a wide range of tillage systems for corn after soybean with particular emphasis on concerns with applying N at the same time as strip tilling. Tillage consisted of NT, ST, SFC, and CP+ with ST performed in the last week in October. Chisel plowing was performed in early November. Anhydrous ammonia without nitrapyrin (N-Serve) was the N source. Fall N was applied near the seed-row zone for the coming crop in the last week in October. Soil temperature at the 6" depth on the date of application was 47°, 48°, and 55° for each of three years and averaged 40°, 43°, and 50° in the subsequent 10-day period, respectively. Spring N was applied midway between the 30" rows in mid- to late April. Soil test P and K were very high and high, respectively.

Corn yields shown in **Table 15** were separated into: a) 1997 and 1998, b) 1999, and c) 1997-1999 average because of large differences in precipitation among years.

In 1997 and 1998, when April-June rainfall totaled 8.5" and 11.8" respectively, corn yields were influenced by tillage system but were not affected by time/placement of N. Yields were highest for CP+ (193 bu/A) intermediate for ST and SFC, and lowest for NT (184 bu/A). In 1999, when April-June rainfall totaled 15.8", corn yields were not significantly affected by tillage but were reduced 36 bu/A when N was fall-applied. Unusually wet conditions, especially in April and May, likely caused significant leaching and denitrification, resulting in substantial yield loss. Across the 3-year period, corn yields were highest for CP+ (184 bu/A) and slightly lower for ST (180 bu/A), SFC (178 bu/A), and NT (176 bu/A). Yields for spring-applied ammonia averaged 186 bu/A compared to 174 bu/A for ammonia applied in late October. An interaction between tillage system and time/placement of N application was never found, indicating the effect of fall vs. spring application was the same for all tillage systems.

Table 15. Corn yield as affected by tillage system and time/placement of N.

Treatments	Years: 1997-98 Avg.	Years: 1999	3-Yr. Avg.
	- - - - - - - - - Yield (bu/A)	- - - - - - - - - -	
Tillage system			
NT	184	160	176
ST	189	162	180
SFC	186	163	178
CP+	193	167	184
LSD (0.10):	5	NS	3
Time/Placement			
Fall, Near row	188	145	174
Spr., Between rows	188	181	186
LSD (0.10):	NS	5	3

Multi-site tillage performance

Summary:

Twenty-nine site-years of tillage research on sites yielding from 92 to 216 bu/A showed that NT yields as a percent of CP+ yields were reduced more when overall yields were limited by inadequate soil fertility. Yields for the 21 non-yield-limited site-years averaged 183 bu/A for CP+ and were reduced 2% for ST (180 bu/A) and SFC (179 bu/A) and 6% for NT (172 bu/A).

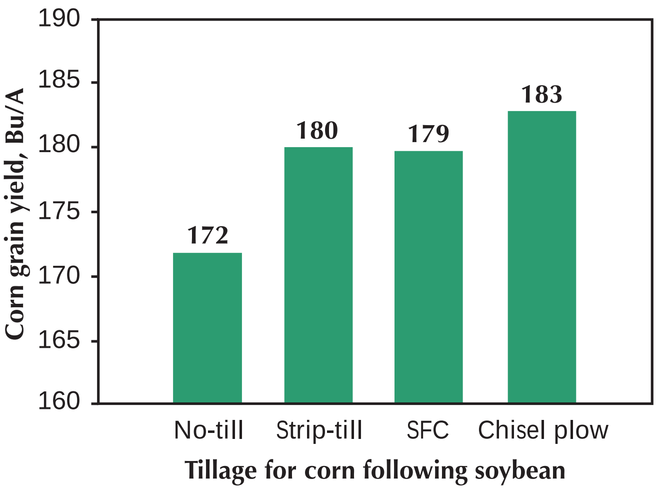
Discussion:

Twenty-nine site-years of tillage research, comparing NT, ST, SFC, and CP+ tillage systems for corn after soybean, were conducted under tile-drained conditions at Waseca between 1997 and 2004. Twenty-one site-years were conducted under conditions where nutrients were not yield-limiting and eight at sites where low soil test P levels were yield-limiting. Average yields across tillage systems for the 29 site-years ranged from 92 to 216 bu/A. Yield ranges from 92-135 bu/A (Low, 7 sites), 136-159 bu/A (Med., 7 sites), 160-175 bu/A (High, 7 sites), and 176-216 bu/A (V. high, 8 sites) were arbitrarily established to determine if yield differences among tillage systems changed with yield level (**Table 16**). With the exception of the seven sites in the high yielding group, yields for the tillage systems ranked: CP+ > SFC ≥ ST > NT. But, NT yields as a percent of CP+ increased as the yield level increased, i.e., 90% for the low-yielding sites and 94-95% for the high- and very high-yielding sites. These findings point to the advantage for establishing high-fertility conditions before switching to NT.

Table 16. Corn yield as affected by tillage system and yield level across 29 site-years.

Tillage System	Site Yield Level: Low	Med.	High	V. High
	- - - - - - - - - - - bu/A	- - - - - - - - - - -		
NT	111	140	163	192
ST	118	147	172	201
SFC	120	149	169	202
CP+	123	154	172	205
NT yield as a percent of CP+	90	91	95	94

Figure 2. Average corn yield across 21 site years with four tillage systems for corn after soybean.



Averaged across all 21 non-yield-limited sites, yields averaged 183, 180, 179, and 172 bu/A for the CP+, ST, SFC, and NT systems, respectively (**Figure 2**). Yield reductions as a percent of CP+ were 2% for ST and SFC and 6% for NT. Economic return may or may not be significantly different for these tillage systems, depending on farm-specific factors.

Additional Resources

Minnesota Pollution Control Agency. 1993. *Selected water quality characteristics of minimally impacted streams from Minnesota's seven ecoregions, addendum to: Descriptive characteristics of the seven ecoregions in Minnesota.* St. Paul, MN.

Minnesota Pollution Control Agency. 1997. Minnesota River Basin information document. p. 261. St. Paul, MN.

Minnesota Pollution Control Agency. 2002. *State of the Minnesota River: Summary of Surface Water Quality Monitoring.* p. 18. St. Paul, MN.

Randall, G. W., S. D. Evans, J. F. Moncrief, and W. E. Lueschen. 1996a. *Tillage Best Management Practices for Continuous Corn in the Minnesota River Basin.* University of Minnesota Extension Service. St. Paul, MN. AG-FO-6672.

Randall, G. W., W. E. Lueschen, S. D. Evans, and J. F. Moncrief. 1996b. *Tillage Best Management Practices for Corn-Soybean Rotations in the Minnesota River Basin.* University of Minnesota Extension Service. St. Paul, MN. AG-FO-6676.

Rehm, G., G. Randall, and S. Evans. 1993. *Fertilizer Management for Corn Planted in Ridge-Till or No-Till Systems.* University of Minnesota Extension Service. St. Paul, MN. AG-FO-6074.

Rehm, G., M. Schmitt, G. Randall, J. Lamb, and R. Eliason. 2000. *Fertilizing Corn in Minnesota.* University of Minnesota Extension Service. St. Paul, MN. AG-FO-3790, revised 2000.

http://www.pca.state.mn.us/data/eda/wqguide.html

www.extension.umn.edu

Production Coordinator: Anita Dincesen, University of Minnesota Extension Service

Graphic Design: John Molstad, Studio 31 Graphics, Inc.

BU-08315
July 2005